Towards Sustainable Energy: A Roadmap for Residential Buildings at Loop Head

24th February 2022

International Class 2022

Energy and Environmental Management

Content

List of abbreviations

°C .... Degrees Celcius
ΔT .... Temperature drop across the radiatoror surface area
AWHP .... Air to Water Heat Pump
BER .... Building Energy Rating
BOS .... balance of system
CE .... Community Engagement
CED .... Cumulative energy demand
CEG .... Clean Energy Guarantee
COCE .... Cost of Consumed Electricity
COE .... Cost of generated Energy
COP .... Coefficient of Performance
CRU .... Commission for Regulation of Utilities
DCCAE .... Department of Communication Climate Action and Environment
DEAP .... Dwelling Energy Assessment Procedure
DHW .... Domestic Hot Water
EEM .... Energy Efficiency Measures
EPBT .... Energy Pay Back Time
E_{pv_gen} .... Energy Generated from the Photovoltaic system
EROI .... Energy Return On Investment
GHE .... Ground Heat Exchanger
GWP .... Global Warming Potentials
HLI .... Heat Loss Indicator
HP .... Heat Pump
IC .... International Class
IEA .... International Energy Agency
IO .... input-output
ISEA .... Irish Solar Energy Association
ISO .... International Organization for Standardization
kJ/kgK .... kiloJoule per Kelvin per kilogram
kW .... kilowatts
kWh .... kilowatt hour
$kWh_{thermal}$ .... Thermal kWh
LCI .... Life Cycle Inventory
LCOE .... Levelized Cost of Electricity
LEAP .... Loop Head Energy Action Partnership
LH .... Loop Head
m .... meter
M&E .... Monitoring and Evaluation
MG .... metallurgical
MJ-eq .... Megajoule equivalent
ml .... millilitres
mm .... millimeter
MPPT .... Maximum Power Point Tracker
MSS .... Microgeneration Support Scheme
NH_3 .... Ammonia
NO_2 .... Nitrogen dioxide
NPV .... Net Present Value
NREL .... National Renewable Energy Laboratory
NSMP .... National Smart Metering Program

η_{grid} .... Grid conversion efficiency
O&M .... Operation and Maintenance
PE_{inv} .... Primary Energy Invested
PV 49
RE .... Renewable Fraction
ROI .... Return on Investment
SEAI .... Sustainable Energy Authority of Ireland
SG .... solar grade
SOX .... sulfur oxide
STEM .... Science, Technology, Engineering, and Mathematics
T .... Life Time
W .... Watts
W/K .... Watts per Kelvin
W/m^2 K .... U value is Watts per square meter per degree Kelvin

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Executive summary

Residential buildings consume a considerable amount of energy to cater for the needs in lighting, space heating and cooling and other households' electrical appliances. Inefficient use of this energy could imply unnecessary consumption which would translate to high energy expenses incurred by the building owners. Hence, this study builds up on prior work done by a group of engineering students from the University of Flensburg, Germany in 2020 and 2021 on sustainable energy in Loop Head, Ireland. This paper documents events, methodologies, findings and recommendations from the 5-weeks community energy project focussed on the Loop Head residential sector that was undertaken by the 2022 batch of students.

A community engagement approach and activities designed to enable researchers to gain a better understanding of the residential demographics and household energy usage have been documented. Further, a set of criteria for the selection of 3 representative households for the case studies have been highlighted. For these houses, energy assessments have been conducted to advise on ways of eliminating electrical and heat losses from the buildings. DEAP 4.2.0 and Excel models have been used to collect buildings' envelope data information and for the calculation of the building energy efficiency rating while the Sketchup software has been utilized for the building dimensions calculations. For case I, the building was estimated to have a heat loss indicator (HLI) of 4.89 W/K/m^2 corresponding to a BER Rating of "D2" in the Sustainable Energy Authority of Ireland BER scale. Case II's HLI of 1.94 W/k/m^2 corresponded to a BER Rating of "C1" while Case III was estimated to have an HLI of 8 W/k/m^2 which corresponds to BER Rating of "G". Recommendations on improving the BER Rating, and hence the buildings' energy efficiency, have been outlined for each of these 3 cases.

Further, the electrical and heat demand for these houses have been analysed to size an efficient space heating system as well as a solar PV system. For space heating, different types of heat pumps are discussed including Brine-to-Water, Air-to-Air and Air-to-Water. Of these, Air-to-Water (AWHP) was suggested for its higher efficiency. In Case I, for instance, an AWHP was estimated to achieve annual savings of up to 273 €/year with a simple payback period of approx. 10 years. For solar systems, an electrical load profile was generated by considering the units consumed as per the energy bills and consumer behaviour. Solar systems have been designed and optimized in HOMER Pro for the three cases. Similarly, the systems' economics have been analysed and recommendations have been provided to the homeowners. Moreover, grants supporting sustainable technologies have been highlighted within this report along with their eligibility criteria.

Additionally, one of the cases with the Solar PV system has been analysed for its environmental and socio-economic impact on the Loop Head community. The analysis has focussed on the carbon footprint for a PV system with a battery and another one without a battery starting from the manufacturing and throughout the 25-years utilization of the PV system. The analysis concluded that the most carbon and energy-intensive stage of the life of a PV system is the manufacturing phase. Further, the effect of introducing a PV system on CO_2 reduction was investigated with results showing that a Solar PV system has the potential to directly reduce emissions by replacing electricity from the grid. On the socio-economic assessment, this research revealed that solar PV installations could serve as an income stream for Ireland with the economy gaining about 30 cents for every 1 euro spent on the system. Moreover, the potential jobs created by solar PV installations is discussed in this paper.

Finally, this study documents a roadmap including steps that the Loop Head residents and community should consider in their journey towards achieving sustainable energy in their residential sector.

Introduction

1. Introduction

By Ifechukwude Chinye-Ikejiunor

The international class (IC) is a compulsory module of the Master programme in Energy and Environmental Management (EEM) at the Europa Universität Flensburg (EUF), Germany. The IC gives students the opportunity to work in a team on a multidisciplinary, practical, energy-related problem in a real-life situation within a given time frame to exercise the application of appropriate scientific research methods. In practice, during the IC module, students and lecturers adopt a problem-solving approach to investigate and address an energy-related challenge in a community. An integral component is the collaboration with the community members and local partners in realizing feasible solutions to the identified challenges in the community.

The IC has undertaken several community-based projects including the Loop Head Energy Action Partnership (LEAP) in Ireland since 2020. This is a collaboration between EEM department at EUF, the development organizations of Carrigaholt, Kilballyowen and Kilkee, Loop Head Tourism, the Farming Community of Loophead (Carrigaholt, Kilballyowen and Kilkee parishes), local residents, business owners, interested individuals and Astoneco Management. The LEAP partnership aims to understand the constituents of the local energy status quo in order to explore possible case studies of prospective energy balances and to help encourage the use of sustainable energy resources in the Loop Head community. The LEAP programme has been in operation since 2020.

1.1. Background

IC 2020 intended to empower the community with adept information on the renewable energy potential with a strategy to involve and facilitate local sustainability.

The study revealed that emigration and lack of job opportunities were among the key challenges of the community, hence, the focus was on Loop Head’s demand assessment, community-level renewable energy resources assessment and their feasibility in the transport, farms and residential sectors.

According to (Astoneco Management, 2020), the findings showed that the geographical location of Loop Head gives it a good potential for wind, solar, biomass and wave energy. Farming, especially cattle rearing, was indicated to be mostly practised by the community as most of the land in Loop Head is grassland; grasses are used to feed cattle in the form of silage. The farming activities from the livestock rearing results in a good potential for the biomass resource. It was estimated that the total biogas that could be produced by slurry and silage in Loop Head would have an energy content of 7,614 MWh/year, which was estimated could heat over 450 homes.

The potential of wind energy at mean wind speeds of 9.2m/s and a height of 100m above ground level was estimated at 13.82 GWh of annual generation.

The solar daily specific yield was found to be in the range of 2.62 kWh/kWp and 2.65 kWh/kWp, which is higher than Ireland's average value of 2.51 kWh/kWp. Loop Head Peninsula has roughly a total electricity demand of 18.4 GWh, and a potentially available area from rooftops in residential and agriculture sectors equivalent to 0.247 km^2. This translates to an estimated installation of 23.52 MWp of solar photovoltaic capacity.

The combined estimated energy from biomass, wind and solar would meet the demand of Loop Head. Findings also showed that a major part of heat and electricity consumption resulted from buildings meant for residence and holiday homes.

Finally, pre-feasibility studies for community-owned wind, solar, and biogas plants were conducted and a simple energy model was designed to study potentials and develop a vision for an energy self-sufficient Loop Head. By modification of different parameters in the model, the share of renewable energies can be varied to attain 100 % and even more of total generation if the total demand experiences an increase on an annual basis.

Seeing the outcome from the synergy with the engagement of the community, the IC2021 sustained the connection with the locals. Although it was carried out online as a result of the global pandemic, community capacity building workshops were conducted through the LEAP Energy Academy to explain relevant topics in community energy for Loop Head.

A step into investigating energy efficiency measures in buildings and their effect on energy consumption in the residential and farming sectors was carried out. As a result, the building energy rating (BER) estimator tool was developed to provide recommendations on improving energy efficiency for households based on their pre-existing conditions. The study also identified several factors which influence the heat demand in the residential sector and the retrofitting measures to reduce heat demand and heat losses in buildings.

Additionally, to promote and assist in the establishment process for the findings, an excel energy modelling tool was developed for Loop Head. The model was designed to aid the users to identify solutions for obtaining energy efficiency in residential buildings and attain sustainability in Loop Head Farms.

Introduction

1.2. Scope and objectives

Building on the previous work done by IC 2020 and IC2021, IC 2022 started by reviewing the previous findings and brainstorming on a possible way-forward to delivering solutions to the observed challenges. A focus on improving energy efficiency in the residential sector was established following the findings where it was observed that the bulk of the energy demand came from the residential sector in the community.

To refine the scope of IC 2022, a questionnaire was shared and a feedback session with the community was organised to gather questions and interests that were later accommodated in the scope of work in order to meet the expectations of the community. Some of the questions asked were:

- How much will a solar installation cost me?
- What capacity of Solar PV should I go for?
- How can I use less energy in my house?
- What is my BER rating now?
- Whom should I contact for retrofitting of my house?
- Are there any grants I am eligible for to improve my house BER rating?
- Are there any environmental effects caused by solar panels?

1.2.1. Scope of work

The study for the IC2022 centres around developing solutions in the residential sector for the Loop Head community. The scope of work, showing the core interests, can be seen in Figure 1.1 below:

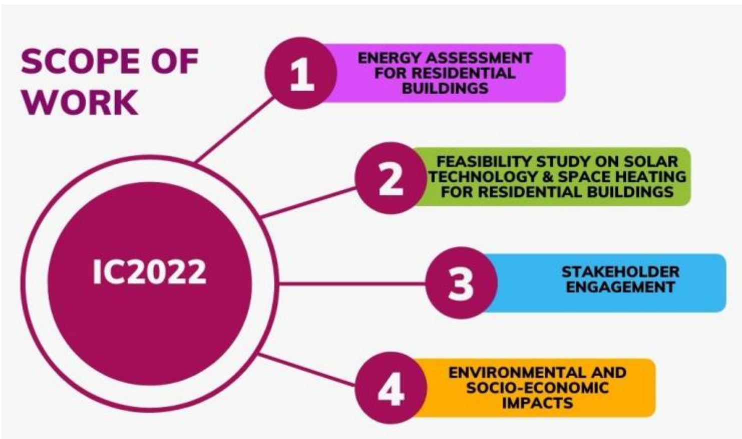

Figure 1.1: Scope of the IC 2022 work

Source: Author

The IC 2022 adopted a holistic approach focusing on four dimensions to specifically provide solutions to the Loop Head community residential sector:

1. Energy assessment for residential buildings: ascertaining and upgrading the houses to be energy efficient.
2. Feasibility study on solar technology and space heating for residential buildings: finding integrated energy-efficient technological solutions.
3. Stakeholder engagement: building and sustaining community participation in the IC2022.
4. Environmental and socio-economic impact assessments: measuring the environmental and socioeconomic impacts of installing a PV system on Loop Head using the methods of Lifecycle Assessment (LCA) and input-output analysis.

1.2.2. Objectives

Therefore, the IC2022 streamlined its focus to finding solutions that could:

- Strengthen **community engagement** and build on existing structures from the previous work done.
- Provide **energy efficiency** recommendations including retrofitting and energy conservation measures to improve energy usage.
- Select representative households as case studies to carry out **energy assessments** covering their energy use and saving potential and the design and modelling of real-life, feasible solutions.
- Create awareness on available SEAI **grants and incentives** and the eligibility criteria.
- Assess **environmental and socio-economic impacts and benefits** such as carbon footprint, value added and employment in order to ascertain the actual impact from clean energy solutions on the community.
- Design **space heating solutions** such as heat pumps and assess the cost implications and potential resultant benefits to address the households' heating challenges.

Community engagement

- Design **Solar Photo-voltaic (PV) systems** and integration solutions to maximise the use of renewable energy at the household level and assess the cost and also benefits from this clean energy for the households in the Loop Head community.

Chapter 2.3 of the IC 2022 report gives detailed information on how the action in Ireland began with an interaction at informal levels and then unto workshops with the community such as the solar deep-dive event. Furthermore, as seen in Chapter 3.2 of this report, pre-assessment surveys where students visited houses of house owners interested in energy efficiency and/or solar PV followed. A scope for each selected household was defined and an energy assessment was carried out to gather the required data for the design of solutions to meet the energy demand of the household through sustainable energy.

Also, an analysis of the cost and benefits and environmental and socio-economic impacts was carried out as seen in Chapters 8.1 and 8.2. Finally, IC 2022 presented the results with recommendations, which can be found in Chapter 10 of this report, to the community.

2. Community engagement

By Max Andriamanalina

Community engagement is a crucial part of LEAP, a program in which EUF is partnering with local development organisations in Loop Head as well as AstonEco Management. Community engagement is used to have a better understanding of the Loop Head community's viewpoint and preferences on the energy sector. Several engagement activities were carried out by the team to interact with the community as well as to integrate the community into the project. These activities were, therefore, an opportunity for the team to familiarize themselves with the community and to investigate the challenges they are currently facing in the energy sector. Knowing those challenges helped the IC 2022 team to identify suitable approaches to tackle these challenges.

As mentioned above, several activities were organized by the students in collaboration with the local partner, Astoneco, for the purpose of bringing the team and the community together. These activities include, informal social interaction with local stakeholders and the community members at,e.g., the local pubs, cultural nights, a solar lab demonstration, and two workshops that took place at Kilkee Bay Hotel. The team also conducted a visit to the Carrigaholt National primary school in an effort to increase clean energy awareness among pupils. Additionally, the IC 2022 team participated in community-initiated Sunday walks. Participating in these walks afforded the team a platform to receive feedback from the community members about previously conducted activities.

2.1. Stakeholders' identification

By Hiram Masese

Constructive community engagement (CE) has been indicated as a prerequisite for the success of projects (Clean Energy Council, 2022). The council further argues that investing time and effort in building relationships is most likely to be reciprocated by embracement and support from the community members. Consequently, CE ought to be a continuous process starting from the planning phase and lasting throughout the life cycle of a project (USAID, n.d.).

Similar to other communities, Loop Head (LH) has its unique challenges and priorities as outlined in the (Loop Head Together, n.d.) 9-point strategy which the project team required to be appraised on, to enable a formulation of an appropriate interaction approach. For instance, IC 2022 learnt in a timely fashion of the lifting of the stringent COVID-19 protocols which had previously been enforced in Ireland. Consequently, this implied that the team could plan for face-to-face interactions with community members while adhering to medical safety precautions on the pandemic. Fortunately, this project's team adopted an early initiation of CE strategy through maintaining contact and holding preliminary planning sessions with the liaison person, John Aston. This ensured that such vital information was relayed well in advance. From spearheading operations of an organization that facilitates and co-develops sustainable community programmes (Astoneco Management, n.d.) – including in LH, he has played an integral social focal point role connecting the Flensburg University's IC to LH community for the past 3 years. IC 2022 used this goodwill, in addition to the previous 2 years' work, to gain insights on the demographics and the existing knowledge of the community in the energy sector as well as to identify and commence the creation of key stakeholders' database.

The IC 2022 team acknowledged the diversity in perspectives that may exist in a community and sought to establish a list of community members who would either be affected by or have an interest in the project. This was a live document which was updated throughout the course of the project whenever new information and contacts arose. The identified list is as tabulated in Annex 1. Further, (Kumar, 2015) work approach was used to classify these individuals and institutions into 4 groups based on the level of interest and the influence they were likely to have on the project as highlighted in the action plan below:

i. Manage – Key stakeholders, with both high influence and interest, who were actively engaged throughout the project lifecycle.

ii. Satisfy – These had great influence, despite low interest, on the project. Activities undertaken were reviewed regularly against their expectations.

iii. Inform – Although their direct influence on the project was on a limited scale, they had the opportunity to influence other project participants.

iv. Monitor – They were watched closely, despite ranking low on the priority list by virtue of having both low interest and low influence on the project.

The detailed classification of stakeholders is highlighted in Annex 2. This information was then applied to help align on expectations and to curate suitable engagement schedules and methods. For instance, contacts of the Kilkee Bay Hotel owner enabled scheduling of the workshop sessions which are discussed later in this chapter as well as the reservation of the conference hall. Moreover, a partnership with a local company that provided solar PV panels and an inverter for demonstration purposes informed the decision on the complimentary electronic measuring instruments carried by the IC team from the University Department. Whereas knowledge on the expected audience demographics enabled the choice of flip charts, powerpoint presentations and practical solar lab sessions as engagement approaches

2.2. Communication approach

By Hiram Masese

A communication schedule is a crucial part of CE for it outlines the plan of activities, techniques and the media through which information is relayed to the community (USAID, n.d.). The same source indicates that clear communication enhances transparency, builds trust and mitigates parties' conflicts. IC 2022 documented and shared a road map, see Annex 3, comprising of the dates and venues for the activities planned towards enriching the stakeholders' engagement efforts. This was yet another live document which was updated based on the dynamic needs of the project.

Prior to that, an energy survey questionnaire, Annex 4, was prepared while still in Germany to establish communication with some 44 community members within an existing WhatsApp group. The design of the survey was characterised by iterations to incorporate various contributions from both internal and the community mobilization teams. Ultimately, the survey received a low participation rate and recorded only 9 responses. Nonetheless, the questionnaire was used as a tool for identifying and contacting house owners who were interested to have their house energy consumption assessed. Invitations to conduct case studies for the 3 sampled households whose findings have been discussed in later chapters of this report were a result of the survey shared. Additionally, the team documented key learning lessons from the preparation exercise as tabulated in Table 2.1below.

Table 2.1: Questionnaire preparation key take-aways
Source: Author based on project planning exercise

Key Take-away	Description
Complexity of the sentences	A fairly designed questionnaire uses simple language structure to reach a wider audience. Where technical terms must be used, defining them is vital for the audience's understanding.
Clear motive of questions	Adequate transparency on formulation of all questions enable respondents to understand the importance and, to an extent, how the information they provide will be used. This affords them comfort when providing the answers.
Length of the survey	There is a risk of respondents losing focus with very long questionnaires. (Versta Research, 2011) estimates that data quality reduces significantly for surveys requiring longer than 20 minutes.
Flow of questions	Keeping questions related to a similar topic in the same section in a way that ensures respondents have adequate foundation knowledge of dependent questions makes the questionnaires clearer.
General Data Protection Regulation	Unless absolutely necessary and on respondents' voluntary acceptance, questions which prompt for personally identifiable information ought to be avoided to maintain anonymity.
Preparation Timing	Iterations of the draft are inevitable as different views have to be incorporated. Preparation should, therefore, commence early.
Questionnaire participation reminders	Significant responses were as a result of face-to-face reminders upon arriving on the loop. Responses are likely to be more forthcoming through increased in-person interactions.

In a bid to achieve familiarity with community members prior to joining them in Loop Head, the Flensburg team documented and shared bio-profiles detailing their country of origin, work experience and expectations on what they hoped to achieve during their IC. Further, the 1st week of the project was heavily invested in interactions with the locals within social gatherings. Collaboration between the visiting students and the locals enabled successful conduction of a music concert (see Annex 5). While all the attendees enjoyed the diverse songs and dance sessions, the project progress gained valuable contact persons - through the interaction - who became instrumental in the execution phase the following weeks.

Community engagement

Communication for such and other events was achieved through various channels including:

i. Social media on LEAP WhatsApp group comprising of 44 local members, IC 2022 constituting Flensburg team and 4 community mobilizing champions and Loop Head Community Facebook page. The project utilized the social media management representative to upload information on the Facebook page.

ii. Radio news item where the LEAP partner, Astoneco, assisted in the dissemination of the upcoming events in the discussed roadmap to the community via a local radio station.

iii. Face-to-face interactions and relaying of information throughphone calls and text messages for the already established contacts. These groups also advised on strategic places to display important communication such as the invitation to workshops.

iv. Organized workshops: Planned sessions were also used for communicating further upcoming events in a face-to-face fashion.

v. Posters: The project team quickly realized that this seemed to be a commonly used communication medium. Posters for upcoming events were designed through consultative meetings before draft designs being rolled out. Plenty of iterations were realized during the incorporation of suggested improvements. The general workflow of the design is as shown in Figure 2.1 below. Ultimately, the final approved posters were circulated for display around Carrigaholt, Kilkee and Kilrush at frequently visited business premises.

Community engagement

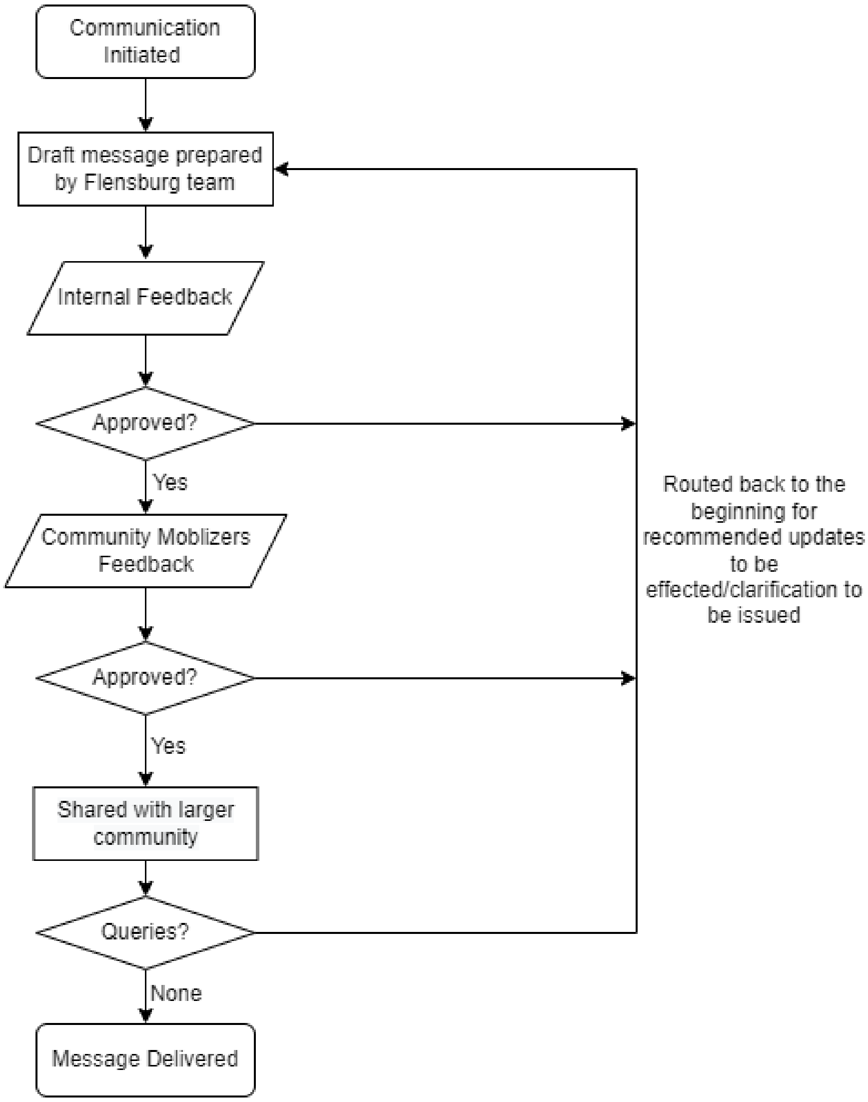

Figure 2.1: Poster communication flow
Source: Author

2.3. Conducted workshops

By Hiram Masese

Workshops were mainly organised to share the scope of IC2022, incorporate input from the community and later sessions were used to share findings of the study and to receive feedback from the community.

Workshop 1 - Saturday, February 5th 2022

Dubbed 'Solar Deep Dive', this session was held in Kilkee Bay Hotel and was attended by 56 people; including 7 children. The 3-hour session as indicated in Annex 6 was a joint facilitation by Flensburg and Astoneco Management. It served the purpose of linking work done by the predecessor IC classes of 2020 and 2021 to the scope proposed by the class of 2022. Additionally, an introduction on working of a solar system was covered followed by a local community member sharing challenges and benefits of his 4.8 kWp Solar PV system. This provided diversity in the engagement approach where the audience were listening from a practical case in their neighbourhood.

The participants were then introduced to physical solar panel components where they had a chance to have hands-on interaction and to pose further questions. Finally, the Flensburg team organized 3 information booths where they provided details to the workshop participants on building retrofit steps, solar and space heating sizings and their economics as well as life cycle assessment and socio-economic assessment of solar PV systems.

The most important outcome of the session were the questions raised by the community members on the scope of what they were interested to know, see Annex 7. Questions which could not be answered immediately were processed and were incorporated within the scope of work. IC2022 noted from the session that nearly all questions raised would be addressed by the initial scope of the project.

Workshop 2 - Saturday, February 19th 2022

A series of events were conducted on this day. First was a 3-hour session attended by 31 individuals at Kilkee Bay Hotel to present the first findings on one sampled case study from the three under review. Since the evaluation of the previously used booths yielded positive feedback, on this day, 5 stations (see

Annex 8 were organized to offer detailed information, including those raised a fortnight earlier on:

i. SEAI grants
ii. Building Retrofits
iii. Heat Pump technologies
iv. Energy consumption and economics of solar PV systems
v. Carbon footprint and emission reduction

Solar lab demonstration

Although the initial plan for this event was to be an actual installation of four 320 Wp solar panels donated by the local F4 Energy Limited Company to Keane's Beer Garden, poor weather conditions prompted a change and the team opted to conduct a solar lab demonstration instead. The 20 participants in attendance were taken through the technical functionalities of the solar system components and their questions addressed, and the system components were connected to produce electricity to the grid.

Carrigaholt National School Visit

Later that afternoon, the team facilitated a clean energy awareness session at a local primary school for 12 children aged between 6 and 12 years. The 2-hour session entailed a basic explanation of solar, biomass and wind energy technologies. The children were taught how to make a home-made solar oven using aluminium foil and cardboard paper, a small biogas plants in 500 ml bottles using soil, organic waste, sugar and warm water by placing the mixture in an environment of about 40 °C and on how to collect the generated gas in a balloon covering the opening of the bottle. Further, they got to make simple propellers from hard paper.

2.3.1. Monitoring and evaluation

Monitoring and Evaluation (M&E) was intended to track, understand and improve the effectiveness of the CE activities carried out during the project. The (USAID, n.d.) indicates that it is significant to have feedback continuously at every significant milestone of a project. IC 2022 collected responses during workshop sessions, through social media platforms and through participating in community-organized events such as the Sunday walks where feedback was solicited. Depending on the feedback obtained, action was taken to achieve the most appropriate level of CE as outlined in Table 2.2 below.

Table 2.2: Indicative level of community engagement
Source: Author based on (IAP2 Federation, 2014)

CE Level	Description and application
Inform	Providing clear information to stakeholders; walk participants who had limited knowledge of Flensburg University presence and objectives were appraised.
Consult	Receiving feedback from members, sometimes suggestions for alternatives; information on where to display event posters.
Involve	Executing tasks to address the concerns of the stakeholders; households energy assessment walkthroughs were conducted in presence of the owners. Members participated in solar panels installations at Keane's Beer garden.
Collaborate	Working in synergy with the members to deliver on a task; the IC team visited a local resident with an installed solar PV system and partnered in the preparation of workshop material.
Empower	Members get a significant understanding and can make decisions on their own; workshop reports and household energy assessments were shared with the community members for their consideration on the solutions they would opt for.

Community engagement

Some of the indicators monitored included:

i. Number of attendees for organized sessions – Low turnout was taken as an indicator that mobilization needed to be intensified. Conversations such as rolling communication early and distributing posters to a wider target were held to improve attendance.

ii. Budget – Expenses were monitored against their allocated fraction of the budget. Alternatives such as printing smaller, cheaper sizes of posters and hosting only necessary sessions were implemented.

iii. Slight delay in starting the first workshop session – Measures such as early set-up for the subsequent sessions were taken to mitigate this challenge.

iv. Feedback in questions format during and at the end of the sessions – Questions raised in the first workshop, for instance, were used to align on the scope and manage expectations.

2.4. Challenges and recommendation

In general, the process of involving the stakeholders in the LEAP program went smoothly. The engagement activities were overall successful. The community was greatly involved, and the turnout in the events was largely satisfying with between 35 and 50 attendees in the two main sessions held in Kilkee. However, there were some challenges that made the community engagement difficult. The first challenge the team encountered was the availability of the community. The community members are mostly available during the weekend. This has significantly changed the plan prepared in advance by the team but also has changed the approaches adopted. Some planned activities were, as a result, cancelled or had to be reorganized. Another challenge the team was facing is the communication process. A lengthy internal approval process for communication caused delays in the activity preparation. In addition, the team relies mainly on a single contact person for communication which also causes delays if the person is not available. Additionally, the broad range of interests in the community became a challenge for the team since the team's scope and available resources are limited. Moreover, the team could not cover all the topics that might be in the interest of the community due to time constraints.

Based on the challenges mentioned above, the team came up with some recommendations. First, knowing the availability of the community in advance would help the team to properly plan ahead of the activities. It is therefore recommended for the next batch of the IC to acquire information on the availability of the community and the different stakeholders prior to travelling to Loop Head. Delays could be avoided by having more than one member of the community as a contact person. Regarding the COVID pandemic, the measures had already been lifted by the time the team arrived in Loop Head. However, for precaution, the team was tested for COVID on a weekly basis.

3. Case study approach to energy efficiency and technologies

3.1. Common definitions used throughout the energy assessments and case studies

Building Energy Rating

Ireland measures the energy performance of the building based on the annual primary energy usage of the building represented in units of kWh/m^2/year[1]. The BER rating scale is divided into categories from G to A where G represents the poorly performing building with the largest primary energy use and A represents the efficient building performance with the lowest primary energy use. The full range of categories is illustrated in Figure 3.1. To improve the BER rating of a house, SEAI recommends building fabric upgrades as the first step. Furthermore, switching from an oil boiler to a heat pump can have a significant impact on the BER. However, it should only be done when the house is very well insulated. An on-site renewable source of energy helps decrease the imported primary energy demand of the house further increasing the BER rating of the house.

[1] Indicated in BER rating scale.

Case study approach to energy efficiency and technologies

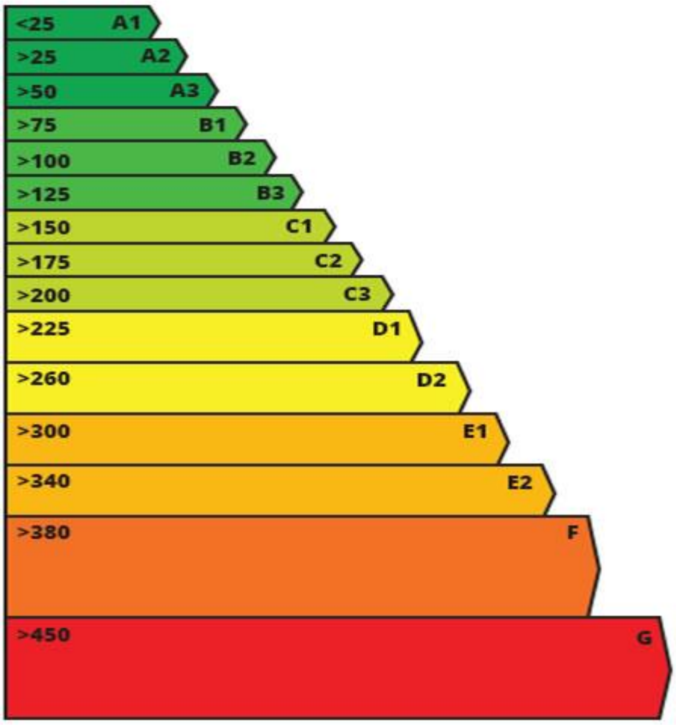

Figure 3.1: Building Energy Rating scales
Source:(Energlaze, 2022)

Heat Loss Indicator

Heat Loss Indicator (HLI) is an indicator to assess if the fabric and ventilation loss of the dwelling is sufficiently low for a domestic heat pump system to work in lower space heating temperature and meet all or most of the water heating demand. HLI is measured by summing up the total fabric (walls, floors, roofs, doors and windows) and ventilation loss of the dwelling divided by the total floor area. It is basically a total heat loss per m^2 of the dwelling.

Thermal Camera

A thermal camera is a measuring device that allows to see the thermal (infrared) radiation of surrounding objects and measure the temperature at any point on the surface with an accuracy of 0.1 ° C and higher. The device allowed to identify the construction defects such as missing or defective insulation, moisture spots, structural shortcomings, sources of heat losses. Sharp thermal images were created based on temperature differences. The hottest places are coloured in red, yellow and orange and the coldest in blue and black. Detail of the thermal camera assessment is available Annex 12.

U-Value

Thermal transmittance (*U*-value) defines the ability of an element of structure to transmit heat under steady-state conditions. It measures the quantity of heat that will flow through a unit area in unit time per unit difference in temperature of the individual environments where the structure intervenes expressed in W/m^2 K The lower the U -Values, the better is the insulation of the material.

3.2. Energy assessment of residential buildings

A series of site visits were carried out between the 2nd and 8th of February, 2022. The energy assessment was carried out based on the following methodology:

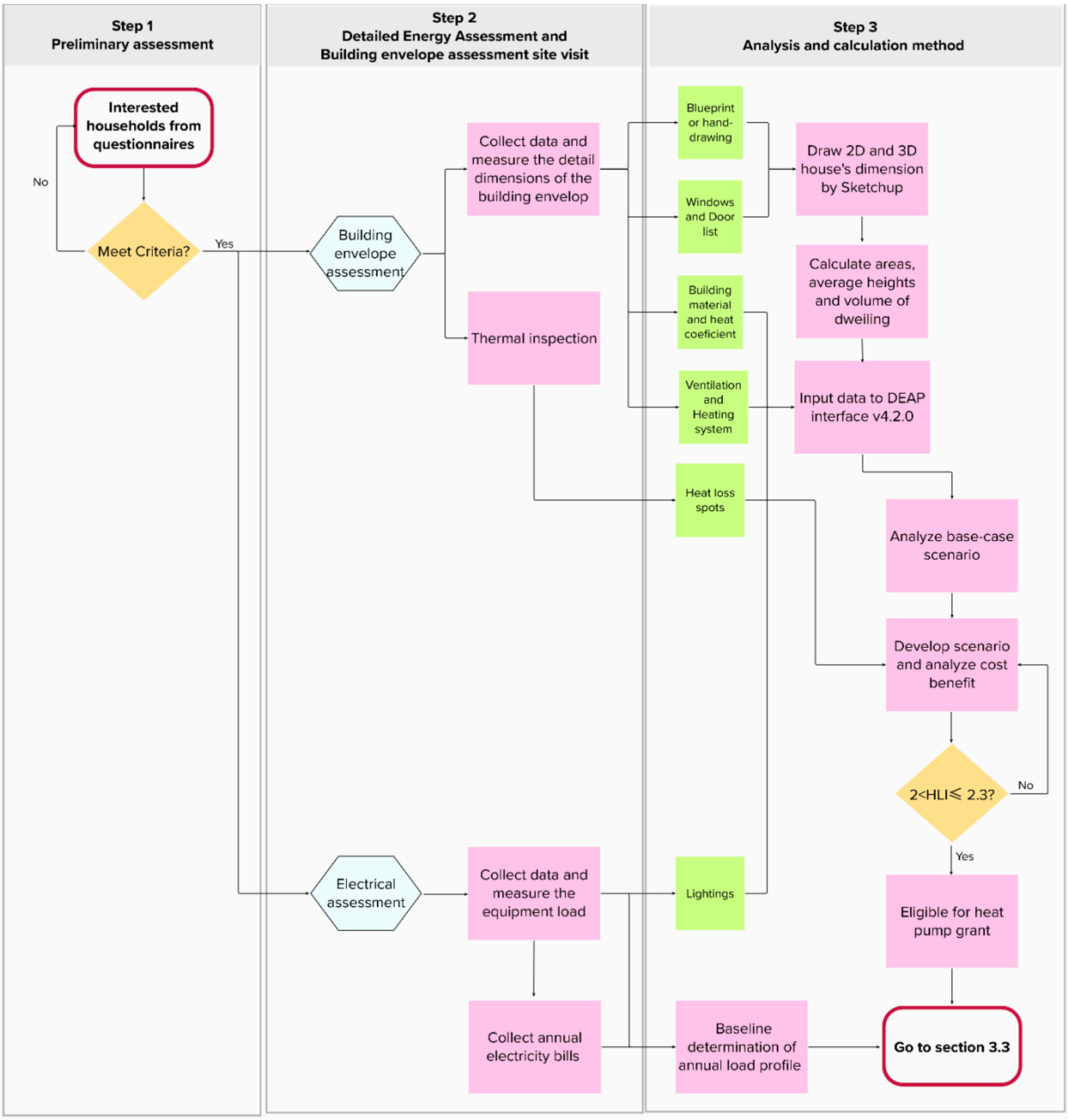

Figure 3.2: Energy assessment methodology
Source: Author

Case study approach to energy efficiency and technologies

Phase 1: Preliminary assessment

For the energy assessment of the residential building, it was essential to sample case study households in Loop Head. For this reason, the methodology began with defining the selection criteria. These needed to be transparent and meet the expectations of the interested households. The defined selection criteria for the case study houses were:

a) The house should be an occupied residential house.

b) The homeowner should provide access to the annual electricity bills for at least one year.

c) The construction year should be between the following years: pre or early 1900, 1950 – 1977 and from 2005 onwards, to represent the majority of dwellings in the LH Community.

d) The house should be available for measurement and data collection for more than one day.

e) The homeowner should allow taking pictures and be willing to be interviewed in case of more data requirements.

f) In order to keep calculations more precise and representative for a more significant number of buildings, the existence of renovation and extension, the number of joints in the house should not be greater than two. Provision of blueprints and/or hand-drawings of the dwelling is preferred.

g) Owners should exhibit interest in renewable energy or heat pump installation.

Through the pre-survey questionnaire, a total of five house owners expressed their interest in having an energy assessment conducted. A survey of the physical characteristics of the building and data collection of annual electricity invoices was carried out by preliminary site visits of the interested households.

Phase 2: Detailed energy assessment

In compliance with the defined criteria, three case studies were narrowed down for the detailed energy assessment. Phase 2 was further divided into electrical and building envelope assessments. Therefore, a team of four was divided into two students each for the respective task. The set of instruments used for the detailed energy assessment were: thermal camera, laser meters, energy meters and measuring tapes. A phone camera was used to capture the building's internal and external characteristics when required.

I. Electrical assessment

An audit of the electrical appliances was carried out including the total equipment counts, nameplate readings, and measurements to determine the equipment load in kilowatts (kW). The hours of operation were determined for all equipment as per the homeowner's schedule and site observations. In the case of inefficient lighting and equipment in the case study sites, energy efficiency measures were employed to identify energy-saving opportunities.

Finally, the energy use calculated above was reconciled to the actual annual metered consumption for a baseline determination of the annual load profile.

II. Building envelope assessment

The first step to assess characteristics of the dwelling was an on-site survey, which considered dimensions of the envelope, material, space heating, type of water boiler system, among others. For each aspect, the type of information collected is described in the following:

Step 1: Envelop Survey

For the data collection of the envelope, it was required two different data sheets; the first one was the DEAP for New – Final and existing Home Survey Form, and the second one is an excel table to address the information of doors and windows

The DEAP[2] Survey Form was used to collect the information according to requirements for DEAP 4.2.0 software (see Table 3.1). This document includes a series of questions evaluating:

- Age or ages of dwelling, in case of joins.
- Years and materials for the walls
- Roof construction; type of roof and insulation
- Floor construction; type and insulation
- A record for each room (dimensions) (a different datasheet was used in particular for this data.)
- Ventilation factors
- Primary and secondary space heating system and the respective fuel used
- Heating system for hot water

[2] Annex 9

Case study approach to energy efficiency and technologies

The second data sheet[3] was required to collect the dimensions per room, including:

a) Dimensions in size and height, for the room, doors and windows

b) The counting of windows and doors,

c) Materials and directions.

d) Height of the window from the floor

Step 2: Thermal Camera Analysis

A thermal camera was used for the thermal inspection of the building envelope. The technical details of the used thermal camera are attached in Annex 11. Before the examination, all the case study houses were heated for at least 24 hours so that the temperature difference between outside and inside would be at least 10 degrees. Each room was examined with the infrared camera for temperature differences in the areas of floors, walls, ceilings, windows and doors. Particular attention was paid to the inspection of ceilings with built-in lighting, ceilings and walls on the attic floors, insulation at the junction of window frames and walls. During the inspection of the premises, infrared images of areas with detected low temperatures were taken. The images were later analysed to identify poor insulation and provide recommendations.

Phase 3: Analysis and calculation

Two software were used for analysis and calculation. Sketchup was used for calculating the area and volume of the house and DEAP Software 4.2 was used for the heat loss analysis and development of retrofit steps.

- Sketchup

Sketchup is a two- and three-dimensional modelling and graphic design program. Because of that, its utilities range from urban design and planning, civil engineering, architecture, industrial design, among others (SketchUp, 2022)

The program has a user-friendly and intuitive interface, which allows them to perform work quickly and accurately. For this reason, SketchUp is the tool used for the building dimensions calculation of the case studies.

In the absence of dwellings blueprints, a method was opted that would allow to process the information obtained during the interview and data collection phase. Necessary inputs for the

[3] Annex 10

Case study approach to energy efficiency and technologies

DEAP were derived from SketchUp, which included total area, dwelling volume, and total perimeter. The steps followed for SketchUp is described below:

1. Draw each room based on the measurements. This process includes the sequences and distribution of the rooms and the determination of the public and bedrooms areas.

2. Based on the type of wall of the dwelling, the dimensions (thickness) of external walls and the internal walls were included

3. Once the particular areas were classified, the calculations of the area per room can be made and cross-checked with the heights.

4. The internal walls are removed in a copy of the drawing to calculate the main floor area.

5. With the clean floor area, another layer is created to project the roof, extending the floor perimeter by 0.30m to consider the eave. The extra space influences the total area of the roof and, consequently, the volume.

   Note: For pitched roofs, geometry calculations to consider the slope are additional to obtain the actual area and volume.

6. In the floor area layer, after calculating the average height of the rooms from the data collected, the value is input in the elevation of the walls and calculates the area.

The calculations performed with SketchUp are the input to the DEAP program, a process that is described in more detail in the next section.

SketchUp building process

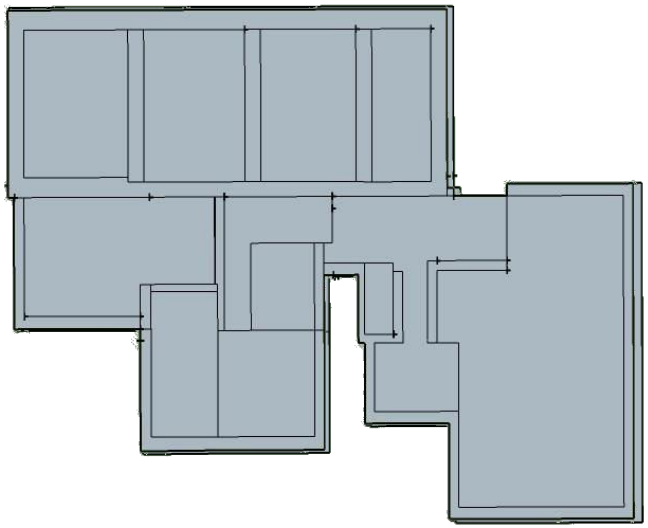

Figure 3.3: Rooms distribution drawings
Source: Author based on own measurements

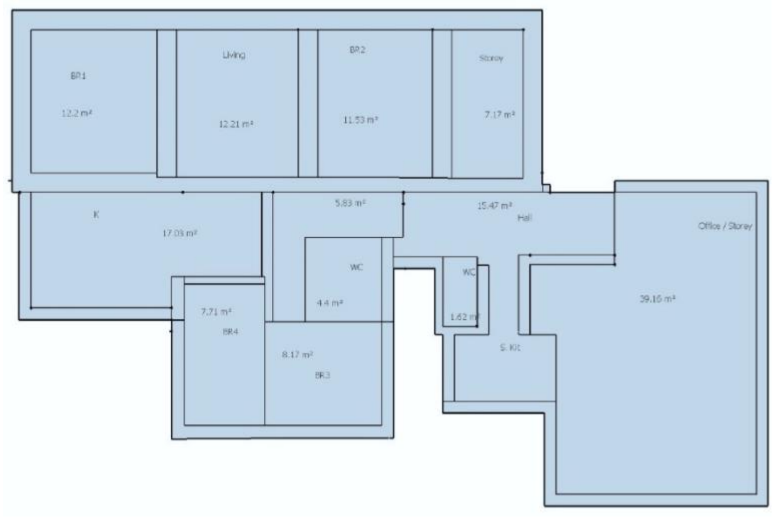

Figure 3.8: Rooms areas
Source: Author based on own measurements

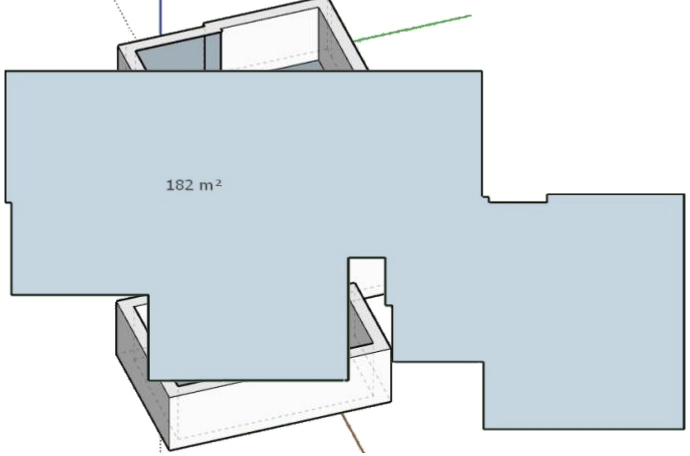

Figure 3.5: Total floor area
Source: Author based on own measurement

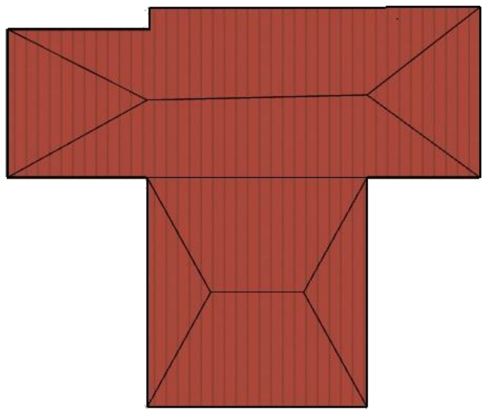

Figure 3.4: Section of a pitchpitched roof
Source: Author based on own measurement

- DEAP

The DEAP 4.2.0 software web interface developed by SEAI was used to calculate and assess the heat loss and the energy required for space heating from building fabrics and to develop retrofit strategies. The calculation of the energy demand for space and water heating is based on the the dwelling dimension and doesn't reflect the consumption behavior of the occupants. The main inputs required for the calculation are summarized in Table 3.1.

Table 3.1: Summary of the main DEAP inputs
Source: DEAP manual(Seai, 2020)

Element	Parameters
Building geometry	Building floor area, living room area, floor heights, volume, exposed wall areas, roof areas, floor areas, window and door area
Building fabric	U-Values of element
Windows	Orientation, type of glazing, U-Value, number of openings, overshading, blinds curtains type, number of draughts stripped openings, overhangs.
Ventilation	Air-tightness (infiltration rate), number of vents, fans and flues, draught stripping, type of structure (masonry or timber), ventilation method (natural or mechanical),
Space heating systems	System controls and responsiveness, boiler efficiency, fuel type, distribution medium, distribution losses, secondary heating system
Water heating systems	System controls and responsive, boiler efficiency, fuel type, distribution losses, storage losses, solar hot water systems
Lighting	Proportion of low-energy light fittings
Renewables	Photovoltaic, biomass, CHP, etc (if applicable)

The retrofit strategy is defined based on the result of the DEAP Software, the thermal camera assessment, and the severity of heat loss from fabrics in the building. The combination of the upgrade suggestions aim at improving the BER rating. The suggestions are provided in the following sequence: lighting measurements, envelop insulation, windows and door improvement and continue through heating system technologies and renewable energy technologies. The upgrade of heating and electricity generation technologies depend on the feasibility.

The U-Values for the upgraded fabrics are referenced from the DEAP Manual Appendix Table S (Seai, 2020) based on the recommended measures. The fabric upgrades involved in this study are for doors and windows, external wall insulation and roof insulation. Due to the relative inconvenience of floor insulation and lack of penetration of floor insulation retrofits in the Irish homes as per (Ahern et al., 2013), floor insulation was considered only in Case Study III where it was necessary for the installation of Heat Pump. The U-Value of the floor, therefore, remains unchanged, Case I and II.

As per the National Housing Retrofit Scheme (*National Housing Retrofit Scheme - House2home*, n.d.), all homes undergoing major renovations must be built to a minimum Building Energy Rating (BER) of B2. However, the maximum fabric upgrades above the advanced retrofit strategies defined under TABULA[4] was not considered irrespective of the energy rating of the house. Instead, heat loss and HLI was accessed in every fabric upgrade step to calculate the energy and cost savings with the associated payback period.

Under conditions when the HLI of the developed retrofit upgrade was within the range of 2 W/K/m^2 and 2.3 W/k/m^2, design and system sizing of a heat pump was done, as the range defines the eligibility for the Heat Pump grant. Where the HLI is between 2 and 2.3 W/km^2, it may not be economically feasible to upgrade the home further (Seai, 2020)

Annual energy costs for each step are calculated using DEAP by multiplying the calculated annual delivered energy (kWh by fuel type) by the relevant fuel price kWh unit costs (including 13.5 % VAT). The unit costs were obtained from Domestic Fuels, comparison of useful energy costs for space heating (SEAI, 2022b). The cost of heating oil and wood pellets bagged was used for the calculation as outlined in Table 3.2.

Table 3.2: Domestic fuels prices
Sources: (SEAI, 2022b)

Heating Oil (€/kWh)	Wood Pellets Bagged (€/kWh)	Kerosene (€/kWh	Electricity unit price (€/kWh)	Electricity night rate (€/kWh)
0.081	0.0716	0.0791	0.2407	0.0983

3.2.1. Cost analysis

- Investment cost including VAT

The investment costs include all material costs referring to the recent Irish market price, construction cost and Irish VAT. The building retrofit and domestic fuels are under a reduced rate of VAT, which is 13.5 % (Irish Tax and Customs, 2022). Equation 3.1 shows the calculation of total investment cost used for building retrofits of every case studies.

[4] Tabula It is a project that produces the Building Typology Brochure of Ireland in the energy performance of typical Irish dwellings. This documented work as a base for retrofit recommendations by the combination of materials.

Equation 3.1: Total investment cost
Source:(Coyle, 2015)

$$Total\ investment = (Initial\ cost \times Irish\ VAT) - Grants\ (If\ applicable)$$

- Total Net saving

The total net savings were calculated by using Equation 3.2. The total energy cost savings are the energy cost difference between the base scenario and the developed scenario.

Equation 3.2: Total net saving
Source: (Coyle, 2015)

$$\begin{aligned} Total\ Net\ Saving &= (Primary\ energy\ saving \times Primay\ Fuel\ cost) \\ &+ (Second\ energy\ saving \times Secondary\ Fuel\ cost) \end{aligned}$$

- Payback Period

Another economic indicator for building retrofitting is the payback period. There are two types of Payback Period calculated to compare the benefits of each scenario's recommendations and alternatives, namely simple and discounted Payback Period. These are estimated as per Equation 3.3 and Equation 3.4.

  - Simple Payback Period

Equation 3.3: Simple payback period
Source: (Coyle, 2015)

$$Simple\ Payback\ Period = \frac{Total\ investment}{Total\ net\ saving}$$

  - Discounted Payback Period

Equation 3.4: Discounted payback period
Source: (CFI, 2022)

$$Discounted\ Payback\ Period = \frac{Net\ Cash\ Flow}{(1 + Discount\ rate\ )^{n}};\ n: period$$

- Cost estimate classification

The cost-benefit consideration has to include the uncertainty in the calculation. Considering the accuracy range according to AACE International Recommended Practice Professional Guidance,(Borowicz et al., 2020) there are five classes for the cost estimate classification which are also able to apply to cost estimates for building retrofitting. The cost estimate class was mapped by primary and secondary characteristics of the project phases and stages as shown in Table 3.3. Each cost estimate class has a different expected accuracy range at an 80% confidence interval. Class 5 has the highest accuracy range and Class 1 has the lowest one as detailed in Table 3.3. The building retrofitting and corresponding cost estimates can be defined as Class 4 which was called "Schematic design or conceptual study" by considering the available drawings, parametric models, and preliminary material. The final calculation will consider the accuracy range between a low range of -10 % and a high range of 30 %.

Table 3.3: Cost estimate classification matrix for the building and general construction industries"
Source: (Borowicz et al., n.d)

Estimate class	**Primary Characteristic**	**Secondary Characteristic**		
	Maturity Level of Project Definition Deliverables Expressed as % of complete definition	End Usage Typical purpose of estimate	Methodology Typical estimating method	Expected Accuracy range Typical variation in low and high ranges at an 80% confidence interval
Class 5	0% to 2%	Functional area or concept screening	SF or m^2 factoring, parametric models, judgment, or analogy	L: -20% to -30% H: +30 to + 50%
Class 4	1% to 15%	Schematic design or concept study	Parametric models, assembly driven models	L: -10% to -20% H: +20% to + 30%
Class 3	10% to 40%	Design development, budget authorization, feasibility	Semi-detailed unit costs with assembly Level lines items	L: -5% to -15% H: +10% to + 20%
Class 2	30% to 75%	Control or bid/tender, semi-detailed	Detailed unit cost with forced detailed take-off	L: -5% to -10% H: +5% to + 15%
Class 1	65% to 100%	Check estimate or prebid/tender, change order	Detailed unit cost with detailed take-off	L: -3% to -5% H: +3% to + 10%

3.3. Solar PV-Heat Pump System Sizing and Integration

After introducing suitable retrofitting and energy efficiency improvement measures at the residential buildings in Loop Head, the feasibility of solar PV technology for electricity generation and the replacement of conventional heating solutions with heat pumps was analyzed.

The output from the PV system is not uniform throughout the year since it depends on various factors, as will be described in sub-chapter 4.3.2. The generated energy exceeds the household demand at a higher energy yield from the PV system. Thus, this study analyzes the system integration of battery storage and domestic hot water storage tank for maximum utilization of the generated excess energy. Further, this study aims to design a low-cost PV system with a higher energy fraction for selected dwellings in LH. Figure 3.12 shows the methodology flow diagram for designing and analyzing a residential PV system.

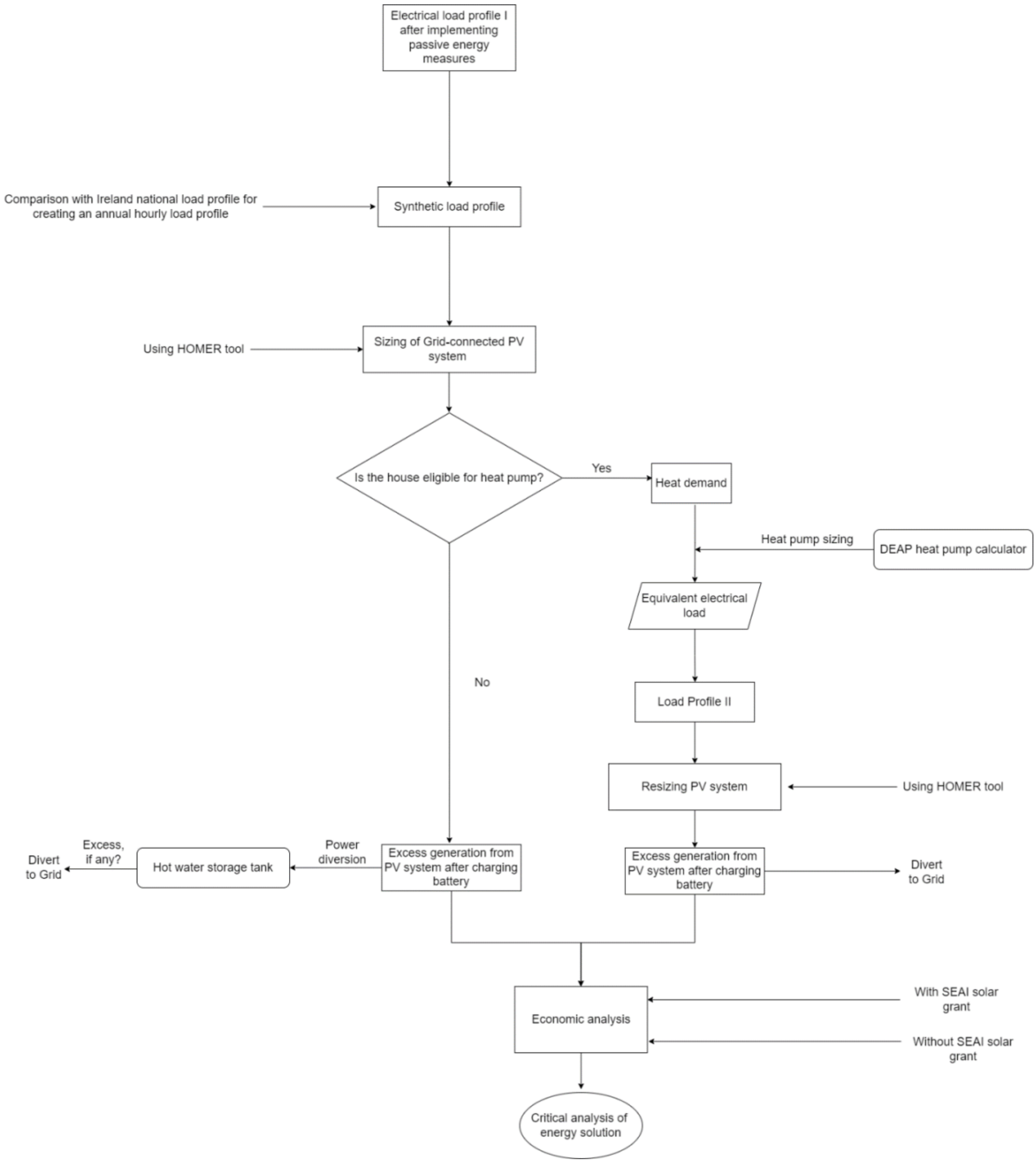

Figure 3.12: Case study approach for PV technology
Source: Author

Step 1: Developing a synthetic load profile

It is imperative to match the erratic behavior of PV energy with the time-varying power consumption of a household. This enables the operators to optimize the cost of the system by addressing subjects of concern on how to: operate the system, size the storage, curtail excess energy. Thus, the analysis of load profiles is crucial for PV system design (IRENA, 2018).

The load profile developed after energy assessments in three different households, as discussed in Chapters 5, 6, and 7 , elucidates the annual electricity consumption of the building after implementing the energy efficiency measures. However, it does not reflect the hourly consumption of the household.

The limited time for IC 2022 challenged the possibility of recording the annual hourly consumption of households in Loop Head. This led to developing a synthetic load profile for residents in Loop Head from the standard national load profile developed by (Ricardo, 2020a). The national load profile considers the average demand of typical Irish households, including the seasonality factor and variation of load pattern on weekends and weekdays. However, the demand profile data is from 1997, and the annual domestic consumption was over 7,564 kWh, which might not represent the consumption of present-day Irish households. Therefore, it is essential to scale down the standard national load profile to match the actual demand of Loop head dwellings. Since many variables are considered in the development of synthetic load profiles, it requires validation for further utilization in the PV system design.

<u>Validation process</u>

A scaling factor was created by dividing the annual electricity consumption of a typical Loop Head household obtained from the pre-energy assessment and annual average residential consumption from (Ricardo, 2020a). The synthetic load profile for Loop Head households was generated by multiplying the hourly annual national load and the scaling factor. Further, the synthetic load profile pattern was compared with the monthly load profile developed after pre-energy assessment. The similar demand pattern of the two load profiles provided a scientific base to adapting the synthetic load profile for the Solar PV sizing throughout the study.

Step 2: Sizing of PV system

HOMER, a software developed by National Renewable Energy Laboratory (NREL), was used to design and evaluate technically and financially apt options for microgenerators. Homer Pro models the physical behavior and lifecycle cost of microgenerators. Microgenerators such as solar PV system take the input parameters as shown in Figure 3.13 and analyze the performance of the system configuration hourly to determine its technical feasibility and life-cycle cost. The three major tasks of Homer Pro include simulation, optimization, and sensitivity analysis. The software simulates various system configurations in the optimization process to satisfy the technical constraints at the lowest life-cycle cost. The sensitivity analysis helps gauge the effects of changes in the model input. The oval representation of the three tasks in Figure 3.13 shows that single optimization requires multiple simulations. Similarly, single sensitivity analysis involves a series of optimizations.

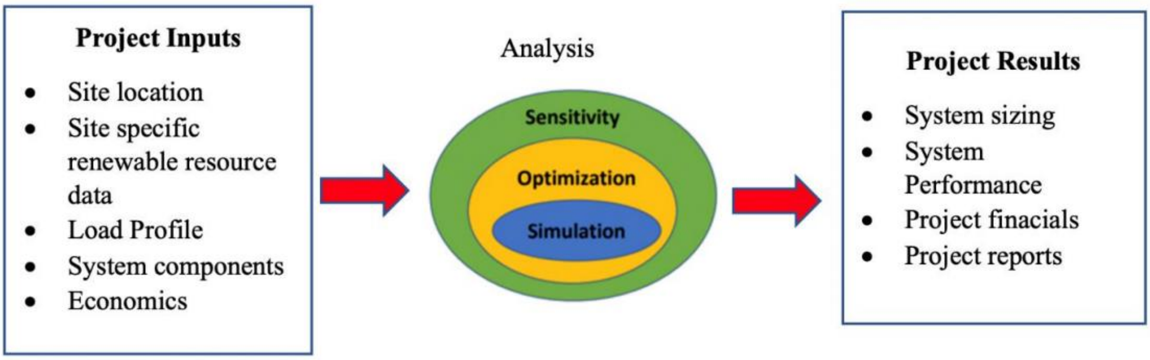

Figure 3.13: Operating mechanism of Homer Pro Software
Source: author

In the case studies, the solar panels, inverter, and battery size options were fed as input parameters in Homer Pro. Further, the optimization tool in Homer was used to find the optimal size to cater to the demand. Two optimization criteria were set for the final selection of the system, as listed below.

I. Cost-optimized-system with the lowest cost for generated electricity compared to the considered electricity tariff of 24.70 cent €/kWh

II. Generation optimized-maximum renewable penetration from the system selected from criteria I by conducting sensitivity analysis on the altered tilt angle

The optimized design was finalized based on the market availability of the components. Also, the system design complied with the SEAI domestic solar PV code of practice.

Step 3: Power diversion to hot water storage

The houses that did not pass the eligibility criteria for installing a heat pump were equipped with a power diversion controller for domestic hot water purposes. In the case of a battery storage system, the excess was diverted only after charging the battery system.

The hot water demand varies significantly depending on the nur of consumers throughout the day/month/year (Herrando et al., 2014). A study (DEFRA, 2008a) in 124 dwellings in England suggested that the mean household hot water requirement is 122 L/day, with a confidence interval of 95% of +/- 18L/day. Generally, a boiler is expected to provide hot water at 60 ^{0}C (Herrando et al., 2014)(. However, considering the studies from (Zondag et al., 2015) (DEFRA, 2008a), this study used an approximate estimate of daily consumption of 120 L at 50 °C for a family of four.

In this study, a water mains temperature of 10 ^{0}C was considered (DEFRA, 2008b),. The hourly simulation result obtained from Homer was rearranged in Microsoft Excel to calculate the daily excess from the PV system, out of which the energy required for hot water tank operation was diverted, and the rest was fed into the grid. The diverted power was used only to heat water up to 50 ^{0}C from the water mains temperature. Equation *3.5* was used to calculate the required energy to be diverted for water heating.

Equation 3.5: Electricity consumption of water heating

$$\text{Energy required} = \frac{Specific\ heat\ of\ water * volume\ of\ water\ to\ heat\ * (50 -\ water\ mains\ temperature)}{Performance\ ratio}$$

Where:

- Specific heat of water= 1,163 Wh/kg°C
- Efficiency= 0.9

Step 4: Economic Analysis

For the economic analysis, the cost of consumed energy (COCE) generated by the designed PV system was calculated using a general NPV approach as shown in Equation 3.6 The discounted payback period and cost savings from the generated PV were also economic indicators. The overall cost of the system was cumulative of individual component cost per kWp and installation cost.

Equation 3.6: COCE
Source: (Homer, 2021)

$$COCE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^n}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^n}}$$

Where:

- I_0= total investment cost for PV system
- A_t = Annual O&M cost for PV system including Grid O&M cost
- M_{el} = Total load served by the system

Case study approach to energy efficiency and technologies

All the parameters involved in the economic analysis, namely operation and maintenance cost, replacement cost, inflation rate, the lifetime of the components, discount rate, feed-in-tariff, and cost of grid electricity, are discussed below.

<u>**Financial Calculation Assumptions**</u>

The financial calculation involved various associated cost values and estimates. This section details the cost involved in the economic analysis of retrofitting, heat pump design, and residential solar PV design.

Nominal Discount rate

For the economic calculation, a nominal discount rate of 3.5% was considered throughout the study based on (IC, 2020).

Inflation rate

The inflation rate impacts the economic analysis and could lead to a misleading result if not incorporated carefully. According to the report (Statista, 2022) the inflation rate in Ireland has been in the range of 3.04 % to 1.9 % between 1986 and 2021. The report further forecasts the inflation rate of Ireland until the year 2026 to 2 %. This study assumed the 2 % per year inflation rate for the financial calculations.

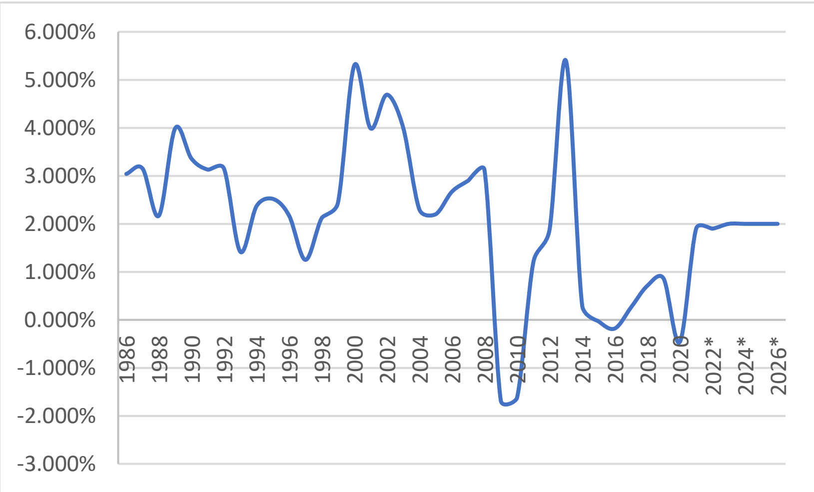

Figure 3.14: Inflation rate in Ireland
Source: author based on (Statista, 2022)

Real Discount rate

A real discount rate of 1.47 % was used for the economic calculation throughout the study.

Investment and O&M Cost

The total investment cost accounts for the investment incurred from the generation technology. The individual component cost for the various solar PV system sizes is attached in Annex . For PV system economic analysis, operation and maintenance (O&M) for panels and inverters was considered to be 1 % of the investment cost. However, the battery O&M was 2 % of the investment cost. While calculating COCE, the operation and maintenance cost of the grid is also considered. Equation 3.7 gives the grid O&M cost.

Equation 3.7: Grid O&M cost
Source:(Homer, 2021)

$$
\begin{aligned}
&Grid\ O\&M\ cost \\
&\qquad = load\ served\ by\ grid\ electricity * cost\ of\ grid\ electricity \\
&\qquad - income\ from\ the\ sales\ of\ electricity\ to\ the\ grid
\end{aligned}
$$

This study restricts the grid sales in the Homer Pro software. Besides, the O&M cost for the heat pump was assumed to be 311 €/year (Anders Rosenkjær Andersen, 2021)

Tariff rate

Different tariff rates were found in the electricity bills of the case study houses. However, none of the tariff rate reflected the the standard charge, the public service obligation levy, VAT and discounts. As a result, the customer pay more than what is mentioned as a “tariff rate” irrespective of day/night tariff or a fixed flat rate. After including all these factors for analyzing the electricity bills of all case studies, average the tariff rate of 24.70 cent €/kWh was considered throughout the study.

Feed-in tariff

The Clean Energy Guarantee (CEG), discussed in sub – chapter 4.6.3, enables the microgenerators to receive payments from their electricity supplier for the electricity fed into the grid. The feed-in tariff rate will be based on a competitive market rate. However, this study considered a feed-in tariff of 0.09 €/kWh (SEAI, 2020).

Degradation factor

The economic analysis includes the degradation factor considering that output from PV panels degrades annually. Thus, to account for it, 2 % factor was considered in the first year, and 0.05 % for later years.

Project Lifetime

The lifetime of the various components and equipment considered in this study are listed below.

Table 3.4: Lifetime of components and equipment

Components	Lifetime (years)
Solar Panel	25
Inverter	15
Battery	10
Heat pump	16

The cost-optimized system was analyzed under two scenarios: with and without SEAI solar grant. A further cost analysis of hot water diversion was added in system integration. Sensitivity analysis was conducted by varying the cost of grid electricity to analyze how it impacts the payback period and return on investment.

Critical analysis

The technical and cost constraints of the designed system were discussed. Further, the effectiveness of the PV system to enhance the BER rating of the building was analysed.

4. Energy solutions for residential buildings

In residential buildings, the energy consumption depends on the level of insulation present, type of space heating and the adoption of solutions to improve energy efficiency of the house in general. Energy-saving measures do not only increase the comfort level of the house but also make it possible to reduce fuel (coal, oil, gas) consumption and increase energy cost savings.

Heat loss of the house is the amount of heat given off by the house per unit of time in watts per kelvin (W/K). It is affected by the temperature difference between the inside and outside the house. The house loses heat through the building envelope (walls, windows, roof, foundation), ventilation and sewerage. 60 – 90 % of all heat losses are through the building envelope, (SEAI Blog, 2019) out of which, up to 25 % is due to the poor roof insulation, 20-35 % due to exterior walls, 25 % due to poor insulated or badly built-in windows and door, and 15 % through ground floors (SEETECH, 2022)

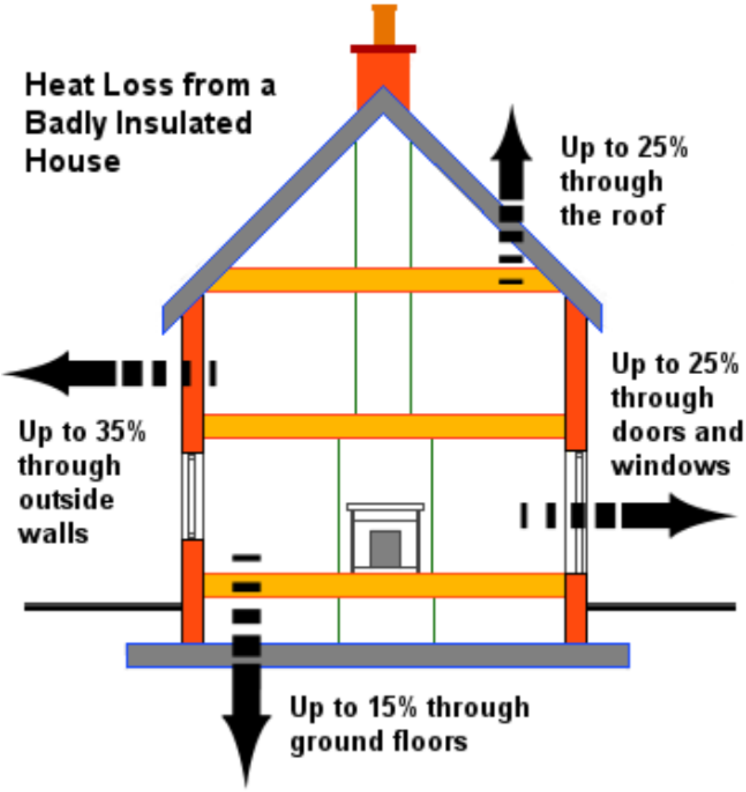

Figure 4.1: Average house heat losses
Source: (SEETECH, 2022)

The extent to which external walls or windows prevent heat from escaping is a measure of the resistance to heat transfer. There is an inversely proportional relationship between the resistance to heat transfer of the enclosing structures of the house and heat losses - with an increase in thermal resistance, heat losses fall. The following factors are taken into account when calculating the heat loss of a house:

- resistance to heat transfer of walls, floors, ceilings, windows;
- heat consumption for ventilation;
- air temperature in a particular place during the coldest period of winter;
- the location of the house on the cardinal points.

It is possible to achieve a reduction in heat loss if the following measures are taken:

- Insulation of the foundation, walls, and roof.
- Installation of the modern multi-chamber double-glazed windows, triple-glazed windows, or replacement of the seals and fittings in old windows.
- Sealing gaps and cracks in walls with polyurethane-based sealant.

4.1. Types of wall and insulation

One of the main measures to eliminate heat loss in the house is the insulation of the walls of the house. The three main wall types are cavity walls, solid walls, and hollow block walls.

External insulation | Internal insulation | Cavity wall insulation

Figure 4.2: Types of insulation.
Source: (Alexey Dedulin, 2019)

4.1.1. External wall insulation

The outer wall of the house performs three main functions:

- A mechanical barrier to protect against penetration into the room.
- Structure of the building.
- A barrier to outside cold air.

When the insulation is located outside, the walls are preserved from environmental impacts like rain, snow, sunlight. It also acts as an additional barrier that excludes contact of the wall with cold air, which is why internal heat is not dissipated into the atmosphere. Accordingly, the temperature of the wall rises, the dew point shifts outward. While doing external insulation different insulation materials can be used for example mineral, wool and polystyrene.

The insulating material is fixed outside the building. Mounting methods depend on the choice of material. To protect the insulating material from moisture and weather conditions, various finishing materials are used, such as decorative plaster, siding, and various decorative panels. Thus, by insulating the house from the outside, it is possible to update the appearance of the building.

4.1.2. Internal wall insulation

Insulating a house from the inside is a cheaper option compared to external wall insulation. Insulation boards are attached to the walls and covered with a vapor barrier layer and plasterboard. However, it is not recommended to insulate the house from the inside because mistakes in the choice of insulation and vapor barrier materials can lead to the constant formation of condensate, which will cause the spread of fungus and mold in the walls. In addition, it must be borne in mind that insulation of the house from the inside will lead to a decrease in the living space of the house and cause difficulties with hanging furniture and cabinets on the walls.

4.1.3. Cavity wall insulation

Insulation of walls of this type lies in the fact that the insulating material is located between the outer and inner walls of the building. Various insulating materials can be used, e.g., mineral wool and polystyrene panels. Injection of insulating products from the outside is considered to be the best method for insulating this type of wall.

4.2. Types of roofs and insulation

When choosing a material for insulating the roof of a house, the difference between three types of roof structures matters:

- Shed roof
- Pitched roof (cold attic)
- Mansard roof (floor)

Shed roof | A pitched roof (cold attic) | Mansard roof (floor)

Figure 4.3: Types of roofs
Source: (DD - Stroi, 2020)

Each of the three types of roofs requires a different approach in the choice of insulating materials.

4.2.1. Shed roof insulation

The shed roof has a simple design. This allows the use of various types of insulation:

- Polystyrene is a very light material and is easy to install.
- Mineral wool has good thermal quality but is extremely sensitive to moisture. Mineral wool is very easy to install from inside the attic by laying mineral wool sheets in between the rafters.
- Eco wool has very similar properties to mineral and cotton wool. Eco wool is made from recycled pulp and waste paper. It has excellent thermal qualities, is light, cheap, environmentally friendly. The material has a long service life and prevents noise and vibration.

The method of installing the insulation will directly depend on the choice of material. Today, roof insulation is usually done quickly and easily, without the need for special tools. In the case of sprayed Eco wool, you will need a special pump through which the material will be injected into the structure. For installation of insulation in the form of tiles or layers of mineral or cotton wool, special clamps with an increased area will be required. The material will be tightly fixed on the structure. It is easiest to start the insulation of a shed roof from the inside, but the waterproof material should be installed from the outside.

Rafter insulation

Attic insulation

Figure 4.4: Roof insulation.
Source:(SEAI, 2020a)

4.2.2. Pitched roof

It is possible to insulate a pitched roof with a cold attic on the floor. However, in some cases, insulation is also inserted between the rafters. For these purposes, soft and elastic mineral wool slabs are most often used, which are inserted into the spacer. The attic floor could be insulated with various materials, both sheets, loose and sprayed.

4.2.3. Mansard roof

The mansard roof is, in fact, the walls of the room, but they are not made of concrete or brick, but of rafters and, for example, tiles. This design is more expensive than a separate, ordinary floor. Roof insulation for a mansard roof should be environmentally friendly, because, in fact, it is warming the room from the inside. There are also increased requirements for fire safety. Most often, such roofs are insulated with mineral wool.

4.3. Floor insulation

Floor insulation in the house is a necessary part of the construction. Up to 15% of the heat goes through the flooring into the ground. An unheated basement under the building leads to heat losses of 5-10%.

The materials used to insulate floor coverings are produced in the form of:

- granules - expanded clay, foam glass, perlite, vermiculite granulated slag;
- rolls with and without a reflective layer - mineral wool, glass, slag, polyethylene foam, expanded polystyrene, cork;
- foil and non-foil boards - expanded polystyrene, foam plastic, foam plastic;
- liquids and foams - special insulating paints, polyurethane foam, Eco wool;

To select the most suitable material, you need to consider the features of their installation and use. The most common floor structures are concrete and wooden floors. Insulation material is different for different floor types.

Wooden floors are most often insulated with mineral wool or eco wool, which fit in the gaps between the floor joists as seen in Figure 4.5

Figure 4.5 Wooden floor insulation
Source: (Dave Judd, 2021)

For the concrete floor, it is better to insulate during the construction phase. The concrete floor is one of the most practical options for a house due to its strength and durability. But concrete is a cold material, and without high-quality thermal insulation in winter, high heat losses and the problem with condensate due to the large temperature difference on the inside and outside of the concrete base can appear.

When constructing a concrete floor, it is necessary to pay special attention to the waterproofing of the lower layer in order to avoid moisture getting into the concrete from the ground. In order to avoid the moisture base of the foundation of the floor, sand is laid first since it does not retain water in itself. The next step is laying the damp-proof membrane and the insulation materials on top of it. It is better to use materials with a low water absorption capacity, such as extruded polystyrene for concrete floor insulation. In the case of installation of underfloor heating, heating pipes should be laid after this process. The concrete mortar is poured on top of all with final floor covering after the concrete has hardened as seen in Figure 4.6

Figure 4.6: Concrete floor insulation
Source: (Insulation Superstore, 2020)

4.4. Types of windows

Today, in comparison with former times, the total area of glazing of buildings has increased significantly. Therefore, the problem of preserving heat in the cold season and its removal in the warm season is currently particularly acute. Therefore, to save heat and reduce energy consumption, first of all, it is necessary to take care of glazing of the building with energy-saving double-glazed or triple-glazed windows and windows with a special coating on the glass.

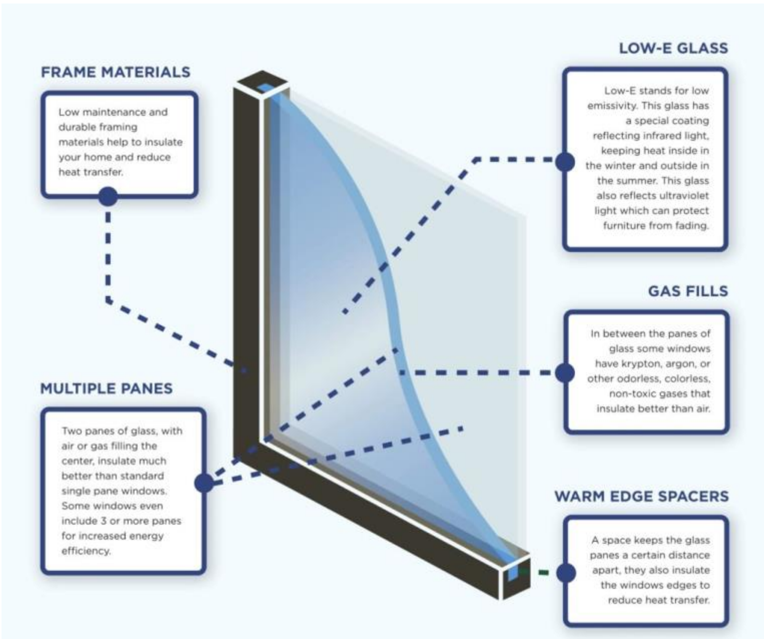

Figure 4.7: Energy-efficient window.
Source: (Window Efficiency, 2020)

Special coating divides all the waves of the spectrum into long and short thermal waves. It is applied to the surface of ordinary polished float glass and can reflect exactly long thermal waves. At the same time, short rays of the visible spectrum passing through such a coating almost unhindered. The inner surface of the double-glazed window independently returns the heat to the room and at the same time freely transmits light. Such coating is called selective or low-emissive.

As outlined, there is a big range of energy saving measures available. Step by step, we can make house more energy efficient, more comfortable and more environmentally friendly. Analysis energy consumption of the building and improving building envelope, replacing light bulbs with energy efficient ones, insulating the windows and doors, analyzing the characteristics of the heating system in house and improving it will help to reduce energy consumption.

If the house needs a radical modernization consultation, SEAI provides support programs and grants as summarized in Sub-chapter 4.4 appliable to the house. However, the "The cost of family retrofit is as individual as family itself". The decision to upgrade the house is individual to each household and depends upon the desired comfort and building efficiency.

4.1. Heating technologies

Heat pumps are based on the second law of thermodynamics that states "*There exists a useful thermodynamic variable called entropy (S). A natural process that starts in one equilibrium state and ends in another will go in the direction that causes entropy of the system plus the environment to increase for an irreversible process and to remain constant for a reversible process*"(NASA, n.d.); in simpler words, "*Heat will flow naturally from a hot source to the colder sink, and as per the first law, heat energy cannot be created nor destroyed but can be transformed from one form to another*"(NASA, n.d.).

Therefore,

Equation 4.1: Change Of Entropy

$$Change\ of\ Entropy\ (\Delta S) = \frac{Amountof\ Heat\ Transfered\ (\Delta Q)}{Temperature\ (\Delta T)}$$

Hence, for a reversible system:

Equation 4.2: Reversible System Entropy

$$S_{Source} - S_{Sink} = 0,$$

while for an irreversible system:

Equation 4.3: Irreversible System Entropy

$$S_{Sink} > S_{Source} \ .$$

However, an ideal reversible system is impossible to achieve in nature, and that can be concluded according to Clausius Statement of the Second Law "*It is impossible to construct a device which operates on a cycle and produces no other effect than the transfer of heat from a cooler body to a hotter body",* and Carnot's Theorem of the second law that states "*No heat engine operating between two reservoirs can be more efficient than a reversible heat engine operating between the same two reservoirs*" (Israel Urieli, 2014).

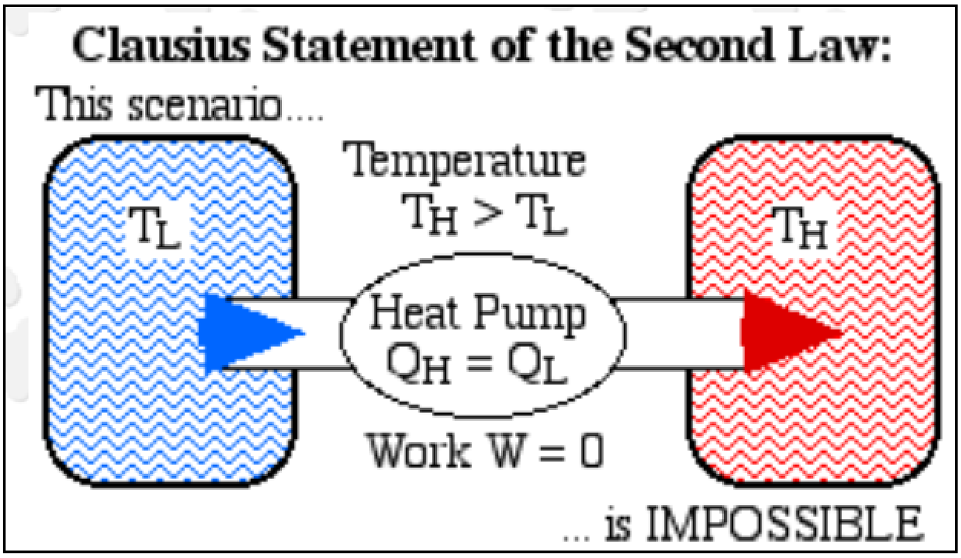

Figure 4.8: Work Has to Be Done to Transfer Heat
Source: (Israel Urieli, 2014)

Therefore, to transfer heat between two independent systems, work has to be done by a heat pump.

In this case,

Equation 4.4: Work of A Heat Pump

$$\text{Work } (W) = Q_H - Q_L \text{ or } W = T_H - T_L$$

and the Coefficient of Performance (COP) of the Heat Pump:

Equation 4.5: Heat Pump COP

$$COP = \Delta Q / W$$

Where,

- Q_H: Amount of Heat added from the Heat Source.
- Q_L: Amount of Heat available at the Heat Sink.
- ΔQ: Absolute Amount of Heat transferred from Source to Sink.
- T_H: Temperature of the Heat Source.
- T_L: Temperature of the Heat Sink.

Modern heat pumps harness heat from the ambient temperature to supply houses with the demanded heat and utilize the free units of heat of the ambient temperature in the form of the difference in temperature between the source and the sink. They employ a thermodynamic cycle that is called a reversed Carnot cycle since it is the reverse of the cycle adapted by refrigerators and air conditioners. To illustrate, instead of absorbing heat by the condenser and releasing cold air by the evaporator and blower as in air conditioners and fridges, modern heat pumps used for heating purposes absorb heat from the source by the evaporator and reject heat to house spaces by radiators. The beauty of modern heat pumps is that, even with the low ambient air temperature, heat can still multiply in the refrigerant by the means of the work done by the compressor, which boosts the refrigerant pressure and temperature. Modern heat pumps generate heat in multiples of units of electricity consumed and confirm the aforementioned laws of thermodynamics. Their coefficient of performance is calculated according to Equation 4.6 below.

Equation 4.6: Heat Pump COP

$$COP = T_H/(T_H - T_C)$$

where,

- T_H: Ambient Temperature
- T_C: Condenser Temperature

and work in this case is the electrical energy consumed by the compressor. Thus, heat pumps are often able to generate 3-5 multiples of electricity consumed, whereas boilers and storage heaters are not able to provide more units of energy than consumed (SEAI, n.d.-b).

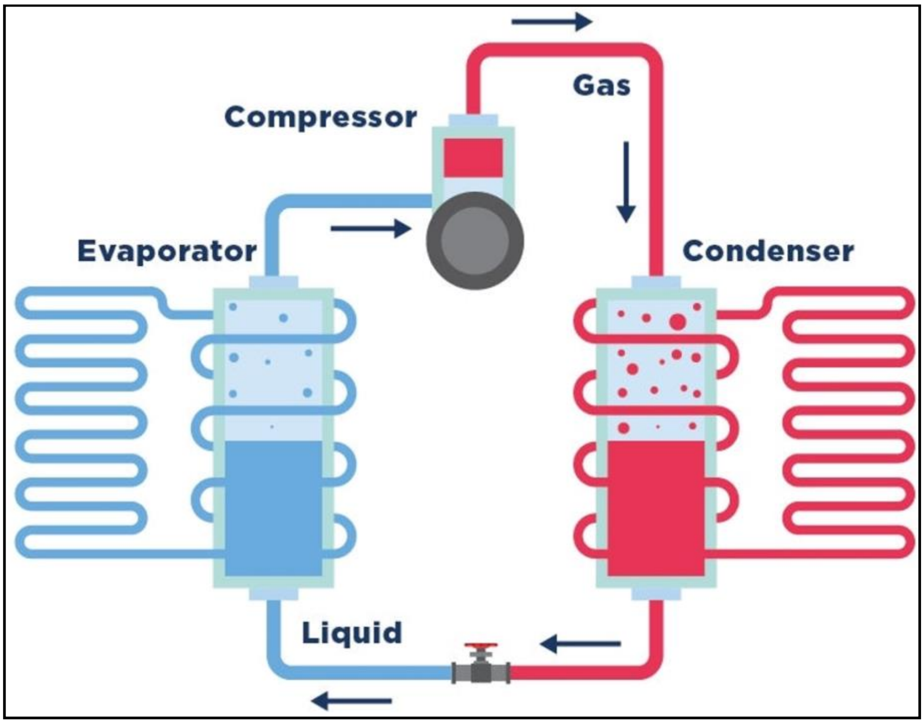

Figure 4.9: Heat Pump Components
Source: (Bord Gais, 2021)

A typical heat pump consists of five main components, namely an evaporator, a compressor, a condenser, a refrigerant, and an expansion valve as depicted on Figure 4.9. The evaporator acts as a heat exchanger to allow the circulating refrigerant to absorb the heat from the ambient air, changing the liquid refrigerant to gas. The compressor increases the temperature and pressure of the gas state refrigerant to super-heated gas at constant entropy. While the condenser receives the pressurized high-temperature refrigerant, releases the units of heat to the surroundings, and condenses the refrigerant back to a liquid state; the latent heat released is the result of the transformation of the refrigerant gas to liquid. Lastly, the expansion valve relieves the exceeded pressure in the refrigerant to maintain the pressure of the fluid in the cycle (Bord Gais, 2021; R Nave, 2014).

Heat pumps do not only utilize free units of heat of the environment, but they also escalate the free energy using electricity. To illustrate, for every kWh of electrical energy consumed by heat pumps, around 4 kWh of heat can be generated, which corresponds to a system efficiency of 400 %. Consequently, it can be interpreted that around 75 % of the energy used is renewable, while 25% of the energy is introduced to the system by electricity. So, if the electricity used to supply heat pumps are to be produced solely by means of PV panels, it can be ascertained that heat pumps are 100% renewable energy powered. Further, according to the International Energy Agency (IEA), heat pumps can easily provide 90 % of the global space heating and DHW heat demands while the potential of CO_2 emissions reduction in Ireland if the most efficient condensing gas boilers are replaced with Air-source heat pumps is 69 % (IEA, 2020). Moreover, heat pumps have an economic positive impact since the majority of heat pumps mounted in Europe are of European origin. Solely based on the sales levels and needed man-hours for type-specific installation of different heat pumps in the European heat pumps market, 40,358 European workers are employed on full-time basis, which in return foster employment in the European Union(European Heat Pump Association, 2021). Heat pumps are designated after the medium from which heat is absorbed from, namely ambient air and ground(SEAI, n.d.-c).

4.1.1. Brine-to-Water Heat Pumps Technology

These heat pumps are also called shallow Geo-thermal, ground Source, or ground-coupled heat pumps. Geothermal heat pumps have the highest thermal performance amongst the three different types depicted in this report. As shown in Figure 4.10, typically this type of heat pump consist of a combination of two thermodynamic circuits for heat transfer. Firstly, a circuit retrieving the heat from an earth depth to the heat pump evaporator; secondly, the main reverse Carnot cycle transferring heat to the house heat emitters (Kharseh & Luleå tekniska universitet. Institutionen för samhällsbyggnad och naturresurser., 2011). In the first circuit, this type of heat of heat pump normally employs water-antifreeze mixture as a circulating fluid to acquire the heat from the depth of earth; on the other hand, common refrigerants are utilized in the second circuit due to their high ability to gain thermal units and their low boiling temperature compared to water. The Ground Heat Exchanger buried (GHE) preferably of a plastic-based material is either cored vertically or horizontally into the earth under the ground surface at an appropriate depth that best balances the thermal efficiency gains against the costs of cored earth, used materials, and employed manpower hours.

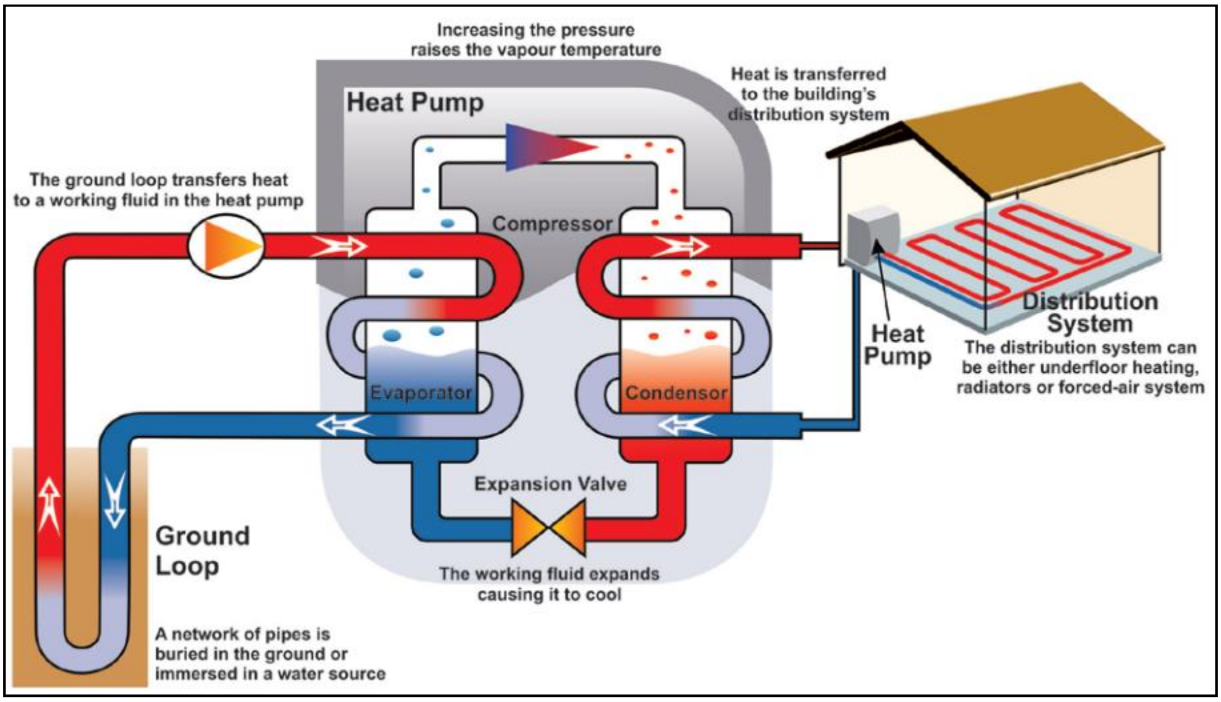

Figure 4.10: Geothermal heat pump schematic
Source:(Lind, 2012)

4.1.2. Air-to-Air Heat Pumps Technology

This type of heat pump has the lowest capital investment amongst the 3 types of heat pumps depicted in this report. They acquire heat from the circulating ambient temperature and provide the desired heat units to the indoor spaces via an air heat exchanger. This type of heat pump is widespread in the global south from the far east to the middle east as they are very convenient to employ for cooling cycles. This type of heat pump still employs a circulating refrigerant within a reverse Carnot cycle, but its main trait is having air as the source and the medium of heat transfer to the house; hence, they were designated as Air-to-Air. To illustrate, this type of heat pump is also referred as “Split Units” since the noisy equipment of the machine, namely the evaporator (Outdoor Coil) is mounted outdoors while the condenser (Indoor Coil) is mounted indoors in case of a heating cycle as shown in Figure 4.11 (Anders Rosenkjær Andersen, 2021). Therefore, one of their disadvantages is their inability to deliver conditioned air to several spaces of the house unless supplemented with an air circulation system. In such cases, these may be referred to as multi-split units; however, the investment cost will increase proportionally with the number of air handling units to be added. Another disadvantage of Air-to-Air heat pumps is their high dependency on their installation locations in the building and the design of that building. To illustrate, natural and artificial air circulation here play an immense role so if the pumps are to be installed constraint with air circulation barriers, such as walls, corners, or separations, their performance will drop significantly (Anders Rosenkjær Andersen, 2021). For this reason, besides the appropriate system sizing, performance analysis must be calculated by experienced engineers, qualified plumbers or technicians are highly recommended for their installation works. Further, to isolate the heated spaces and maintain the heat supplied by this type of heat pump; windows and openings are always advised to be closed, otherwise, the compressor will be overloaded to catch up with the extended heat demand of the desired temperature due to hot air leakage via openings. Therefore, they are capable to supply 60–80 % of large spaces with good air circulation (Anders Rosenkjær Andersen, 2021). On the other hand, if windows and openings are to be closed all the time to maintain the heat supplied by the heat pumps, new fresh air will not be supplied to the air-conditioned spaces, which in return will increase health risks and the spread of viruses. Moreover, Air-to-Air heat pumps can not independently provide hot water for domestic usage; thus, they are usually supplemented with an in-parallel heating system. However, regardless of their several disadvantages; they can still be a convenient choice for retrofitting houses especially summer houses with an existing heating system due to their lower capital costs, their installations practicality, and their usage flexibility (Anders Rosenkjær Andersen, 2021).

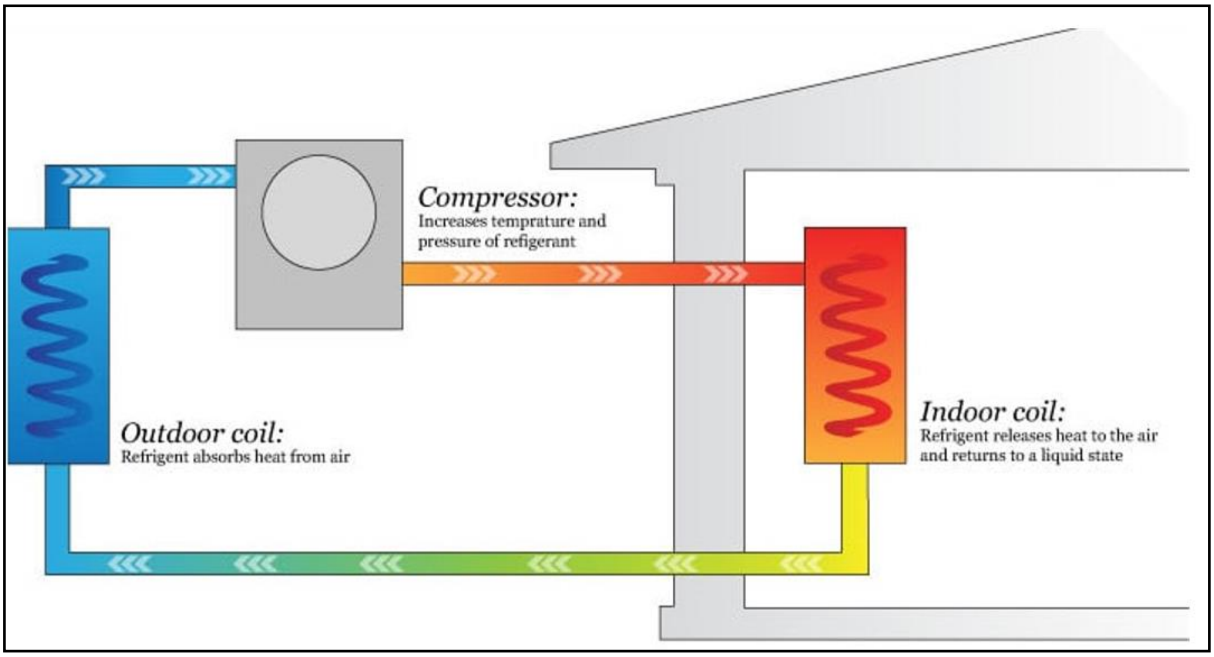

Figure 4.11: Air to Air Heat Pump Schematic
Source:(MB services, 2019)

4.1.3. Air-to-Water Heat Pumps (AWHP) technology

Alike, the Brine-to-Water heat pumps this type of heat pump depend on two heat transfer circuits; firstly, these pumps are typically installed outdoors to withdraw the heat units available in the ambient air via the refrigerant circuit having the heat pump major components, such as the evaporator, the compressor, the expansion valve, and the condenser. Secondly, the water-based distribution circuit that receives the heat from the condenser and provide it to indoor heat emitters, such as radiators or under floor heating (Anders Rosenkjær Andersen, 2021).

On the contrary to Air-to-Air heat pumps, AWHP are capable of providing 95-98 % of space heating demand as well as supplying the full Domestic Hot Water (DHW) heat demand. In addition, the older models of these pumps are usually supplemented by a direct heating coil in their DHW tanks, while newer models are independently able to heat domestic water to the aimed 55-65°C that assures Legionella bacteria elimination(Anders Rosenkjær Andersen, 2021). Nevertheless, Heat pumps are not typically capable of providing instantaneous DHW; hence, a four occupants' dwelling requires an insulated tank of 200 liters to be attached to the system, allowing dwelling's occupants 24 hours of hot water consumption(Anders Rosenkjær Andersen, 2021). An integrated system of DHW and space heating supplies the DHW heat demand as a priority in its operational logic before catering for the space heating demand (SEAI, n.d.-a). Even though during the summer months DHW is the only heat demand for a dwelling in Loop Head, it is still a valuable asset to consider owning the newer AWHP models that employ direct heating coils in their DHW tanks for stand by operation. To illustrate, the direct heating coil will not only reduce the number of compressor start-ups in case of slight heat demand in the domestic tank, but it will also be able to heat the water in the summer season independently (Anders Rosenkjær Andersen, 2021).

The compressor start-ups can also be reduced by either adding a buffer hot water tank to increase the volume of hot water available or by obtaining the newer models having an inverter-controlled compressor that is capable of 20-30 % nominal load operation (Anders Rosenkjær Andersen, 2021).

Since this type of heat pump depend on two heat transfer circuits, they can be constructed as monobloc or split units. The monobloc arrangement is normally situated outdoors including the refrigerant circuit components, while the antifreeze water distributing circuit can be connected at the condenser interface of the first circuit. While the expansion tank and DHW tank are located inside the dwelling as depicted in Figure 4.12.

On the other hand, the split type splits the noisy components of the main refrigerant circuit of the heat pump outside the dwelling, including the evaporator, and the compressor, whereas the condenser exchanges heat units with the antifreeze water circuit and it is located indoors (Anders Rosenkjær Andersen, 2021). Besides, the split configuration needs a higher technician's expertise as well as more plumbing works at installation, monobloc configurations are mobilized to sites fully refrigerant pressurized. A vital advantage of split configuration is their ability to cater higher heat demand for large buildings as cascade arrangements having the indoor units and the DHW tanks serving each floor independently, which is cheaper than customizing a single high-capacity unit. Hence, monobloc heat pump arrangement is usually preferred for one family houses even though the presence of the condenser outdoors might possess a slight risk of freezing if the pipes are jammed and circulation stops. However, the likelihood of this risk occurring is minimal (Anders Rosenkjær Andersen, 2021).

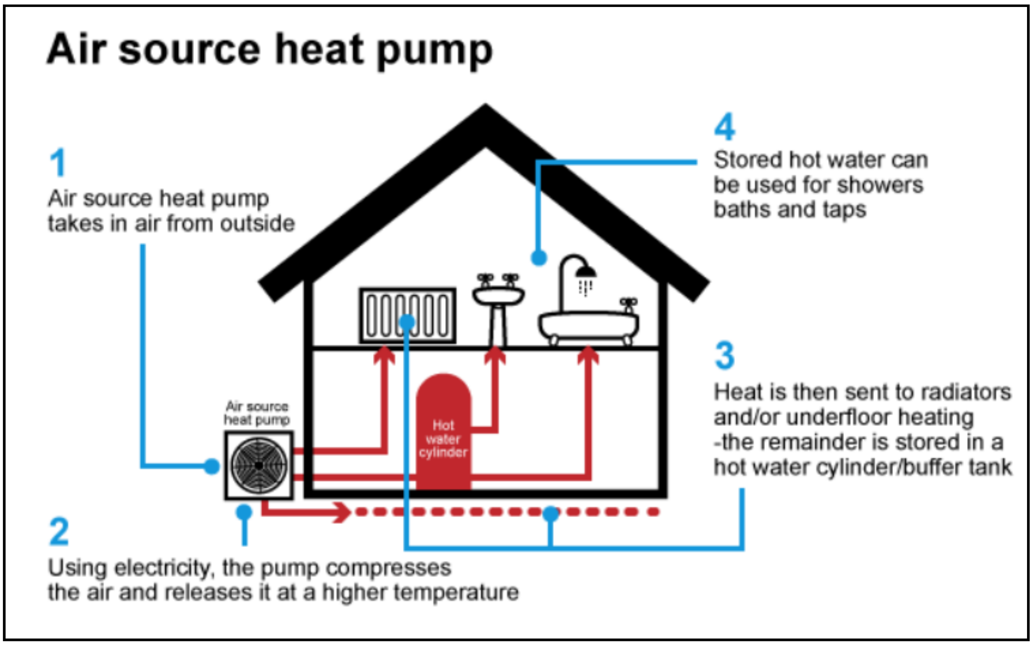

Figure 4.12: Air to Water Heat Pump Schematic
Source: (Asset Heating & Solar, 2020)

4.2. Heat emitters

There are several types of heat emitters that can serve heat pumps as the last point of transmitting the heat transferred of the antifreeze water circuit, Such as:

4.2.1. Steel radiators

Standard radiators transmit heat by convection, and they are constructed of steel fins. They are used as an emitting technology for Air-to-Water heat pumps, but they must be oversized to compensate for the lower forward temperature[5] generated by AWHPs compared with conventional oil boilers.

[5] Forward Temperature: the temperature at which water enters the heat emitter.

4.2.2. Low-temperature fan assisted radiators

This type of radiator can supplement AWHP especially to cater for spaces with higher heat demand, and they utilize lower forward temperature than convection radiators. They are designed to permit higher heat output than convection radiators since they are constructed with aluminium fins forced with fan blowers. This type of radiator has a higher capital cost than convection radiators, and they can be installed in specific rooms with high thermal loads.

4.2.3. Underfloor heating

The most detaining aspect of this technology is that it has to be considered as part of a major refurbishment or in newly constructed dwellings due to its excessive under floor works. The temperatures required and the quantity of heat emitted utilizing this technology is dependent on the material of flooring and floor coverings. Solid floors covered with tiles generate the most thermal mass. Highly insulated floor coverings, for example, thick carpet or underlay, hinders heat delivery via the floor and are not recommended with underfloor emitters. This technology tends to be the highest cost of all emitting technologies; however, it can deliver high thermal mass and operate at low forward temperature.

As a general rule when designing a heat-emitting system the forward temperature required for emitters has to conform with the heat pump forward temperature. Also, if considering more than one heat emitting technology the heat pump forward temperature must align with the highest forward temperature required of all emitters. Therefore, if considering steel radiators for installation, it is of no sense to consider other technologies in parallel unless they are not able to suffice the heat demand at specific rooms. That’s due to their lowest investment costs and highest forward temperature required, so the heat pump will be sized to supply the high forward temperature anyways(Heat Pumps Implementation Guide, 2020). Heat pumps performance is inversely proportional with the heat emitters' required forward temperatures. The lower the forward temperature required, the higher the performance of a heat pump.

4.3. Solar PV

4.3.1. Introduction to solar technology

When light hits a semiconductor material, the electrically charged particles are released from or within a material. This phenomenon is referred to as the Photoelectric effect. Solar Photovoltaic (PV) cells are based on this phenomenon to convert sunlight into electricity. Sunlight is composed of photons with various amounts of energy having different wavelengths.

Energy solutions for residential buildings

When sunlight hits the PV cells mostly made up of silicon, the photons may be absorbed or reflected. The absorbed photons transfer the energy into an electron in an atom of the cell and generate DC electricity. Several cells that generate a small amount of electricity are combined to form a module that can then be arranged into arrays to increase electric energy production. Additional equipment is required to convert the generated DC electricity into useable form Alternating Current (*AC*) electricity and to store the excess DC electricity for later use. The generated electricity can be used to power electrical devices such as lights, electric vehicles in the house.

The solar PV system is one of the feasible solutions for generating electricity for domestic use. According to the Code of Practice of Ireland, the system should be sized for the self-consumption of the energy within the home. Therefore, it is necessary to size the solar PV sizing depending upon the individual household electricity demand.

In the Irish market, different varieties of solar PV technologies are available. The most commonly used PV technologies are Monocrystalline, Polycrystalline, Multi-crystalline and Thin film panels. Moreover, the performance and the cost of the Panels vary widely. Table 4.1 shows the comparision of different types of solar panels.

Table 4.1: Summary of different types of solar panel
Source:(Aurora, 2021)

Panels	**Monocrystalline**	**Polycrystalline**	**Thin Film**
Materials	Made from a single pure silicon crystal	Made from different fragments of silicon crystals instead of one	Made from Cadmium telluride (CdTe), Amorphous silicon (a-Si), and Copper indium gallium selenide (CIGS) not from silicon wafers
Appearance	Dark Black Colour with rounded edges	Blue with Square Edges	It comes in both black and blue depending on the type of thin-film variant
Efficiency	Over 20%	Between 15% -17%	CIGS 13%-15% CdTe 9%-11% a-Si 6%-8%
Initial Cost	High	Middle	Highest to Lowest CIGS

Panels	Monocrystalline	Polycrystalline	Thin Film
			CdTe a-Si
Lifespan	Around 40 years	20-35 years	10-20 years
Advantages	Highest efficiency Highest power capacity per square meter Most space-efficient Long-lasting panel Slightly less affected by high temperature in comparison to polycrystalline	Mid-range option in terms of cost, efficiency, and power capacity	Flexible and light-weighted solar panel Easier to install and less labour intensive Lowest Cost Less affected by high temperature
Disadvantage	High Initial Investment	Not recommended for hot environments because of low heat tolerance capacity	Shorter lifespan Least Efficient Requires more space

Bifacial solar panels absorb sunlight from both the front and back of the PV panels producing more electricity by utilizing the same space than the traditional PV technology. As the panels are provided with a transparent back, the sunlight goes through the panel and reflects off the ground surface towards the back of the solar cell of the panel. Bifacial panels are used primarily in large commercial, utility sectors but can also be used in residential. However, the type of solar panel appropriate for the installation depends upon the individual's property specifications, budget, preference, specific situation, and the type of PV system (ground-mounted or rooftop) installation. If an individual is going for a bifacial PV system, the roof must have a light-coloured surface for optimal performance.

4.3.2. Factors Affecting Solar Energy Generation

All the sunlight that reaches the PV module is not converted into electricity. The output from the PV system installation is the PV output minus the losses through the rest of the system. Several factors to be considered while designing a Solar PV System that determines the maximum annual yield are discussed below.

PV Module Orientation and Tilt Angle

The solar radiation at the specific location or at the building in that site is important. The Loop head, Peninsula lies in the northern hemisphere. To obtain maximum annual incident solar radiation, the orientation of PV modules must be towards the south with an optimum tilt angle from the horizontal of 37°(PVGIS, 2019). A slight deviation from the optimum tilt angle will not significantly affect solar availability (SEAI, 2017).However, depending upon the geographical location and the consumption pattern of the consumer, the tilt angle can be adjusted for maximizing the self-sufficiency of the system.

Solar Irradiance

Irradiance is an instantaneous measurement of solar power over some area. The units of irradiance are watts per square meter (w/m^2). The Global Horizontal Irradiance (GHI) s the total irradiance from the sun on a horizontal earth surface. The GHI is the sum of the solar radiation that directly reaches the earth's surface (Direct Normal Irradiance, DNI), and the radiation that is scattered, diffused or reflected by the molecules or particulate in the atmosphere (Diffuse Horizontal Irradiance, DHI). Figure 4.13 shows the solar irradiance on the solar panel.

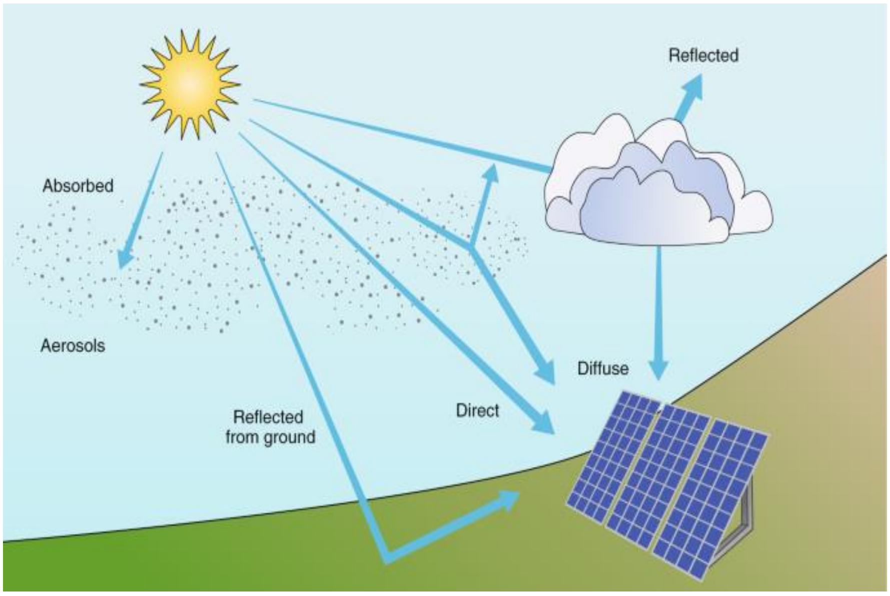

Figure 4.13: Solar Irradiance
Source:(SpringerNature, 2021)

The Loop Head Peninsula is located at Latitude 52.6°N and Longitude 9.6°W. The average GHI is 985 kWh/m^2 per year, with a maximum of 1000 kWh/m^2(Global Solar Atlas, 2021). The average GHI of Loop Head is higher than that of Irelandx (924 kWh/m^2)(Global Solar Atlas, 2021). That implies that, on average, Loop Head is sunnier than many other parts of Ireland. A PV plant of 1 kWp installed in Loop Head will produce between 934 and 960 kWh per year (Global Solar Atlas, 2021). Figure 4.14 shows the generation profile of a 1 kWp PV system. It is clear that Loop Head receives the highest solar irradiation during May whereas the lowest irradiation is during December.

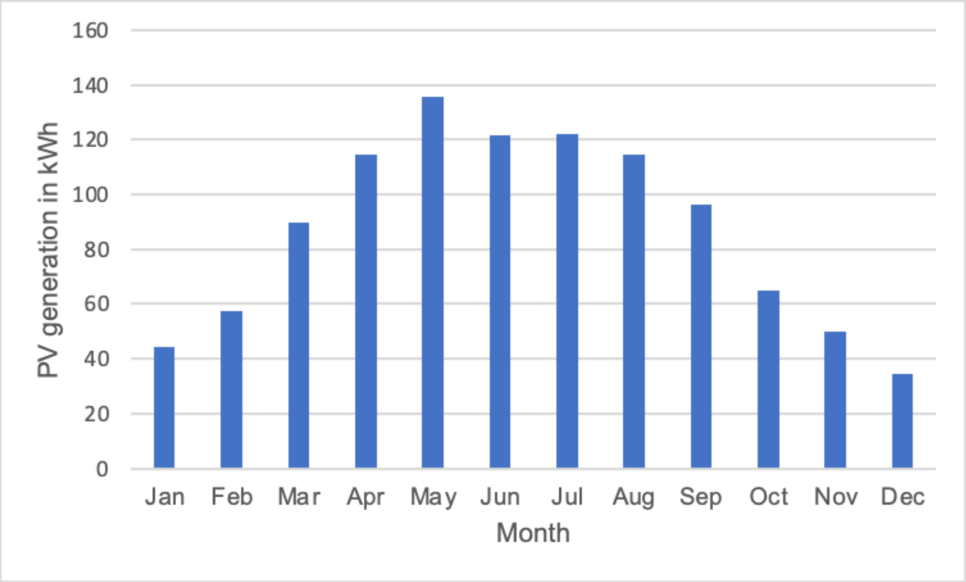

Figure 4.14: Monthly PV generation of 1kWp system
Source: Author based on simulations using Homer Pro

The monthly data of GHI for the location has been retrieved from the European Solar Energy Platform PVGIS (PVGIS, 2019). The solar irradiation data for each month from 2006 to 2016 was used to calculate the average monthly PV production. Figure 4.15 shows the average monthly global horizontal irradiation and global irradiation at an optimal angle of 39°. The maximum irradiation at an optimum angle is in May and June, around 144 $kWh/m^{2,}$ and the minimum is in December, around 31 kWh/m^2 (PVGIS, 2019)

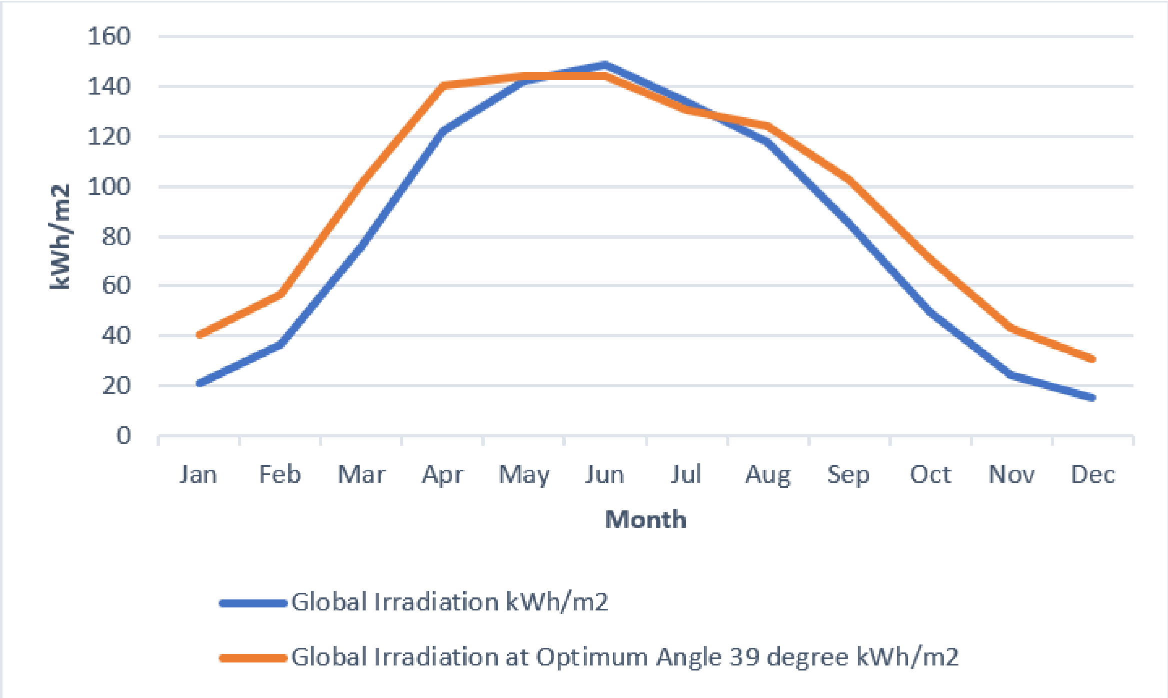

Figure 4.15: Average monthly solar irradiation
Source: (PVGIS, 2019)

Sun Path

The sun path diagram reads the solar azimuth and altitude for a given location. It provides information about how the sun's position will impact the site throughout the year. Figure 4.16 illustrates the sun path and sun elevation angle of Clare County and provides information about the daylight length. In June, the summer sun rises roughly at around 47° and reaches the maximum elevation angle slightly above 60° at solar noon, and sets at an angle just close to 315° (UO SRML, 2007). During summer, Clare County receives long daytime hours from 4 AM to 54pprox.. 9 PM. It is in contrast to the winter sun path. During December, the sun rises at roughly around 130° (8.30 AM) and sets at approximately 230° (3:30 PM) with a maximum elevation angle of 13° (UO SRML, 2007).

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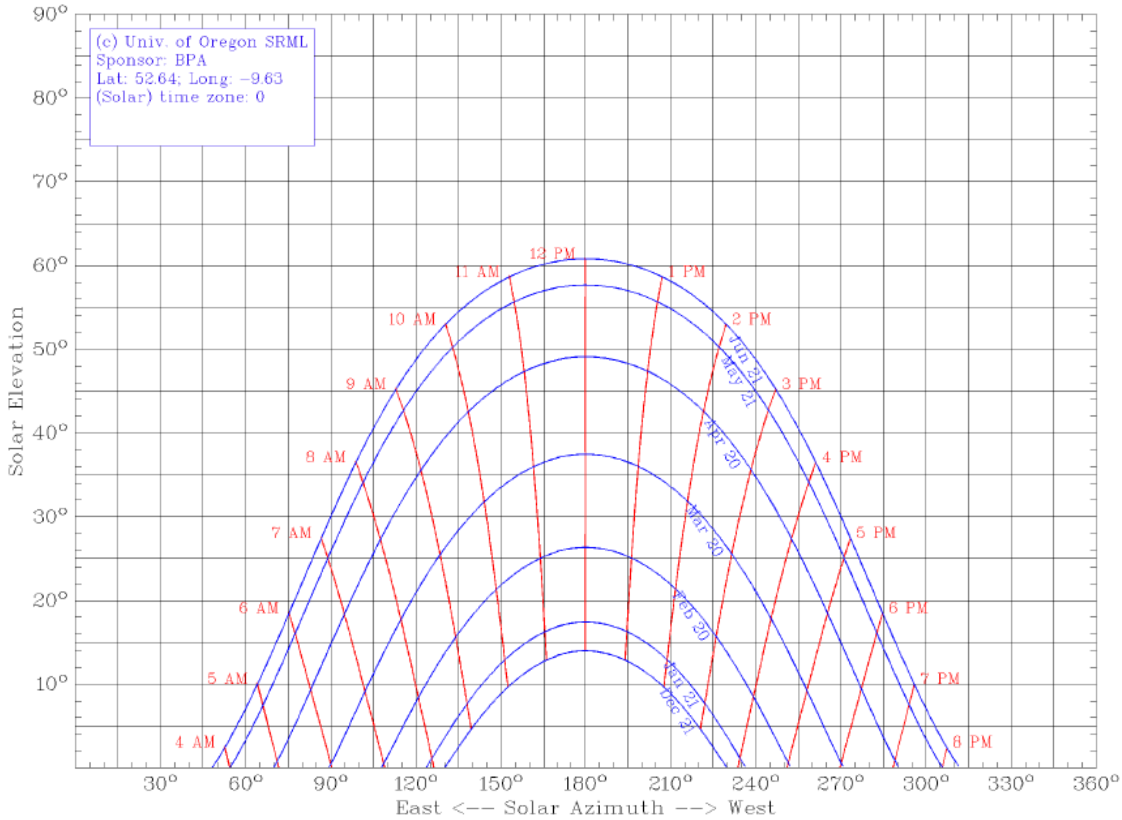


Figure 4.16: Sun path chart of Loop Head, Peninsula
Source: (UO SRML, 2007)

Temperature

Irradiation and temperature share a strong correlation. The temperature has a significant impact on the efficiency of the Solar panel. The solar panel is tested at a standard temperature of 25°. Moreover, every panel is provided with temperature coefficient Pmax which illustrates the change in efficiency with rising and fall by every degree. So, for high efficiency, cooler sunny weather is suitable. In order to appropriately design the PV system, it is therefore essential to analyze the weather condition of Loop Head. The warmest month is July, with an average daily high temperature of around 19° C and a daily low temperature of 13° C (WeatherSpark, 2021). The coldest month is January, with an average daily high temperature of 9° C and a daily low temperature of 4° C (WeatherSpark, 2021).

Precipitation

In Loop Head, the chance of wet days differs significantly throughout the year. The wet season lasts from October to February, with a more than 40% chance of being a wet day (WeatherSpark, 2021). Moreover, April has the fewest wet days of precipitation from rain. There is a strong correlation between cloud cover and precipitation. Changes in precipitation influence the cloud cover, and an increase in the cloud cover reduces the output power.

Shading

The cells in each PV module are connected in series to increase the voltage. As the cells are in series, when one cell is shaded, the output current from the whole string is affected. Regardless of the number of cells in the string, the shading of one cell causes the output power of the module to fall to the level of the shaded cell. Shading can be caused by neighbouring buildings, trees, poles, or self-shading by the array itself. During the system design, the overshading factors need to be considered.

Soiling

Another factor that should be considered while designing a PV system is the soiling effect. The PV modules are placed outdoors and are subjected to soiling. Small dust particles on the module's surface act as an obstacle to the solar irradiation hitting the cell's surface, ultimately reducing the module output power. The bigger dust particles are cleaned by the rainfall, whereas the rainfall has a very minimum cleaning effect on smaller dust particles. The soiling loss is indirectly proportional to the tilt angle of the PV module.

4.4. Solar PV System integration

Domestic solar PV systems can be designed as grid-connected systems with or without energy storage. Proper integration of domestic solar PV systems with household electric appliances, energy storage systems, and the national grid helps maximize the electricity consumption generated by the solar PV system. In this case, the priorities can be given for different systems, as shown in Figure 4.17. Using the electricity generated by solar PV for household electrical appliances is the primary requirement. Then, surplus electricity can be used to charge the battery storage system. If there is no battery storage system or if there is further surplus energy after charging the battery, it can be directed to an immersion heater to generate hot water for domestic consumption. Finally, the excess electricity can be fed to the grid. Currently, the energy suppliers are not obliged to pay for the electricity export from the domestic solar PV system. Hence, homeowners' intelligent management of day-to-day energy consumption will help to minimize surplus energy export to the grid.

Energy solutions for residential buildings

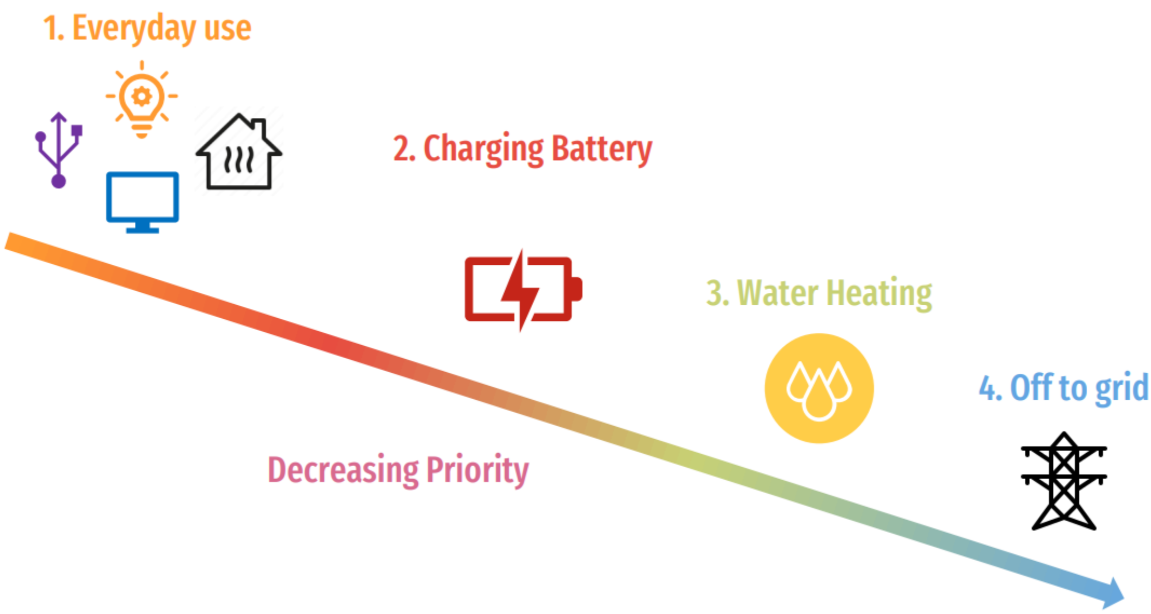


Figure 4.17: Domestic solar PV system integration priority
Source:(Leonard, 2022a)

4.4.1. Battery storage system

A rechargeable battery helps to store surplus electricity without exporting it to the grid. The stored energy drains during the cloudy or dark hours of the day. The battery storage can increase the solar PV-based electricity penetration, and also it can be used as a standby system for power outages. Even though adding battery storage to the solar PV system increases capital investment by a considerable amount, it allows storing electricity generated by solar PV at a lower cost compared to the grid tariff. Further, the system can be programmed to charge batteries during the lower night rate times. James Frith,(2021) reports that the higher demand in Battery storage due to the booming Electric Vehicles (Evs) and the solar market has driven massive technological improvements in battery storage, such as a longer life span, higher charging and discharging rates, higher efficiencies, and energy densities. The report further emphasizes that high demand and rapid technological improvements make the prices of batteries low, with the prediction of a 50% further drop in Lithium-Ion battery price by 2023.

4.4.2. Store energy as hot water

The discussion with the community people and energy assessment at selected houses revealed that typical houses in Loop Head peninsula use 200 Litres insulated cylinders to store hot water for their daily consumption. An immersion type heater is fitted to the cylinder, and the heater rating is 3 kW. The cold water preheats up 35 - 40 ºC using the oil or gas-fired boiler or heat pump and stored in the cylinder. The cylinder is well-insulated with minor heat losses. If water temperature goes down drastically, the immersion heater is turned on to increase the temperature. As (Energyd, 2022) explains, the hot water inside the cylinder must be heated up above 65ºC at least once per week to avoid forming "Legionella" bacteria growing in the lukewarm water.

Surplus electricity of the solar PV system can be used for domestic hot water heating by installing a simple power diversion controller. The immersion controller automatically detects and throttle the surplus electricity to the immersion heater without export to the grid.

4.4.3. Grid connection

As per (ESBN, 2021b), domestic solar PV systems can be connected to the distribution network under the condition of peak export from the system inverter not exceeding 6 kVA for single-phase systems and 11 kVA for three-phase systems. The ESBN further explained that the domestic solar PV systems are categorized under the micro-generation scheme covered under IS EN 50549-1 standard, and the owners can export surplus electricity to the national grid after obtaining approval from the ESBN using N6 form. The applicable conditions for connecting a microgenerator to the ESBN are given in (ESBN, 2021a) publication on "Conditions governing the connection and operation of Micro Generation Policy". The owner of the PV system shall make sure to wire the system to comply with the ESBN published technical and safety rules and regulations while assuring the acceptable quality of the electricity fed to the grid. For example, the solar PV system must be equipped with protective devices to automatically close down the micro-generator when the grid's loss of power gives non-live systems in the grid to carry out the breakdowns repairs safely. If a microgenerator is used with a battery storage system as standby, it is required to be wired according to ESBN recommended safety requirements. At the end of the installation, the solar PV system owner shall submit the Microgeneration protection setting confirmation certificate (ESBN, 2021a) issued by a safe electric electrician and type test certificates with the N6 application form to get approval for connecting to the ESBN.

f.4.4 Household appliances load management.

The residential solar PV system is a grid-dependent system. When the grid power is lost, the PV system should be isolated from the AC side. During this situation, even if the PV system generates power, it cannot be utilized to cater the household demand. The battery storage system can be used as the backup for the house while storing solar PV-generated electricity during grid power outages. However, installing a battery backup system requires extra investment, maintenance, replacement, and extra space within the house. In this case, the homeowner can decide to use a battery storage system for a whole-home backup or a critical load-only backup (Florida solar design group, 2020).

Moreover, changing the electricity consumption pattern to match the availability of solar irradiance in the location would help maximize the solar PV electricity utilization during the daytime. For example, operating the washing machine and oven in two different periods during high solar irradiance hours of the day helps get done both the works only using solar PV electricity without taking extra electricity from the grid. Solar PV systems come with a monitoring platform as a mobile app and web portal. This platform provides real-time data to the user to monitor their electricity generation, consumption, storage, and feeding to the grid. This application helps the user manage their daily electricity consumption to maximize benefit from their solar PV system. Figure 4.18 shows the solar PV monitoring platform used by one solar PV system installed in Loop Head area.

Figure 4.18: Mobile app for solar PV system performance monitoring
Source:(Leonard, 2022a)

4.5. Solar PV system component specifications

The components of the solar PV system are shown in Figure 4.19. The solar PV panels, inverter and battery are the major components. The DC and AC isolators, optimizers, energy meter, and fire safety help the safe and reliable operation of the system. The specification and performance of each component are discussed below.

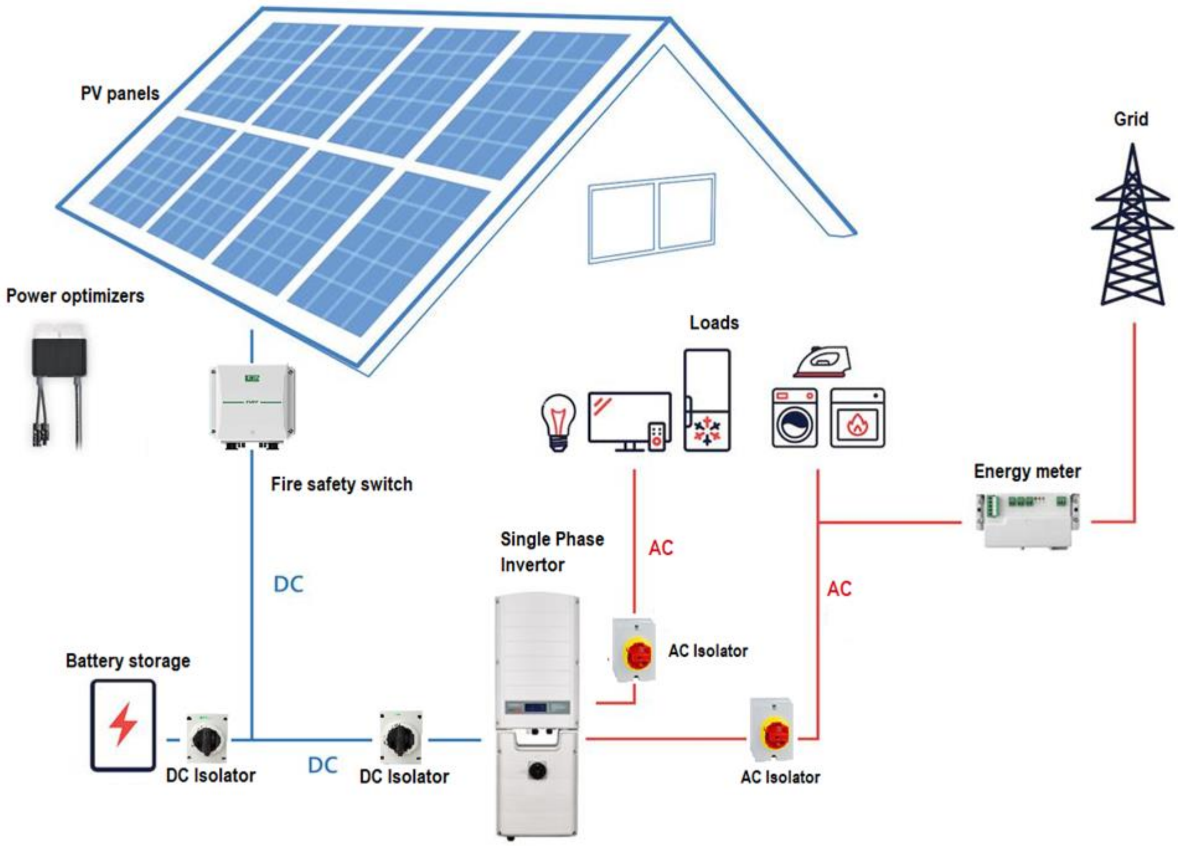
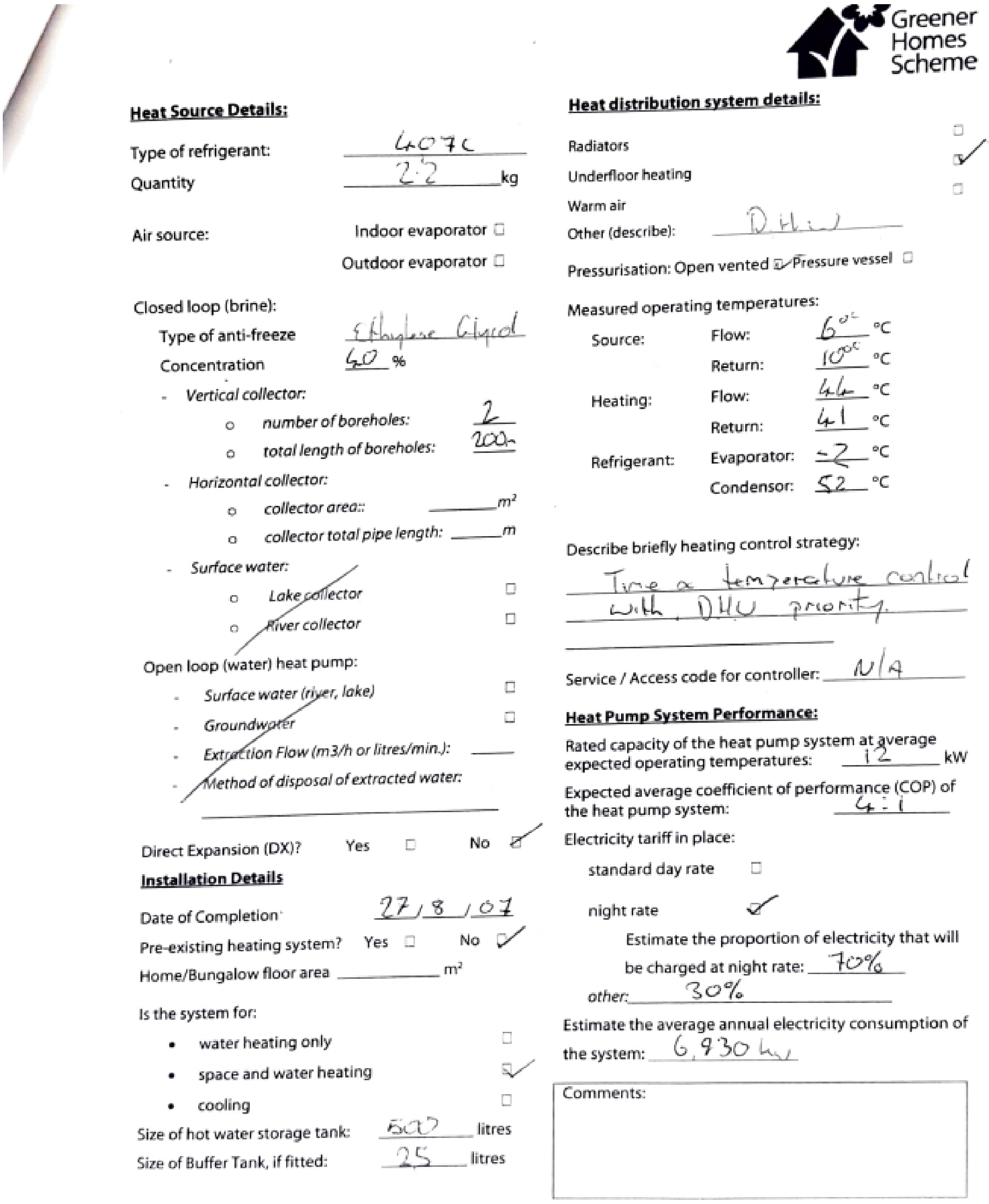


Figure 4.19: Solar PV system configuration
Source: Author based on(Koones, 2020)

4.5.1. Solar PV panels

Monocrystalline solar PV panels are commonly used for residential solar PV installations and, currently, the panels are available in blacked framed panels for giving a better aesthetic appearance for the house. As per (SEAI, 2022c) standards, solar PV panels shall comply with EN61215 and 61730 standards. The minimum peak output (Wp) requirement is 170 Wp/m2 at Standards Test Condition (STC). During the visits to solar domestic PV system owners and solar PV installers, it was recognized that Longi, Qcells, and LG None are commonly used brands of solar PV panels used in the Loop Head area. Based on that, the Longi PV panel was selected for the PV system design of all three case studies. Important specifications of the selected PV panel are given below and the data-sheet is attached in Annex 18: Existing Geothermal Heat Pump Commissioning Sheet


Greener Homes Scheme

Heat Source Details:

Type of refrigerant: 407C
Quantity 2.2 kg

Air source: Indoor evaporator ☐
Outdoor evaporator ☐

Closed loop (brine):
Type of anti-freeze Ethylene Glycol
Concentration 40 %
- *Vertical collector:*
  - *number of boreholes:* 2
  - *total length of boreholes:* 200m
- *Horizontal collector:*
  - *collector area::* ______ m²
  - *collector total pipe length:* ______ m
- *Surface water:*
  - *Lake collector* ☐
  - *River collector* ☐

Open loop (water) heat pump:
- *Surface water (river, lake)* ☐
- *Groundwater* ☐
- *Extraction Flow (m3/h or litres/min.):* ______
- *Method of disposal of extracted water:* ______

Direct Expansion (DX)? Yes ☐ No ☑

Installation Details

Date of Completion 27/8/07
Pre-existing heating system? Yes ☐ No ☑
Home/Bungalow floor area ______ m²

Is the system for:
- water heating only ☐
- space and water heating ☑
- cooling ☐

Size of hot water storage tank: 500 litres
Size of Buffer Tank, if fitted: 25 litres

Heat distribution system details:

Radiators ☐
Underfloor heating ☑
Warm air ☐
Other (describe): DHW

Pressurisation: Open vented ☑ Pressure vessel ☐

Measured operating temperatures:

Source:	Flow:	6°C	°C
	Return:	10°C	°C
Heating:	Flow:	46	°C
	Return:	41	°C
Refrigerant:	Evaporator:	-2	°C
	Condensor:	52	°C

Describe briefly heating control strategy:
Time & temperature control with DHW priority.

Service / Access code for controller: N/A

Heat Pump System Performance:

Rated capacity of the heat pump system at average expected operating temperatures: 12 kW

Expected average coefficient of performance (COP) of the heat pump system: 4:1

Electricity tariff in place:
standard day rate ☐
night rate ☑
Estimate the proportion of electricity that will be charged at night rate: 70%
other: 30%

Estimate the average annual electricity consumption of the system: 6,930 kwh

Comments:

Annex 19

a. Maximum Power at STC of 25°C cell temperature and 1000 W/m2– 370 W

b. Module efficiency – 20.3%

c. Voltage at Maximum Power – 32.8V

d. Current at Maximum Power – 8.43 A

e. Panel dimension – 1755 x 1038 x 35mm

f. Panel Weight – 19.5kg

4.5.2. Single-phase Inverter

The inverter is used to convert the DC electricity generated by solar PV panel into AC current with 230 V voltage fore use in household appliances. As per (SEAI, 2022c), the selected inverter for the solar PV system is required to meet the EN62109 and the Irish protection setting standard of EN50549. Further, the rated efficiency of the inverter shall be greater than 95% and the DC power rating of the inverter shall be a minimum of the DC peak power of the solar PV array. If the solar PV system is designed with a DC-coupled battery storage system, the inverter rating can be lower than the DC peak power of the solar system. However, a commonly used solar PV array to inverter ratio is 1.15 to 1.2 and the inverter manufacturers and solar system designers do not recommend this ratio greater than 1.5. In the case studies, the inverters for solar PV systems without battery storage are selected considering DC peak power and for the system with battery storage, the inverter is sized assuming a 1.2 arrays to inverter ratio.

An internet survey about the residential solar PV inverters available in the Irish market found that these are single string inverters with a capacity of 1kW to 3kW and dual string inverters with capacity ranging from 2.5kW to 6kW. Those modern inverters come with in-built charge controllers for the batteries and there is no requirement to install a charge controller. Moreover, there are hybrid inverters that include both inverter and battery storage in one single unit. The capacity of the hybrid inverter ranges from 3.6kW to 6kW. Microinverters can be used if the solar system is designed with a capacity of less than 1 kW. Also, individual panel optimizers are the effective solution not only for 62malller capacity PV systems (less than 1kW) but also for the system having the risk of uneven electric output from each and every panel in the array due to shading on panels, roof facing different directions and different angle of installations (SEAI, 2022c). In the following three case studies, single string or dual string inverters are selected based on the solar PV system capacity. Solis, Solax and Hypontech are the single-phase inverter brands used in solar PV systems installed in the Loop Head area. The data sheets of the selected single-phase inverters are attached as Annex 20 and Annex 21

4.5.3. DC Battery

The solar PV system with battery storage has been designed by connecting the battery to the DC side of the inverter. The lithium-ion battery is the available DC battery type for residential solar PV systems in Ireland's solar PV component selling websites. Pylontech, Triple power, and Weco are Lithium-ion battery brands used in the Loop Head area. The capacities of batteries available in the Irish market are 2.4 kWh, 3.6 kWh, 4.5 kWh, 5.3 kWh, and 6.3 kWh. The selected Lithium-Ion battery shall comply with EN 62133 or EN 62619 standards (SEAI, 2022c). The data sheets of the selected batteries are attached Annex 22 and Annex 23

4.5.4. Mounting system

(SEAI, 2022c) accepted mounting systems are pitched or flat roof, in-roof of integrated, cantilever to the wall or Brise Soleil, carport or ground mounting systems.

The three selected houses are not suitable for rooftop mounting systems because of the unavailability of suitable roof area towards the south. In addition, the visits to the existing solar PV system revealed the following drawbacks of the roof mounting systems.

a. Shallow roof pitch of less than 30º angle
b. Difficulties in access to solar PV arrays for cleaning
c. Insufficient roof strengths for installing solar PV system under the stormy weather conditions in Loop Head.

More importantly, the market survey about the cost of solar PV system installation revealed that the rooftop mounting is more expensive than the ground mounting system. This is especially true for the two-story house with slate roofs. The drivers of the high cost of the roof mounting system are the cost of hiring scaffolding and more labour hours required for a system installation on the roof.

The solar PV system design of the three case studies has been proposed with a ground mounting system considering the constraints and drawbacks of the rooftop mounting system. Further, the houses are located in large land areas with shadow-free locations for solar PV panels. The proposed ground-mounted system is shown in Figure 4.20. The mounting method is called a "Tree system" that uses an anchoring device without ground excavation (Solartricity, 2022).. The cabling from the solar PV system to the house has been planned to pass through underground using cable conduits.

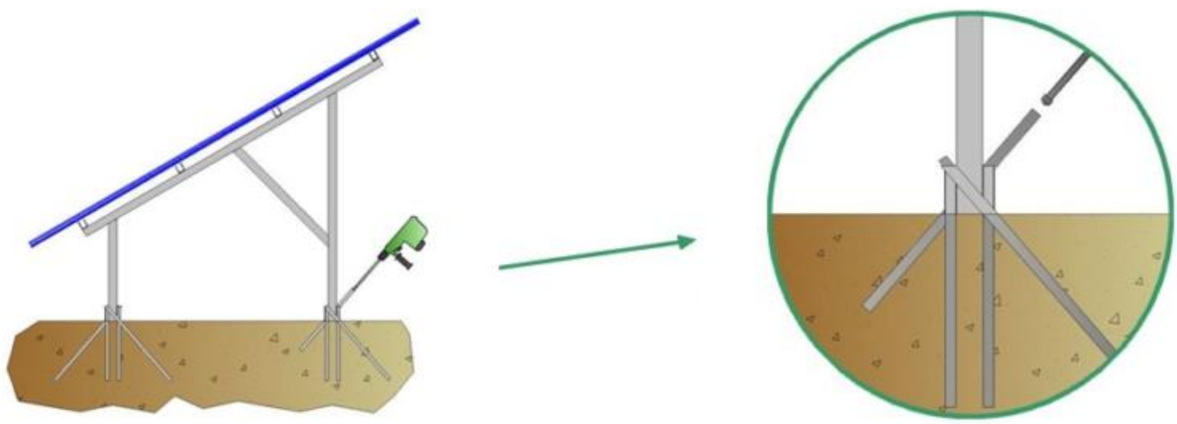


Figure 4.20: Ground mounting system solar PV panels
Source: (Solartricity, 2022)

4.5.5. Balance of system components

(SEAI, 2022c) has recommended the following balance of system components for assuring the safe operation of residential solar PV systems.

- Two-pole DC isolator/s at the connection of string to the inverter
- Two-pole DC isolators at the connection point of the DC power line to the battery
- Two-pole AC isolators in the AC power line between the inverter and consumer unit (distribution board)
- Firefighter safety switches within 1.5m distance from the solar PV array
- Energy meter in the AC power side of the inverter to measure the amount of solar PV electricity generation
- Labelling the system including warning signs (SEAI recommended Solar PV system Labile sets are available in Irish market)

The (SEAI, 2022c) guideline gives the standards, product warranty,performance requirements and installation procedure of the complete solar PV system in detail. Designing, purchasing and installation of solar PV systems complying with the given guideline helps to obtain the SEAI grant.

4.5.6. Hot water diverter

The hot water diverter comes with two parts, namely the CT sensor and power diverter controller. The CT sensor is installed near the energy meter on the grid side to detect the surplus electricity export to the grid. The controller is connected to the immersion heater. The two parts are connected through wired or wireless communication mode. When the CT sensor detects any surplus energy to the grid, it communicates to the controller to use this energy for water heating. After the water reaches the set temperature of the storage tank, the surplus electricity diversion stops and allows to export surplus electricity to the grid. This controller allows using grid electricity when required for water heating.

There are two types of water heater diverters in the Irish market. They are diversion controller "Zero-export" diverter and "Battery-compatible" diverter. The "Zero-export" diverter is used for diverting surplus electricity of the solar PV system without battery storage. Its operation is simple as discussed above. However, the drawback of this type of diverter is that sometimes it takes battery electricity for a short period when the surplus electricity generation stops.

Energy solutions for residential buildings

The recommended diverter for the solar PV system with battery storage is the battery compatible power diverter. The CT sensor does not trigger the controller to drain electricity to the heater until the surplus electricity reaches a set point. Normally, the set point ranges from 50-100W (Energyd, 2022). The most commonly used hot water diverters in Ireland are "Solar i-Boost +", "Solic 200" and my Energy Eddi. The functions of each type are given in Annex 25.

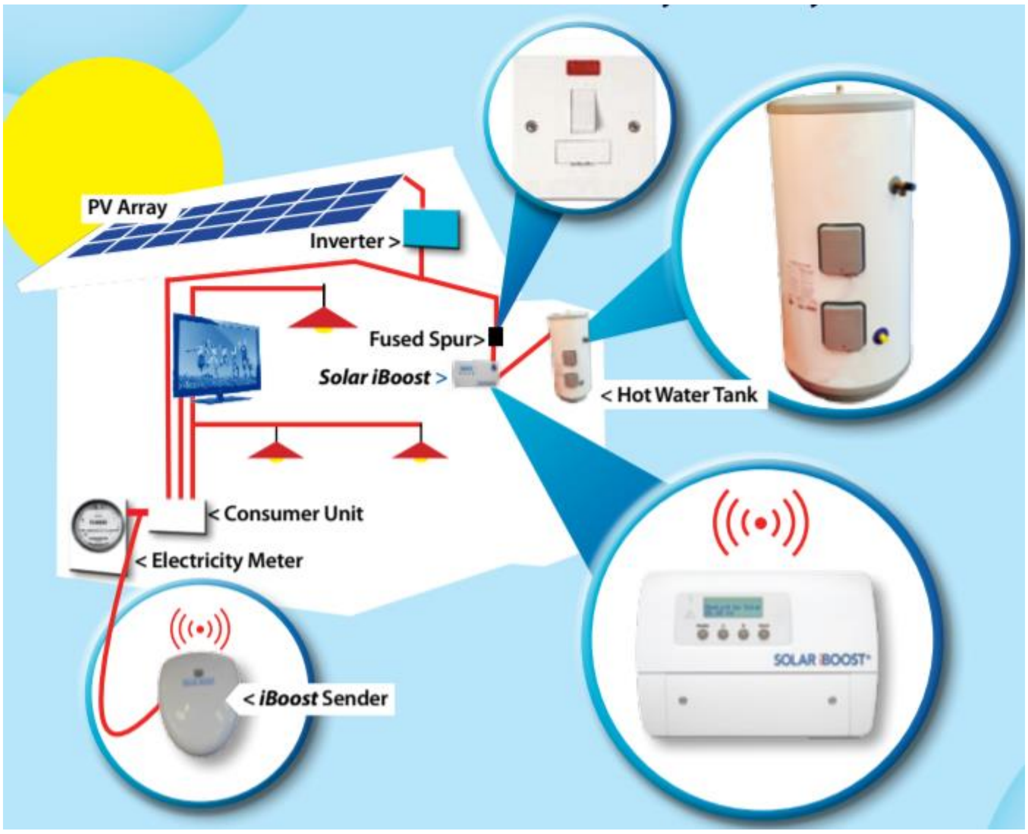


Figure 4.21: Hot water diverter configuration
Source: Author based on (Marlec, 2016)

4.6. SEAI grants

4.6.1. Home energy upgrade

SEAI provides many ways for a homeowner to upgrade their home for more energy efficiency. Each upgrade option has different criteria and services that can be summarized in Table 4.2.

Table 4.2:Home Energy Grants options
Source:(SEAI, 2022g)

Upgrade options	Service	Criteria	Upgrades offered
Free Energy Upgrade	• Home survey • Contractor selection • Contractor works	• The homeowner must own and live as the main residence	• Attic insulation • Cavity wall insulation • External wall insulation

Energy solutions for residential buildings

Upgrade options	Service	Criteria	Upgrades offered
	• Follow up BER	• 2006 for insulation and heating systems A homeowner receives one of the following welfare payments. • Fuel Allowance • Job Seeks Allowance • Working Family Payment • One-Parent Family Payment • Domiciliary Care Allowance • Carers Allowance • Disability Allowance for over six months with a child under seven	• Internal wall insulation • Secondary work such as lagging jackets, draught proofing and energy efficient lighting • New heating systems and windows are occasionally recommended
One-Stop-Shop Service	• Home energy assessment • Grant application • Project management • Contractor works • Follow up BER	• 2011 for insulation and heating controls • 2011 for renewable systems • All homes must complete a minimum level of energy upgrades and achieve a minimum BER rating of B2 • Has not previously received grants for the same home energy upgrades • Multiple energy upgrades	• Upgrade to a minimum B2 BER • A fully managed solution including grant applications and project management • Pay for the works net of eligible grant • Assigned a contractor • Complete the post-work by BER Assessor and publish the certificate
Individual Energy Upgrade Grants	• Contractor selection • Grant application • Contractor works • Follow up BER	• 2011 for insulation and heating controls • 2021 for heat pumps and renewable systems • Individual energy upgrades • To manage their own project • To apply for the grant themselves • To pay for the full cost of works and claim grants afterwards	• Attic and walls insulation • Heating controls • Heat pump system • Solar PV (electricity) • Solar thermal (water heating)

Energy solutions for residential buildings

The qualifying homeowner for the free energy upgrade option is to receive certain welfare payments. The changes as of 8th Feb 2022 will prioritize new applications of homes built before 1993 that have a pre-works BER of E, F, G. This option is funded by the Irish Government and the European Union Regional Development Fund (SEAI, 2022h).

The option of One-Stop-Shop Service suits a homeowner who is seeking a wider range of grants and full-service including project management for a complete home energy upgrade. The highlighted point from this option is that grant values can be deducted from the cost of work upfront (SEAI, 2022j). On the other hand, the homeowner or landlord who chooses the individual energy upgrade grants option has to pay for the full cost of the works and claim the grants afterwards. Also, the homeowner or landlord must get the approval for grant before proceeding with any work (SEAI, 2022i). The payment of the grant timeframe is limited to four to six weeks (SEAI, 2022i). In addition, an applicant who applies for this grant option has to read the important notes carefully to avoid any uneligibility issues. Table 4.3 shows the grant amounts for the different building retrofitting options.

Table 4.3: SEAI Grant amounts of Building retrofits
Source:(SEAI, 2022j)

Grant name	Types of home	Grant Value (Max.)	Free Energy Upgrade	One-Stop-Shop Service	Individual Energy Upgrade Grants
Attic insulation	Apartment (any)	€ 800	✓	✓	✓
	Mid-Terrace	€ 1,200			
	Semi-detached or end of terrace	€ 1,300			
	Detached house	€ 1,500			
Rafter insulation	Apartment (any)	€ 1,500	×	✓	×
	Mid-Terrace	€ 2,000			
	Semi-detached or end of terrace	€ 3,000			
	Detached house	€ 3,000			
Cavity wall insulation	Apartment (any)	€ 700	✓	✓	✓
	Mid-Terrace	€ 800			
	Semi-detached or end of terrace	€ 1,200			
	Detached house	€ 1,700			
Internal Insulation (Dry Lining)	Apartment (any)	€ 1,500	✓	✓	✓
	Mid-Terrace	€ 2,000			
	Semi-detached or end of terrace	€ 3,500			

Energy solutions for residential buildings

Grant name	Types of home	Grant Value (Max.)	Free Energy Upgrade	One-Stop-Shop Service	Individual Energy Upgrade Grants
	Detached house	€ 4,500			
External Wall Insulation (The Wrap)	Apartment (any)	€ 3,000	✓	✓	✓
	Mid-Terrace	€ 3,500			
	Semi-detached or end of terrace	€ 6,000			
	Detached house	€ 8,000			
Windows (Complete Upgrade)	Apartment (any)	€ 1,500	✓	✓	✗
	Mid-Terrace	€ 1,800			
	Semi-detached or end of terrace	€ 3,000			
	Detached house	€ 4,000			
External Doors	Remake: max. 2	€800 per door	✗	✓	✗
Floor Insulation		€ 3,500	✗	✓	✗
Mechanical Ventilation		€ 1,500	✓	✓	✗
Air Tightness		€ 1,000	✗	✓	✗
Home Energy Assessment		€ 350	✓	✓	✗
Project Management	Apartment (any)	€ 800	✗	✓	✗
	Mid-Terrace	€ 1,200			
	Semi-detached or end of terrace	€ 1,600			
	Detached house	€ 2,000			

4.6.2. Heat pump grant

Homes built and occupied before 2021 are eligible to apply for Heat Pump Grants. An individual can apply for heat pump grants if the home heat loss is within the range as mentioned in sub-chapter 3.2. An independent SEAI registered technical advisor must be selected before applying for the grants to carry out the technical assessment of the home. SEAI provides 200 € grants for the technical assessment which is paid with heat pump system grants. The heat pump grant support has been increased from 3,500 € to 6,500 € under Better Energy Homes Schemes (Government of Ireland, 2022).

Table 4.4: Heat Pump Grants
Source: (SEAI, 2022a)

System	Dwelling Type	Grant
Air to Water Heat Pump	Apartment	4,500 €
	Semi-Detached/ Detached/ Terrace/ Mid- Terrace	6,500 €
Ground Source to Water Heat Pump	Apartment	4,500 €
	Semi-Detached/ Detached/ Terrace/ Mid- Terrace	6,500 €
Exhaust Air to Water Heat Pump	Apartment	4,500 €
	Semi-Detached/ Detached/ Terrace/ Mid- Terrace	6,500 €
Water to Water Heat Pump	Apartment	4,500 €
	Semi-Detached/ Detached/ Terrace/ Mid- Terrace	6,500 €
Air to Air Heat Pump	Apartment/ Semi-Detached/ End of Terrace/ Detached/ Mid Terrace	3,500 €

4.6.3. Grants for Solar Electricity

The government of Ireland, in July 2018, launched a support scheme to assist homeowners in installing microgeneration systems in their homes, which resulted in rapid growth of solar PV throughout the country. Homeowners can apply for grants from *SEAI* to purchase and install solar PV systems and battery energy storage systems. According to the updated regulations, since February 2021, the grant rate and minimum BER rating requirement went through some changes. The recently updated solar electricity scheme removed the grants of € 600 for the battery storage system. In addition, as per the Code of Practice published by SEAI, the system must be sized for self-consumption of the energy within the home. The new supporting solar scheme levels are as mentioned in Table 4.5.

Table 4.5: Solar PV Grants Available
Source: (SEAI, 2020)

Solar PV Installations	
Up to 2 kWp Solar PV System	900 € per kWp installed
2-4 kWp Solar PV System	300 € per kWp installed

For example, a house with an estimated solar PV system of 3 kWp system will receive a grant of 2100. € In 2022, the solar PV grant scheme will be at the same level per KW as the current grant, which is capped at a maximum of 2400. €

How to apply for a Solar PV Grant?

The landlords or the homeowners of buildings built and occupied before 2021, defined through the date of electric meter installation, are eligible to send an application to SEAI. Before sending the application to SEAI, the applicants should choose a registered SEAI solar PV installer company and request a quotation. The applicants must receive a grant offer from SEAI before starting any work. Once the grant is approved, the offer will be valid for eight months to complete the work and submit the required documents. In order to connect the solar PV system to the grid network, the chosen installer should apply for the ESB Network NC6 form before installation, which usually takes a minimum of 4 weeks.

Until now, once the installation of the PV system is complete, post-work BER certificate assessment is required with a BER rating of C or better, and the cost to carry out the assessment is included in the grant amount. Then, once the solar company submits the necessary documents to the user and SEAI, the SEAI processes the claim (SEAI, 2017c).

Planning Permission required for Grants

There are certain planning permission requirements that need to be taken into account while applying for SEAI solar grants for installing residential solar panels under Planning and Development Regulation, 2007 (SEAI, 2020). If the PV system in the domestic roof covers more than 50% of the total roof area, then the homeowner requires planning permission; otherwise, it is not required (SEAI, 2020) . The height of the ground-mounted solar array should not exceed 2 meters above the ground level and the PV system should not be placed in front of the front wall of the house (SEAI, 2020) . In addition, the distance between the pitched roof and the PV panel should not exceed more than 15 cm (SEAI, 2020) .

Microgeneration Support Scheme

In January 2021, a public consultation on the new Micro-generation Support Scheme (MSS) was launched by the Department of Communication, Climate Action and Environment (DCCAE), Ireland. The Climate Action Plan 2021 introduced an MSS with a target to support the deployment of an expected 260 MW of new micro-generation by 2030 (Government of Ireland, 2021). The DCCAE and other key members led the Micro-Generation working group to deliver the six Micro-Generation Support Schemes. One of the schemes is the "Scheme for Rooftop Solar PV panel support." The MSS provides a market for homes, businesses, farms, and communities to produce their own renewable energy and receive competitive tariffs for exported electricity.

In response to the public consultation in February 2021, the Irish Solar Energy Association (ISEA) provided elaborated suggestions regarding the pricing structure, planning requirement, BER requirement, no export requirement, and new building inclusion to increase the rollout of solar PV. The MSS received final approval from the government on 21 December 2021, and the final scheme design will be published on Q1 2022.

The capital grants of rooftop solar PV MSS will be a continuation of the existing grants of SEAI for domestic applicants. The transition from existing domestic solar PV to MSS grant scheme will be from Q2 2022 (Government of Ireland, 2021). According to this newly approved MSS, residential buildings built pre-2021 can apply for grants. Further, the residential buildings, even after installing new efficient equipment, do not have to meet a minimum BER standard. The grant will be the same per kW as the current solar PV grant scheme. However, taking into account the declining PV system cost, from 2024, the MSS support will be deducted gradually over time (Government of Ireland, 2021)

After public consultation, the Commission for Regulation of Utilities (CRU) published a Clean Export Guarantee (CEG) in December 2021. Under the micro-generation enabling framework, the homeowners will be eligible for a CEG tariff for all surplus energy exported to the grid at a competitive market rate from different electricity suppliers with a minimum price of 0 €/kWh (CRU, 2021). The individual suppliers will set their own CEG tariff rates, providing them with the flexibility of dynamic pricing. Moreover, the customer can benefit by exporting significant energy during peak periods when the CEG tariff is higher than average (CRU, 2021). The CRU has not yet fixed the date for the first payment or credit from the suppliers. But it is announced by the government that the first export payment to the customer is expected to start by 31 August 2022 at the latest (CRU, 2021, CRU 2022). The CRU expects the supplier to provide back-payments or back-credits for the exported electricity to the customers from the very first day after the micro-generation has been installed and registered with ESBN. (CRU, 2022).

A smart meter measures the energy demand profile, assists micro-generators in increasing their self-consumption and measures the surplus exported to the grid. The country has the National Smart Metering Program (NSMP) that aims to install over two million smart meters in Irish homes for six years from 2019 to 2025 in three phases (CRU, 2022). The CRU and ESBN have collaborated to deliver the electricity meter throughout the country on a phased basis. The use of a smart meter offers the consumer the Time of Use tariff which means the cost of electricity changes depending on the time of the day. This provides the consumer with the flexibility to use energy at a cheaper price. The rate of electricity at peak hours, during the day time and during the night time differs. However, the suppliers can provide a customized tariff rate that fits best for the user.

The micro-generators will be eligible for remuneration by CEG based on smart metered export data or deemed export quantity. According to the updated Interim CEG Decision Paper (CRU, 2022), CRU expects the grid electricity suppliers to provide clear information to their customers (micro-generators) on whether they are currently eligible for metered or deemed payments or when the customer will be eligible. The customer who has installed micro-generation and is eligible or wants to upgrade their meter to a smart meter to receive the remuneration has to submit the NC6 form to ESBN. Customers with smart meters will receive remuneration from the supplier companies based on the metered quantity of electricity that is being exported to the grid generated from the PV system. CRU expects smart meters to be installed by ESBN within four months of the request from the customer. Currently, ESBN is installing smart meters for MCC01 customers based in the current deployment planning area (Government of Ireland, 2021) The MCC02 customers with dual or day & night tariffs have to contact their electricity supplier and agree to the new smart tariff. As the customer agrees to the new tariff, the suppliers on behalf of the customer request ESBN for a prioritized smart meter exchange. Moreover, if the customers are not eligible for a smart meter installation under the ESBN-led deployment approach under NSMP at that particular time or are eligible but cannot get it at the moment, they will receive the payment based on the calculation of deemed export quantities as a short-term interim measure (CRU, 2021). The customers who have avoided, rejected or delayed the installation of a smart meter offered by ESBN under NSMP are ineligible to apply for deemed export quantity remuneration (CRU, 2021).

CRU has considered 35% as an export factor for the calculation of the deemed export quantity (CRU, 2021). The deemed export quantity is calculated based on Equation 4.7

Equation 4.7: Deemed export quantity calculation
Source: (CRU, 2021)

$$Deemed\ Export\ Quantity = MEC * Capacity\ Factor * Export\ Factor * Provision\ Interval$$

Where:

- Deemed Export Quantity: Quantity of electricity in kWh
- MEC: Generation Capacity of the installed generation equipment
- Capacity Factor: Ratio of average electricity produced to the theoretical maximum possible if the installed capacity was generating at a maximum for a full year
- Export Factor: Amount of electricity deemed to be exported
- Provision Interval: Number of hours for which the cumulative export quantities are to be calculated

Further, the single-phase grid connection for domestic micro-generation projects up to 6 kW is done through ESB Network's "Inform, Fit and Forget" notification process (Government of Ireland, 2021)

5. Case study I

5.1. Status quo

5.1.1. Building Envelope

The first case study building is a typical detached dwelling initially constructed in 1910, with a total floor area of 107 m^2. The dwelling has a 500 mm stone wall from the original construction. In 2011, the owner retrofitted the house with partial insulation of the walls and turned the second floor into a "Mezzanine floor[6]". Therefore, the house is a mixture of two wall types, concrete block and stone wall.

Two kinds of space heating systems are present in the case study dwelling; an oil condensing boiler and a wood pellet stove. The condensing oil boiler is also for domestic water heating purposes. It has thermostatic temperature control for the heating and hot water systems.

Table 5.1 summarizes the main inputs for the DEAP analysis mentioned in subchapter 3.2.

Table 5.1: Status quo of Case study I

Description		**Value**	**Unit**
Dwelling Floor Area		82.95	m^2
Total Door Area [7]		3.52	m^2
Total window Area		9.92	m^2
Number of occupants		1	
Number of rooms		9	
Fabric U-Values	Wall 1(Stone walls, 500 mm uninsulated)	2.1	$W/m^2 \cdot K$
	Wall 2 (Stone walls, unknown insulation)	1.41	$W/m^2 \cdot K$
	Roof (100 mm mineral wool insulation)	0.22	$W/m^2 \cdot K$
	Ground floor (uninsulated, solid)	0.84	$W/m^2 \cdot K$
	Mezzanine floor (uninsulated, solid)	0.28	$W/m^2 \cdot K$
	Windows (double-glazed)	2.2	$W/m^2 \cdot K$
	External Doors (double-glazed)	3.1	$W/m^2 \cdot K$
Appropriate default U values were used as per the year of construction values are labelled as [d] as per			

[6] Mezzanine or interior balcony, is an area of floor in a dwelling which overhangs the storey below.
[7] Area of door that are expose to the exterior

DEAP manual.

Although the house was renovated in 2011, it is only partially insulated. During the on-site thermal inspection of the building, the following deficiencies were found in the insulation of the building

- Inadequate Attic insulation

Cold zones were detected on the attic walls and roof as seen in Figure 5.1. In the under-roof space, a non-uniform decomposed insulation material was seen, as a result of which cold air can penetrate and cool down the under-roof space. It is recommended to adequately insulate the walls of the attic floor and the roof. There are multiple insulation materials available for this purpose with varying costs as explained in sub-chapter 4.2. Among all the options, mineral wool insulation is considered for the cost analysis.

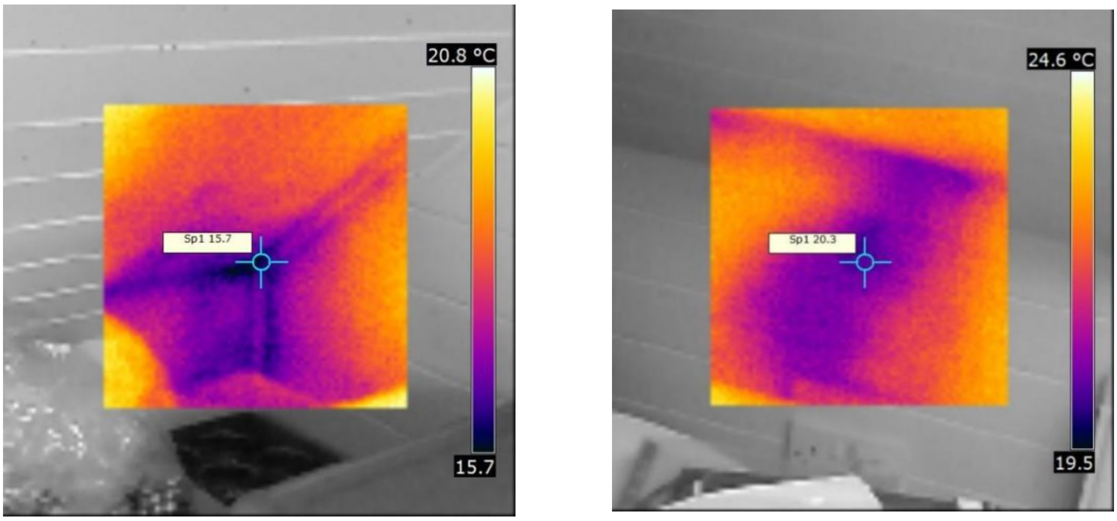


Figure 5.1 Infrared and digital image of the attic walls
Source: Thermal camera

- Partial external wall insulation

During the inspection of the house walls in infrared radiation, the temperature difference between the insulated and not insulated external walls of the house is visible. Since the walls of the house are made of natural stone, they have a high thermal conductivity which causes significant heat loss. In order to reduce heat loss at home, it is recommended to insulate the outer walls of the house, as was recommended in sub-chapter 4.1.

Case study I

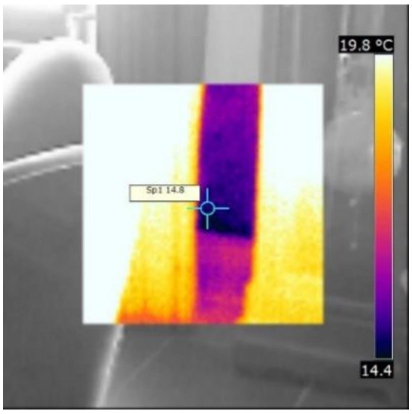


Figure 5.2: Infrared and digital image of the external walls.
Source: Thermal camera

- Windows and Doors

The house has 11 windows, out of which four are roof windows. All the windows are double glazed and do not manifest urgent change requirement. The two exposed doors, however, on replacement can provide an energy-saving opportunity.

5.1.2. Electricity usage pattern

The annual electricity consumption of the building in the year 2021 was summed up to be 1571 kWh as per the provision of monthly electricity bills. The billing units and the amount was not the actual one and was often estimated. This is a common occurrence in Loop Head as was observed in all three case studies. Moreover, the billing period was mostly two months. Hence, the average daily consumption for the billing period was multiplied by the number of days to estimate the monthly electricity consumption. The resulted annual load profile is as seen in Figure 5.3. The highest electricity consumption was observed in December and January corresponding to the coldest months of the year. Since the number of occupants in this particular case study is only one and electricity is not used for space heating, the electricity demand is seen to be fairly constant throughout the year. To minimize the uncertainty in the accuracy of load profile, synthetic load profiles as defined in sub-chapter 5.1.1 have been developed for PV system sizing.

Case study I

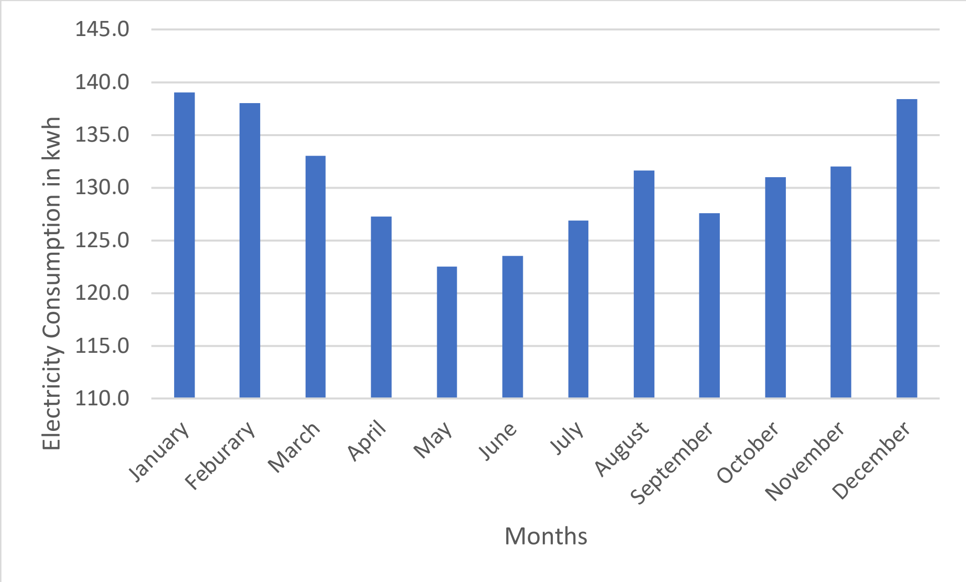


Figure 5.3: Annual estimated electricity demand profile

As per the electricity assessment conducted during the site visit, the end-use breakdown of electricity has been done for Case Study 1 to categorize what appliance consumes the most electricity as illustrated in Figure 5.4. Lighting accounts for 6% of the total electricity demand and all of them are either LED or CFL. Since electricity is not used for space heating purposes, the remaining 94% is consumed by the appliances in the house No energy efficiency measures were applied in this case study as the house has efficient appliances.

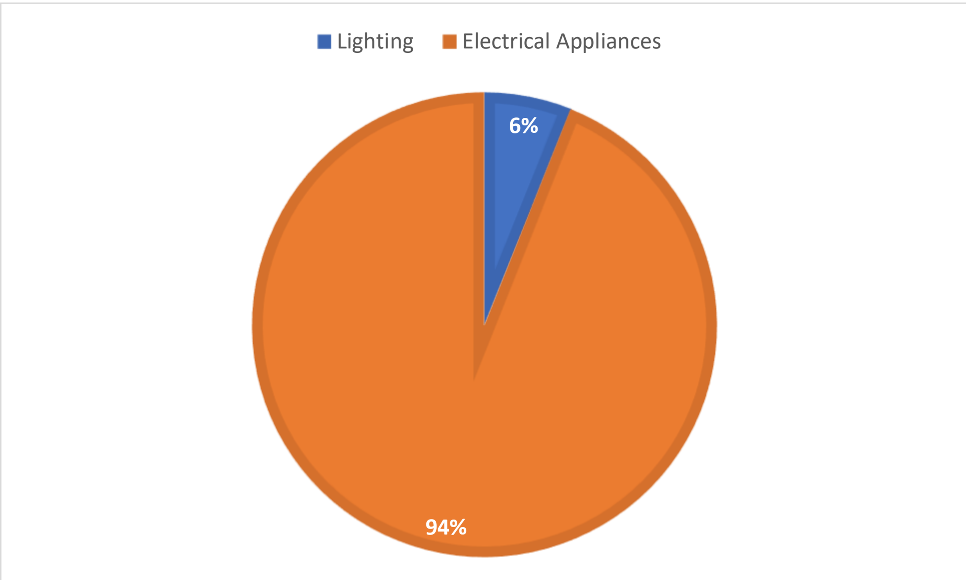


Figure 5.4 End-Use Breakdown of electrical appliances
Source: Author

Case study I

5.1.3. BER Rating

A BER assessment of the original dwelling was calculated utilising an online version of DEAP 4.2.0 software developed by SEAI. The building geometry and fabric U-values referred to in Table 5.1 have been considered to calculate the BER rating of the building. The primary energy use of the building is 284 $kWh/m^2/yr$ and HLI is 4.89 $W/K/m^2$ corresponding to a BER Rating of "D2".

5.2. Identified energy-saving measures

5.2.1. Building envelope

Based on the thermal camera inspection, we saw the need for the following fabric insulation:

a) Roof insulation

b) External wall insulation

c) Exposed door replacement

The objective of the retrofit strategy applied was not only to minimize heat loss but also to increase the rating of the house to a minimum of B2 or comply with the HLI criteria. Hence, the recommendations have been presented in the form of steps to present alternatives for the homeowner. The homeowner thus will have a complete picture of where he/she is at and how will the insulation impact him/her.

Individual energy upgrade grant does not necessitate reaching a B2 BER rating. The one-stop-shop, on the other hand, mandates a BER rating of B2. Therefore, two scenarios are developed to address each scheme.

Individual energy upgrade grant

Insulation of attic and walls have been considered in this case.

a) Wall insulation: Although the wall is partially insulated, it is assumed that all the walls are insulated with 100 mm of Rockwool insulation to lower the U-value to 0.27. It is the standard refurbishment step as defined by TABULA (Tabula, 2014). With this step, the HLI is reduced to 3.52 $W/K/m^2$ and total heat loss is reduced by 44.85% leading to a BER rating of "C1".

b) Roof insulation: The current roof insulation comprises around 100- 150 mm of fibreglass insulation. Adding an insulation layer to make it to 300 mm insulation will reduce the heat loss by 4.86 %. The HLI is 4.65 W/K/m^2. With this upgrade, the BER rating remains at "D1" as base case.

Table 5.2: Energy cost savings and payback period of insulation

Type of insulation	Grants	Total Investment Cost (Euro)	Total energy saving* (kWh/y)	Estimated annual savings (Euro/y)	BER rate	Simple Payback Period (Years)
Wall insulation	No	14,256	6,475	501	C1	28
	Yes	6,255				13
Roof insulation	No	3,662	1,064	82	D1	44
	Yes	2,162				26
* Total energy saving is delivered energy saving from primary and secondary space heating energy systems. **Replacement of doors and windows is not recommended under this scheme as there is no available grant and the payback period is more than 90 years.						

From these two options presented in Table 5.2 it was observed that although the initial cost of wall insulation is higher, the payback period is less as compared to that of roof insulation. Hence, the homeowner could opt for higher savings (wall insulation) or lower investment costs (roof insulation).

One-Stop-Shop Service

The One-Stop-Shop Service mandates a post-refurbishment BER rating of B2. The above-recommended measures are not enough to achieve that level. Therefore, to assess the reduction in heat loss and increment in the dwelling rating, step-by-step fabric improvements were investigated.

Base Case: "Do Nothing" Scenario: No fabric upgrades have been considered in this scenario.

Step 1: Roof and External wall insulation

The recommendation as summarized in Table 5.2 was combined in this step. The heat loss was decreased by 49.6 %. The HLI of this step was reduce to 2.43 W/K/m^2. The BER rating of the house could be improved to "C1".

Step 2: Doors and windows replaced in addition to roof and external wall insulation

Case study I

The dwelling presently has eleven double glazed windows. Therefore, replacing them with triple glazed windows should be of last consideration. However, for the attainment of a heat pump grant, the homeowner should consider this step. Further, the two exposed solid doors should be replaced with the door having the material with better U-value of 0.8 W/K/m^2. This reduces HLI to 2.6 W/K/m^2, only a 2.72 % decrement from the previous step. The rating of the house remains at "C1".

The HLI indicator after Step 2 was 2.4 W/K/m^2, which is not in the range of eligibility for heat pump grant. Therefore, as a final step, the walls were recommended to follow an advanced refurbishment step as suggested by TABULA (Tabula, 2014).

Advanced Refurbishment: Roof insulation, advanced external wall insulation with doors and windows replaced.

In this case, the external wall insulation could be change to 200 mm with the better material with lower U-value of 0.15 W/K/m^2. The final rating of the house after this step could be B3. It was not possible to achieve the desired B2 rating as outlined by the National Retrofit Scheme without reducing the U-values of the floor. However, with the advanced refurbishment step, the HLI was within the desired range for heat pump grant. The calculation of the heat pump sizing for the particular case study is explained in sub-chapter 5.3.

The recommended changes with the upgraded U-values are listed in Table 5.3.

Table 5.3: Upgrade recommendation with their U-Values of case study I
Source: (Tabula,2014)

Upgrade Recommendation	**Upgraded U value (W/K/m^2)**
300 mm of mineral wool insulation in the roof	0.13
100 mm of Grey EPS external wall insulation	0.27
200 mm of Silver EPS external wall insulation	0.15
Triple glazed Argon Low E (0.15, hard)- Wood/PVC – 16mm Gap for window	1.4
Munster Joinery GRP Joinery door	0.8
Appropriate default U values were used as per the year of construction values are labelled as [d] For the upgraded value of the roof, table S4 of the DEAP manual (Seai, 2020) is referred, based on the recommended insulation.	

5.2.2. Cost analysis of building retrofit

The range of retrofit measures chosen for the retrofit program is in line with available grants at the time of analysis. The calculation was nevertheless done with and without a grant. The estimated annual savings after the fabric upgrades along with their cost breakdown and payback period is set out in Table 5.4.

Table 5.4: Cost Analysis for different retrofitted steps of case study I
Source: Author

Steps	Grants	Estimated Investment Cost (Euro)	Total energy saving* (kWh/y)	Estimated annual savings (Euro/y)	BER rate	Simple Payback Period (Years)
Step1	No	32,037	12,407	960	C1	33
	Yes	22,537				23
Step2	No	44,403	12,571	973	C1	46
	Yes	27,803				29
Advanced Refurbishment1	No	46,907	13,558	1049	B3	45
	Yes	30,307				29
The estimated investment cost breakdown is in Annex 13						

As mentioned in sub-chapter 3.2, the uncertainty of the cost analysis was included by using the accuracy range between a low range of -10% and a high range of 30%. Figure 5.5 shows the total investment costs and discounted payback periods, both with and without grants at each step. Giving an example, the total investment cost without grant of advanced refurbishment is 46.91 thoudsand euro with an uncertainty range between 42.22 to 60.98 thousand euro. The discounted payback period of this case is 77 years with an uncertainty range between 69 to 100 years. On the other hand, the applicable grants can reduce both investment costs and discounted payback period significantly. The total investment cost with "One-Stop-Shop Service" grant for advanced refurbishment could be reduced to 30.31 thoudsand euro with an uncertainty range between 27.28 to 39.40 thousand euro. The discounted payback period of this case would be 38 years with an uncertainty range between 34 to 49 years.

Case study I

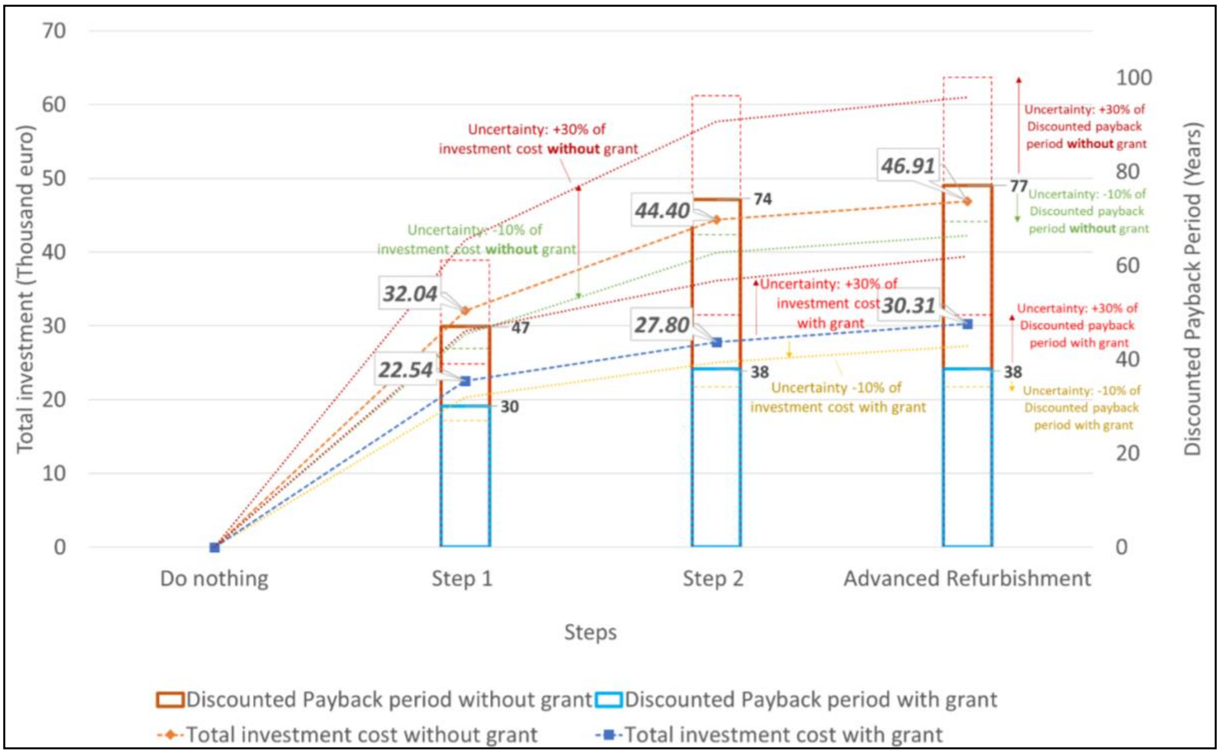


Figure 5.5: Total investment cost and Discounted Payback Period of case study 1
Source: Author

5.3. Domestic Hot Water (DHW) and Space Heating Supply

5.3.1. Space Heating

To identify a feasible and renewable energy solution to supply the case study house with the sufficient heat demanded, several aspects have to be considered and analyzed. Firstly, the house's current heating system and expenditure on heating. Secondly, the behavioral patterns of the house owners in running the system since this will affect the system under development. Thirdly, the house's current insulation, heat losses, and heat demand status. Fourthly, the heat energy efficiency level of the dwelling that can be reached by the proposed renovations.

Consequently, an onsite inspection was carried out to find that two heating systems are employed to complement each other, namely a condensing gas boiler and a traditional stove system. The condensing oil boiler is manufactured by "Grant", this brand and boiler type was found to be used in 2 case studies out of 3 analyzed in Loop Head, fuelled by class 2 kerosene and installed in 2011. The installed machine was found to be working in the heat output range of 26-36 kW, heating the water distribution circuit to 75°C according to the machine nameplate as depicted in Figure 5.6.

Case study I

Figure 5.6: Condensing oil boiler name plate
Source: Author

On the house owner interview, it was reported that he/she operates the condensing oil boiler for 1 hour in the morning and 1-2 hours in the evening, then he/she would most likely start the stove heating system to maintain the heat inside the house. According to the house owner, he/she uses 1300 -1500 Litres of gas oil per year at a cost of 70 cents per litre excluding the value-added taxes; on the other hand, he/she uses wood or coal for firing the stove system at a cost of 500 Euros per year.

Since analyzing the dwelling's current insulation, heat losses, and heat demand include several sub-activities and information that have to be provided by the house owner, which might not be available. A reverse engineering exercise was undertaken to measure the current dimensions of the radiators in the house. Through this method, the heat emitted from each emitter per heated space can be roughly estimated, especially since it was confirmed by the owner that the heating system can easily reach his/her desired room temperature and that is the reason why the system only operates for 2 hours a day. In addition, the owner reported using the stove system only to keep the house warm for the rest of the day.

Case study I

The house consisted of a total of eight heated spaces: a kitchen, 2 living rooms, 3 bedrooms, and 2 toilets. The heat emitted per radiator was estimated based on a temperature drop across the radiator surface area (ΔT) of 50°C, which is the typical ΔT generated by a condensing oil boiler. Hence, the dimensions of the existing radiator were measured and their equivalent heat emitted were calculated as shown in Table 5.5.

Table 5.5: Existing Radiators' Sizes and Heat Emittance
Source: Author

Room	Existing Rad Size (m)	Existing Heat Emitted (W)
Kitchen	0.9*0.5	480
Living Room 1	1.4*0.5	774
Living Room 2	0.9*0.5	480
Bedroom 2	1*0.5	578
Toilet 2	0.34*0.5	382
Bedroom 1	1.16*0.5	774
Toilet 1	0.34*0.5	382
Home office	0.9*0.5	480
Bedroom 3	1.16*0.5	774

Accordingly, the total heat emitted by all radiators was found to be 5104 Watts (W), which is very sensible for a house with a total area of 107.55 m^2. As for now, an estimate of the heat demand is available, thus the next step was to estimate the heat losses per each room, and they were found for the base case scenario as shown in Table 5.6.

Table 5.6: Base Case Scenario Room Wise Heat Loss
Source: Author

Room	Heat Loss (W)
Kitchen	2293
Living Room 1	3520.4
Living Room 2	2063
Bedroom 2	651.4
Toilet 2	594.1
Bedroom 1	1010.9
Toilet 1	845
Home office	888.9
Bedroom 3	811.8

Case study I

The sum of the heat losses from all spaces was found to be 12,678.5 W, which is much higher than the estimated heat emitted by the existing radiators. This may suggest that the existing heating system is undersized and that is why the house owner has to complement the condensing oil boiler with the stove system. Alternatively, this may be due to the non-availability of exact thermal conductivity values of the house's different fabrics. Regardless, the most important aspect for designing an effective heating system will be the heat demand after retrofitting the house by considering an advanced level of insulative material irrespective of the house's current losses. In other words, the house must reach a high thermal efficiency by upgrading the fabrics' thermal conductivity utilizing the available SEAI insulation grants, so it can reach a BER rating of B2. Based on that, the household will not only be eligible for heat pump grant but also a smaller heat pump size will be ascertained reducing the whole cost of introducing energy sufficiency and energy efficiency for the household.

On this basis, the economically feasible refurbishments advised sub – chapter 5.2 can upgrade the household to a BER B2 rating with the heat losses as shown in Table 5.7.

Table 5.7: Refurbished house room wise heat loss
Source: Author

Room	Heat Loss (W)
Kitchen	1189.6
Living Room 1	1406.8
Living Room 2	787.6
Bedroom 2	308.2
Toilet 2	252.9
Bedroom 1	531.3
Toilet 1	429.1
Home office	431.6
Bedroom 3	338

These thermal losses sum up to 5,675.1 W. Accordingly, the Heat loss indicator of the dwelling was checked to be 2.21 W/K/m^2. Hence, it lies in the range of eligibility for Heat pump grants by SEAI after conforming to the 4 special criteria mentioned in sub–chapter 4.6.2.

As of now the demanded heat per each room is known in the case of upgrading the house to BER B2, thus a new space heating system can be sized in two concurrent steps after selecting the proper heat pump and heat emittance technologies. Air-to-Water heat pump was selected since Air-to-Air heat pumps only caters 60 – 80 % of the load, while Ground Source heat pumps require excavation works that increase the investment cost. The decision was made to select radiators as the appropriate heat emittance technology since they are relatively cheaper than underfloor emitters, which would require excessive construction works on top of their cost. Also, due to the fact that the thermal mass demanded is manageable by acceptable dimensions of radiators that are cheaper than other alternatives available on the market while still being effective.

The space heating design methodology was selecting an equivalent heat pump size that is able to overcome the heat demand of the house from the variety available in the market; concurrently, the radiators were sized according to the heat pump forward water temperature, and the heat emitted per each radiator is equal to the amount of heat lost due to temperature drop across its surface area (ΔT).

The dwelling's existing radiators were also checked for their compatibility with the new system. However, it shall be noted that the ΔT generated by Air-to-Water heat pumps is lower than that of the condensing oil boiler at 30°C and 50°C respectively since an Air-to-Water Heat Pump can heat the water circulating to the radiators in the range of 15-65°C, while an oil boiler heats water in the water distribution circuits to 75°C. Therefore, it was found that even if it will be decided to utilize the existing radiators; it is impossible to assure their efficiency under the new working conditions of a lower ΔT in the absence of their datasheets. Nonetheless, for the sake of other households in the community which might still have the datasheets of the installed radiators, some radiators might not need to be changed.

Suppliers of radiators usually quote radiators' capacities of heat emitted for different levels of ΔT since not all space heating technologies can elevate water temperature to the same level. To illustrate, a radiator size 1 X 0.5 m of a brand X is capable of emitting 722 W of heat at ΔT of 30°C, whereas the same radiator size emitted heat can increase to 1,048 W at ΔT of 40°C. Hence, a ΔT of 30°C was decided based on the specifications of the prospect heat pump under study since this heat pump can heat water in the range of 15 - 65°C. Another method adopted by other radiators suppliers would be providing heat emittance of different radiators sizes at ΔT of 50°C accompanied with conversion factors for other ΔT values.

A brand X was selected based on their acceptable dimensions at low ΔT so that the total heat demanded from the heat pump is 5,917 W as shown in Table 5.8. For more information see Annex 17.

Table 5.8: New Radiators Sizes and Heat Emittance
Source: Author

Room	Radiator Size (m)	Heat Emitted (W)
Kitchen	1.8*0.5	1299

Case study I

Living Room 1	2*0.5	1443
Living Room 2	1*0.5	722
Bedroom 2	0.5*0.5	361
Toilet 2	0.4*0.5	288
Bedroom 1	0.8*0.5	577
Toilet 1	0.6*0.5	433
Home office	0.6*0.5	433
Bedroom 3	0.5*0.5	361

An LG model HM051M.U43 monobloc AWHP heat pump of a rated heat output of 6 KW was selected, so it can overcome the heat load of the whole system and provide the desired room temperature to all heated spaces. Not only the selected AWHP can provide heat emitters a forward temperature up to 65°C, but it also elevates the DHW temperature up to 80°C. The selected machine employs R32 refrigerant in its reverse Carnot cycle circuit, which is considered a replacement refrigerant for lower forward temperature heat pumps (Agas, 2022). R32 has a low Global Warming Potential (GWP) of 675 and a lower carbon footprint than other common hydrofluorocarbon refrigerants (BOC Online, 2022) . For more information about the selected AWHP see Annex 14

5.3.2. The Space Heating and DHW Excel Model

To further analyze the selected Air-to-Water heat pump performance, an hourly ambient temperature data set was collected for Shannon Airport weather station for the year 2021 (Met Eireann, 2022). The data set was principally collected to calculate the hourly COP, heat load, and electrical load of the selected AWHP at different hourly ambient temperatures, so Loop Head's house owners can estimate their annual electrical consumption, AWHP's annual COP, and the total annual heat supplied in case of transforming their dwellings towards energy efficiency and sufficiency. In order to achieve these objectives, an Excel model was constructed such that a homeowner can input the heat pump size, and the total heat demanded of the dwelling according to the radiator sizes based on "SEAI Room Heat Loss and Radiator Sizing Guidance", "SEAI Designer installer Sign Off Form", and "DEAP" as executed to design the system in sub-chapter "5.3.1"(SEAI, 2021b). The "SEAI Room Heat Loss and Radiator Sizing Guidance" will allow the house owner to calculate the rooms' heat losses as in Table 5.7, integrating these losses to size a heat pump and emittance technologies as concluded from Table 5.8. Then, the homeowner can use the "SEAI Designer installer Sign Off Form" to validate the results, specifically the Heat Loss Indicator (HLI) being in the range of an eligible heat pump grant. Finally, from the DEAP online software, a house owner can retrieve the total annual heat demand of the dwelling after renovations. Implementing the developed Excel model for their dwellings' refurbishments process, Loop Head's house owners will be capable of figuring out, the AWHP's annual COP, total annual heat supplied, and annual electrical consumption. For more information, see Annex 16

Utilizing the aforementioned constructed model, it was found that the "Total Annual Heat Supplied to Dwelling" is 10,818 $kWh_{thermal}$ compromised of 9,622 $kWh_{thermal}$ as "Total Heat Demand for Space Heating" and 1,196.84 $kWh_{thermal}$ as "Annual Domestic Hot Water Heat Demand" in case of the dwelling being occupied by 2 residents. The "Yearly COP" was found to be 3.63; in other words, the heating system generates 3.63 units of heat for every electrical unit consumed. The AWHP monthly thermal generation and electricity consumption can be automatically displayed on the second sheet of the model "HP Monthly Energy Profile" as per the given input required in the first sheet.

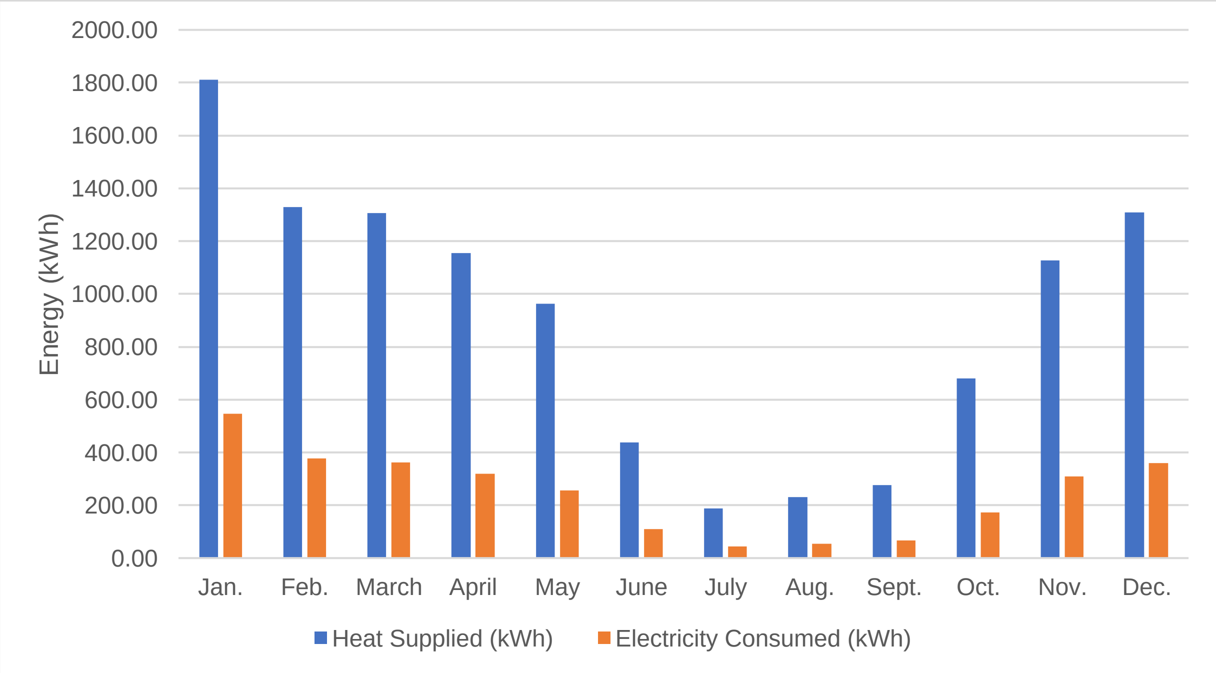


Figure 5.7: Heat Pump Monthly Heat Generation Vs Electrical Consumption
Source: Author based on (Met Eireann, 2022)

In the case of the dwelling under analysis, as shown in Figure 5.7, it was found that the highest heat generation, gains, and transfer to the heated spaces occur during the coldest month of the year, January, at 1,811.95 $kWh_{thermal}$ due to the fact that the AWHP will be able to exploit the higher difference in temperature between indoors and outdoors. As the mid-summer season approaches, the heat pump will not generate much heat for spaces but rather solely for DHW. It can be noticed that the COP of the AWHP varies according to the ambient temperature, while the lowest electrical consumption and highest COP ocurr in July at 44.74 kWh_e and 4.22 respectively.

Even though the ambient temperature will reach -4.5°C on Jan 9th at 6:00 am, the AWHP will still be capable of generating 2.81 thermal units for every electrical unit it consumes. To illustrate, the AWHP will generate the maximum thermal units per hour at 4.16 $kWh_{thermal}$, consume the maximum electrical units per hour at 1.48 kWh_e, and it will have the lowest COP in the year at 2.81 as shown in Figure 5.8.

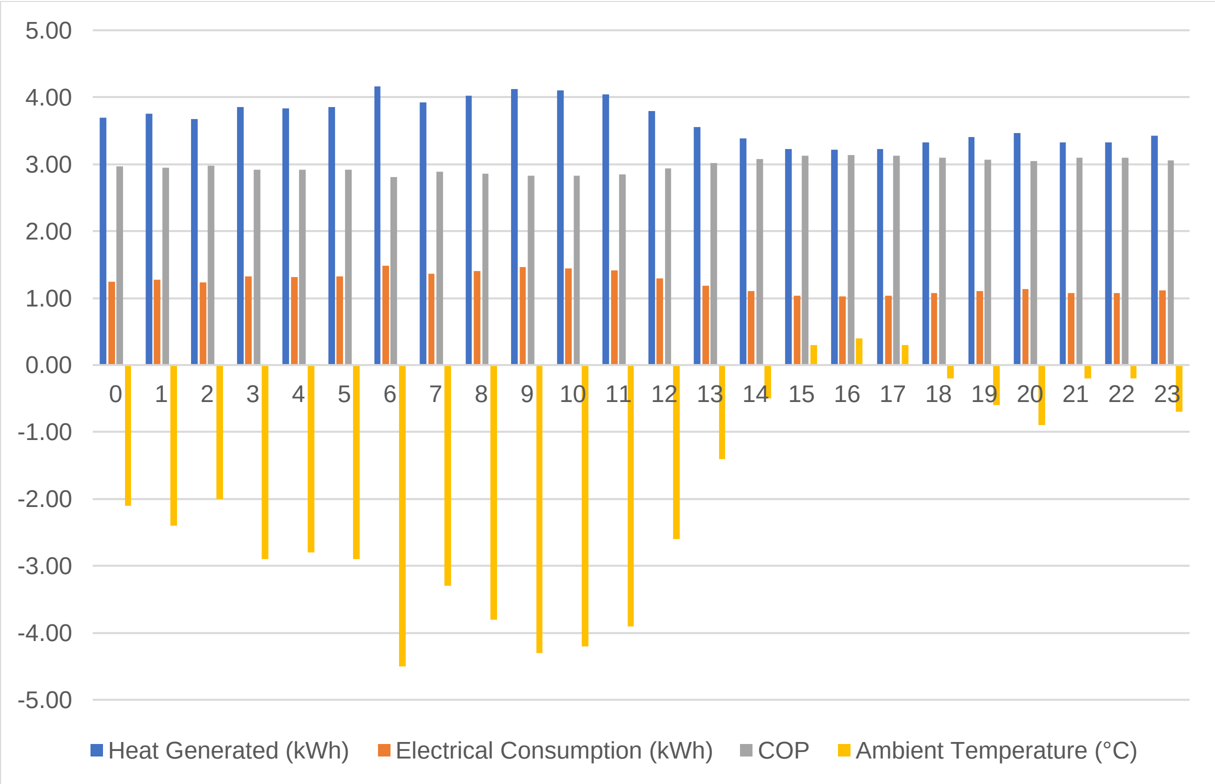


Figure 5.8: Heat pump performance on the coldest day of the year
Source: Author based on (Met Eireann, 2022)

To conclude, the space heating and DHW systems were found of significantly high performance at Loop Head ambient weather conditions since the median COP is 3.95. In other words, at 77 % of the total hours of the year, namely 6,800 hrs, the space heating and DHW system is able to supply 3.63 units of thermal heat against every unit of electricity consumed. In addition, at 59 % of the total hours of the year, namely 5,200 hrs, the space heating and DHW system is capable of supplying more than 3.84 units of heat to the dwelling at the cost of a single electrical unit, a COP of 4.45 is achieved for 13 % of the total hours of the year for 1,200 hrs as depicted on Figure 5.9.This suggests that the heat pump operates efficiently throughout the whole year, including in the summer.

Case study I

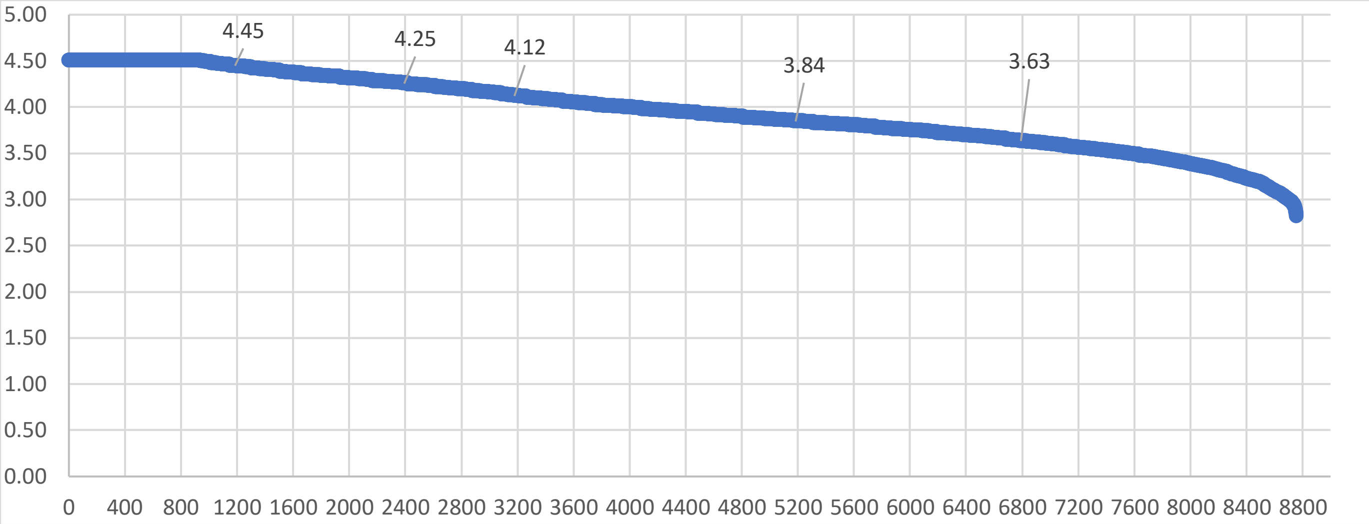


Figure 5.9: Selected AWHP COP uration Curve
Source: Author based on (Met Eireann, 2022)

5.3.3. Space Heating and DHW economic analysis

In order to analyze the economic feasibility of the space and DHW heating system, a nominal investment cost and an annual operational & maintenance cost of €9,385 and €311 were assumed respectively to calculate the cost of annual energy savings, simple payback period, and discounted payback period (Anders Rosenkjær Andersen, 2021). The selected AWHP is a monobloc type that only requires four spring mounts, an electrical connection, and a water connection. In addition, the nominal investment and maintenance costs selected were noticed to exceed the prices on the Irish market since they are extracted from Danish Energy Agency a data set (Anders Rosenkjær Andersen, 2021). Further, the nominal investment and operational costs include spare parts, DHW tank, and auxiliary equipment.

Exploiting the SEAI heat pump grant of €6,500 and assuming an interest rate of 1.47 %, the total initial investment was found at €2,885 (SEAI, 2022b)

Calculating the annual energy savings, the selected AWHP generates 10,819 $kWh_{thermal}$ while it consumes 2979 kWh_e. Thus, at a levelized cost of energy of 0.2209 €cents/kwh generated from the integrated energy solution utilizing solar PV, the AWHP electrical consumption is 658.11 €/year. The annual maintenance cost of the existing oil condensing boiler was reported during the house owner interview to be 100 €/year, while the fuel consumption was reported to be 1500 L/year and the delivered energy cost of gas oil is 8.09 €cents/kwh (SEAI). Therefore, the same annual thermal units using the existing boiler will cost 931 €/year. Hence, the annual energy savings is 273 €/year.

Case study I

For calculating the simple payback period, the initial investment of installing AWHP is divided over the annual energy savings resulting in 10.56 years to pay back the initial investment.

Nevertheless, in order to calculate the discounted payback period, the investment cost and the operational cost of the existing oil condensing boiler have to be considered since the brand of the boiler installed has a lifetime of 12 years, and it has already been installed since 2011 as reported in the interview (Grant Engineering, 2022). €1,905 has been estimated as the investment cost of the condensing boiler as of today's prices, while it will cost €1,933 and €2,302.95 in 1 year and 13 years respectively (My Building Supplies, 2022). A project lifetime of 16 years was assumed, the same as the economic lifetime of AWHP. In other words, even if the existing boiler is to be replaced next year, it will need to be replaced one more time during the lifetime of the AWHP. Therefore, the AWHP initial investment will pay back the house owner after 12 years, considering lifetime, discounted maintenance costs, discounted replacement costs, and discounted annual energy savings.

5.3.4. Domestic Hot Water Heat Demand excel model update

The heat demand of the Domestic Hot Water (DHW) cannot be assumed to be catered within the annual total heat demand retrieved from DEAP. The system will serve the DHW heat demand first, but there might be a shortage in the total units of heat to be supplied to the dwelling. Therefore, the space heating and domestic hot water model has an input cell for the number of occupants per dwelling, and an output cell that will show the annual DHW heat demand. Subsequently, the output cell for the “total annual heat supplied to the dwelling” is updated to include both the heat demand for space heating and DHW.

5.4. Solar PV

5.4.1. Residential Demand

The energy assessment for case I revealed the annual electrical demand to be 1571 kWh/year. Figure 5.10 shows the monthly load profile. As discussed in sub-chapter 3.3, the hourly synthetic load profile was developed from the standard national load profile. Figure 5.10 shows the comparison of synthetic and actual monthly load profiles. The similar load pattern of the two load profiles validates the synthetic load profile for further sizing of the PV system.

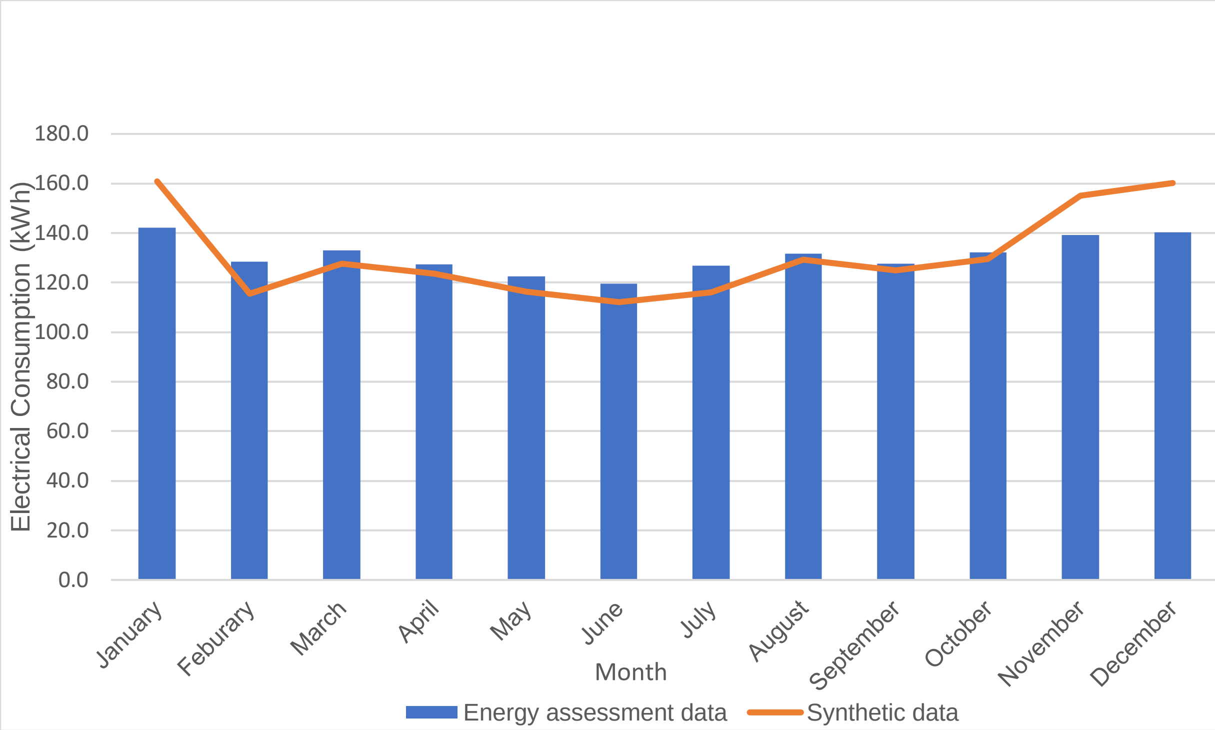


Figure 5.10: Comparison of Synthetic and actual monthly load profile
Source: author based on (Ricardo, 2020a)

5.4.2. System Design

The PV system was designed to cater for the electrical demand under two scenarios: with and without battery storage system, using Homer Pro software. The best suitable PV system was selected based on the optimization criteria defined in sub-chapter 3.3

Different battery capacities available in the market were kept as input parameters in Homer Pro for simulating the system. All the possible PV system configurations with the cost of consumed electricity (COCE) below the considered tariff rate are tabulated in

Table 5.9. As per the least cost optimization result, a 1.2 kWp capacity PV system with 2.4 kWh storage capacity results in the lowest COCE of 22.98 cent €/kWh. This system served 58.2 % of the total electricity demand from generated PV electricity. However, with a 0.729 kWp system with no battery storage, the system served only 29 % of the total electricity demand and the COCE is closer to the cost of grid electricity.

Case study I

Table 5.9: Least cost PV system configurations- Case study I
Source: Author using Homer Pro optimization tool

System	PV capacity kWp	Battery capacity kWh	Initial investment €	COCE cent €/kWh	RE fraction (%)
1	0.729	-	1,304	24.07	29
2	1.2	2.4	2,865	22.98	58.2

The 1.2 kWp system with 2.4 kWh battery storage fitted the cost-optimized criteria for the PV system. However, the PV system was resized to 1.48 kWp for installing 4 "Longi" solar panels with 370 Wp capacity each, and a 2.4 kWh Pylontech Lithium-ion battery. The peak DC power of the designed system was 1.317 KW on 21st August. It means that the selected inverter's DC peak power should be more than 1.317 kW. Subsequently, the 'Solis' two-string MPPT inverter with a capacity of 2.4 KW was selected with a peak DC power rating of 3KW based on the market available inverter size. The technical specifications for the panels, inverters and battery are attached in Annex 26,. The designed system catered to 70.7% of the total electricity demand of the household. Moreover, the total area required for this system was calculated to be 8.6 m^2. Table 5.10 elucidates the performance of the designed PV system.

Table 5.10: PV system performance of cost optimized system- Case study I
Source: author based on Homer Pro simulation

Electricity demand of household kWh/year	Electricity generated from PV kWh/year	Demand met by PV generation kWh/year	Grid purchase kWh/year	Surplus electricity to the grid kWh/year	RE fraction (%)
1571	1547	1086	461	1113	70.7

Case study I

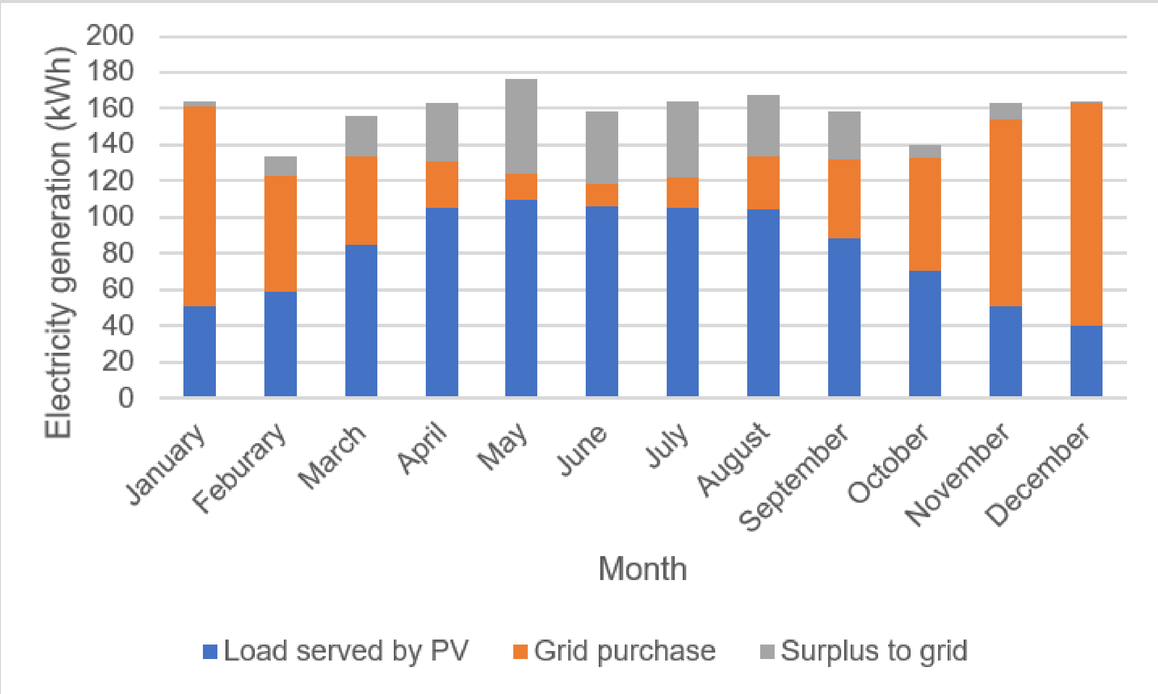


Figure 5.11: Monthly PV performance for cost optimized system- Case I
Source: Author based on Homer Pro simulation

The generation from the PV system was maximum at 162.4 kWh during May, and minimum at 41.5 kWh during December as shown in Figure 5.11. To increase the renewable penetration of the system, there should be more generation during winter and less excess during summer times. This requirement was attempted to be met by adjusting the tilt angle to improve the performance of solar PV panels during winter. Since the location of the case study is in the northern hemisphere, the sun is low with respect to the horizon in winter. Thus, placing the panels at a deep tilt angle might help the sun rays to hit the panel perpendicularly, thereby, increasing the energy generation. A sensitivity analysis was conducted by changing the tilt angle of the panel and the panel azimuth to analyze the variation in power generation from the PV system. The sensitivity analysis result would help to fulfil the second criteria of the optimized system.

Table 5.11 shows the energy generation of the cost-optimized system with varying tilt angles.

Table 5.11: Sensitivity analysis by varying tilt angle- case study I
Source: Author based on Homer Pro simulation

Tilt angle	Azimuth angle, south to west	PV generation (kWh/year)	Surplus to grid (kWh/year)	Grid Purchase (kWh/year)	Renewable fraction (%)
37^0	**0^0**	**1547**	**490**	**581**	**63.1**
37^0	10^0	1539	481	581	63.1

Case study I

Tilt angle	Azimuth angle, south to west	PV generation (kWh/year)	Surplus to grid (kWh/year)	Grid Purchase (kWh/year)	Renewable fraction (%)
45^0	0^0	1545	490	583	62.9
45^0	10^0	1536	480	581	62.9

The renewable fraction is maximum with a tilt angle of 37^0 and it is the optimal tilt angle for Loop Head. It can be concluded that the PV energy yield decreases with the deviation from the optimum tilt angle and 0^0 azimuth angle, i.e., south faced. Therefore, the 1.48 kW system integrated with a 2.4 kWh battery placed south faced at a tilt angle of 37^0 is finalized as the optimized system for Case I.

5.5. System integration

5.5.1. Domestic hot water

Case I is a single resident household where condensing oil boiler is used to meet its hot water requirement. As per the interview with the house owner, the boiler is operated one hour in the morning and two hours in the evening for space heating and hot water purposes. In addition, the water cylinder tank is equipped with a 3 kW rated immersion heater, and the immersion heater is used once or twice a week for 30 minutes to increase the temperature up to the set point. . According to this consumption pattern, the annual electricity demand for water heating is 117 kWh/year.The integration of a power diverter controller in the PV system could be an effective solution for meeting the hot water demand during the excess electricity generation time. This increases the self-consumption of the PV system and with the existing uncertainty of feed-in tariff, it is better to increase the self-consumption.

As discussed in methodology sub–chapter 3.3, a typical family of four people consumes 120 liters of hot water daily heated up to 50 ^{0}C from the water mains temperature. Therefore, a hot water requirement of 30 liters was considered for this case study. The power required to meet the hot water demand was calculated to be 566 kWh/year, out of which 220 kWh/year can be catered by diverting the excess PV power. The remaining excess of 284 kWh/year power can be diverted to the grid.

Table 5.12: PV system performance with battery storage and power diversion to hot water tank
Source: Author based on Homer Pro simulation

Case study I

Electricity demand of household (kWh/year)	Electricity generated from PV (kWh/year)	Demand met by PV generation (kWh/year)	Grid purchase (kWh/year)	Surplus PV energy diverted to grid (kWh/year)	Surplus PV energy diverted to hot water storage tank (kWh/year)	Renewable fraction (%)
1571	1547	1086	461	270	191	70.7

<u>PV system considering electrical demand from heat pump</u>

The energy assessment for Case I suggests the installation of heat pumps for more efficient use of energy. In sub-chapter 5.3, a 6 KW heat pump was designed to cater to case I's heating demand for space heating and hot water purposes. After incorporating the annual electrical consumption of the heat pump, the electrical demand of the house increases to 4550 kWh.

The previously optimized system was further analyzed to meet the new additional demand. An additional electrical load profile was fed as input to Homer. The same approach of determining the cost-optimal system as in sub-chapter 5.4.2 was followed. All the possible system configurations with the cost of consumed electricity (COCE) below the considered tariff rate are tabulated in Table 5.13. Although the system with 2.71 kWp with battery storage systems have higher RE fraction, the COCE is closer to the cost of grid electricity. Therefore, these systems were not considered.

Table 5.13: Least cost PV system configuration for the system with heat pump electrical demand- Case study I
Source: Author based on Homer Pro simulation

System #	PV capacity kWp	Battery capacity kWh	Initial investment €	COCE cent €/kWh	RE fraction (%)
1	2.17	2.4	3,917	22.5	32.5
2	1.63	-	2,277	23.1	20.6
3	2.71	2.4	4,877	24.2	38.8
4	2.71	3.6	4,927	24.3	38.8

Case study I

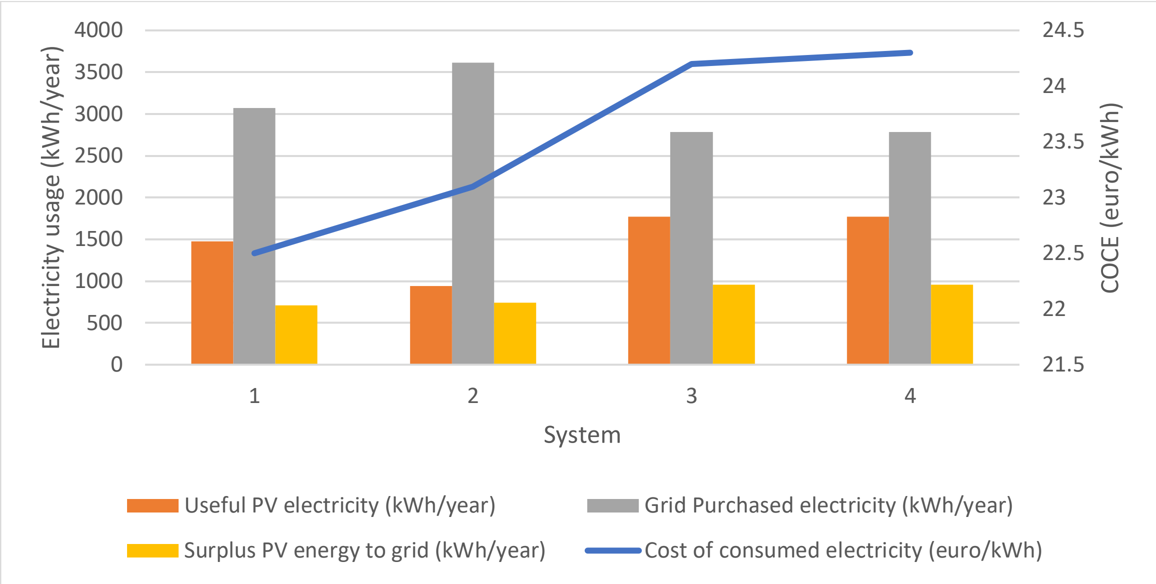


Figure 5.12:*Perfomence comparision for the lowest COE system*
Source: Author based on Homer Pro simulation

The 2.17 kWp system with 2.4 kWh battery storage was the least costsolution. Considering 6 'Longi' solar panels with 370 kWp capacity each, the solar PV system was fixed to 2.2 KW. The 'Solis Dual MPPT' 2.5 kW inverter was selected based on the market availability. The selected inverter has a peak DC rating of 3 kW. The Pylontech lithium-ion battery of 2.4 kWh capacity was selected. Finally, the 2.2 kWp system with 2.4 kWh at an angle of 37^0 was selected as the optimized system for Case I to cater for the electrical demand including the electrical consumption from the heat pump. The total required area for this system was calculated to be 12.7 m^2.

The solar penetration rate for the optimized system was 32.7% while the excess generation was 13.7% and the system meets most of its demand from grid purchased electricity. The behavior of the system is as such because of the higher consumption and demand pattern of the heat pump. Although the heat pump is operated throughout the year, the consumption is highest during the winter season and lowest during summer. However, the generation from the PV system is low during winter and high during summer. Thus, installing a higher capacity system to cater to most of the electrical consumption from the heat pump demands a larger battery storage, which drastically increases the system's investment cost. Therefore, it is economically feasible to go for a lower system size and cater to the high consumption of the heat pump from grid electricity during the winter season.

Table 5.14 shows the details on the performance of the PV system.

Table 5.14: Performance of PV system including electrical demand from heat pump- Case I
Source: Author based on Homer simulation

Case study I

Electricity demand of household (kWh/year)	Electricity generated from PV (kWh/year)	Demand met by PV generation (kWh/year)	Grid purchase (kWh/year)	Surplus PV energy diverted to grid (kWh/year)	RE fraction (%)
4594	2300	1532	3062	733	32.7

Figure *5.13* shows the time series plot of the system during low irradiance. These days, almost all the demand is catered from grid purchased electricity as there is not enough solar irradiation and the battery is also fully discharged most of the time. However, during the high solar irradiance, as shown in Figure 5.14 the load during the daytime is fully served by PV generated electricity, only nighttime load is served from grid electricity. The battery is fully functional with constant charging and discharging.

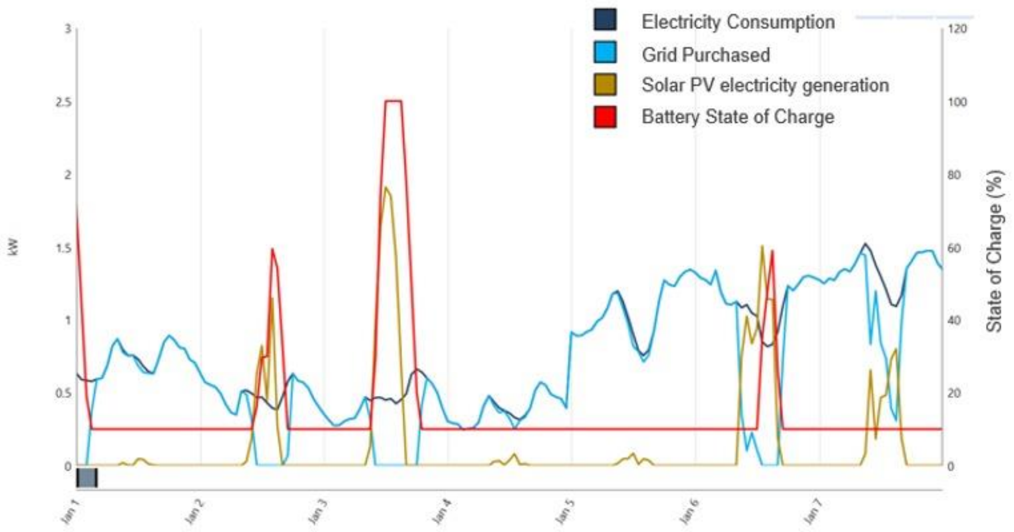


Figure 5.13: Time-series plot of PV system during lowest irradiation- case study I
Source: Author based on Homer Pro simulation

Case study I

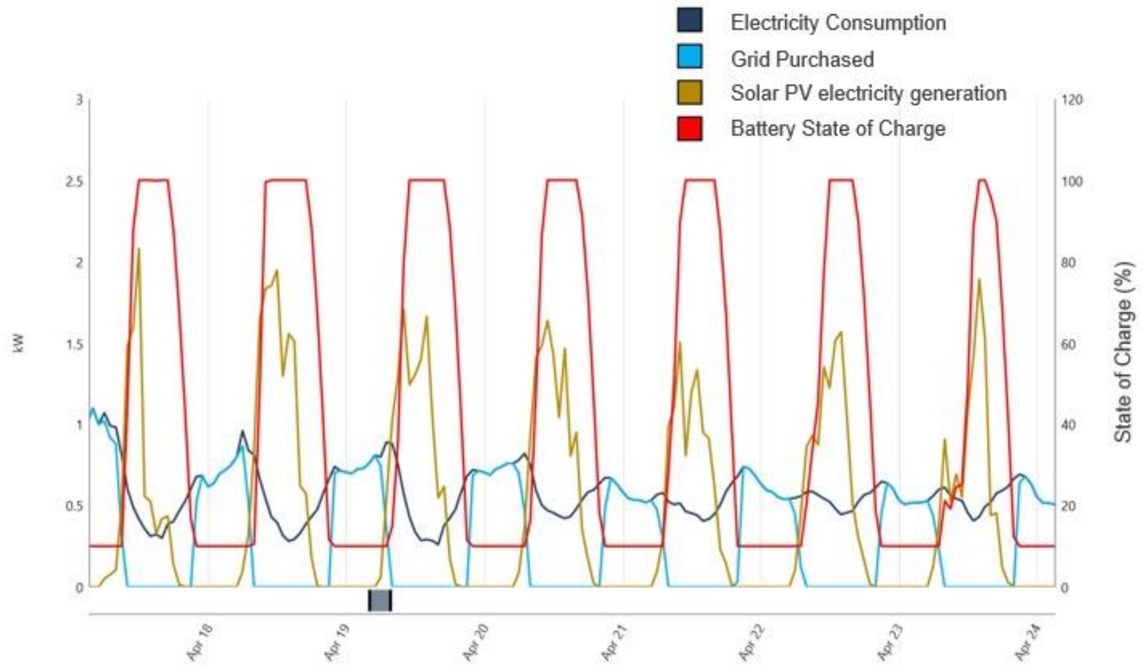


Figure 5.14: Time-series plot of PV system during highest irradiation- case study I
Source: Author based on Homer Pro simulation

Figure 5.15 depicts the monthly performance of the PV system integrated with the heat pump. The high demand during winter and low generation from the PV system results in high grid electricity purchase. Similarly, during summer, most of the demand is served by the PV system along with excess electricity sales to the grid.

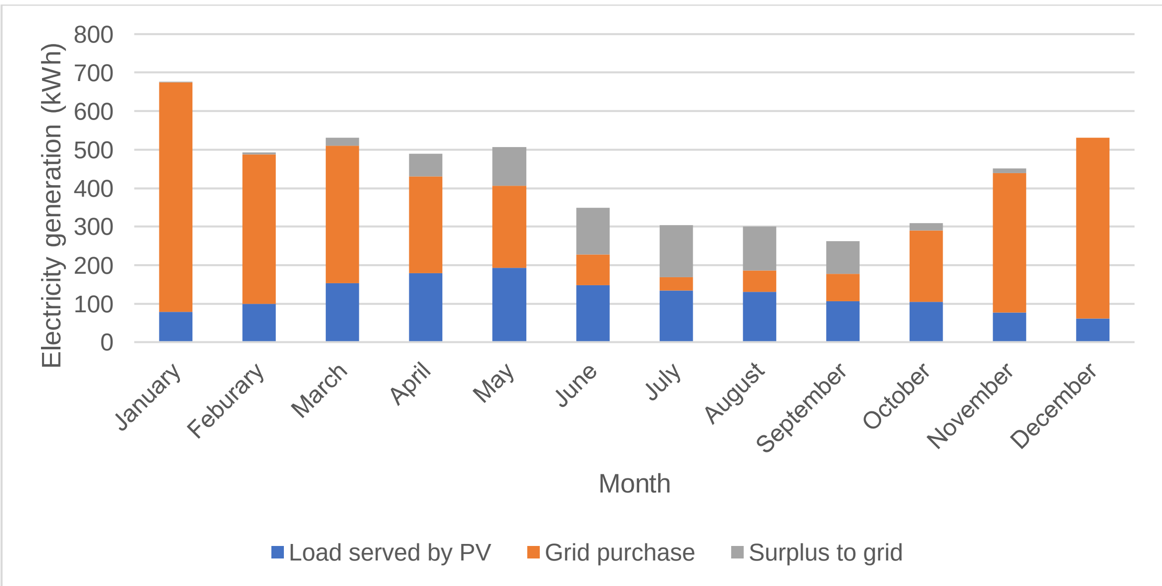


Figure 5.15: System performance throughout the year
Source: Author

5.5.2. Cost-effectiveness analysis

The cost analysis for the above-mentioned systems was carried out without grants and with grants. All the economic parameters used for the calculation is as mentioned in sub–chapter 3.3. The COCE of the proposed solar PV system varies from 20.6 cent €/kWh to 23.54 cent €/kWh, which are less than the considered grid tariff rate. The summary of the cost analysis is presented in Table 5.15.

Table 5.15: Cost analysis summary for Case I
Source: Author based on Homer Pro Simulation

PV System	Grants (€)	Capital Cost (€)	COCE (cent €/kWh)
1.48 kW PV system with battery storage	-	3,719 €	23.54
	900 €	2,819 €	20.79
2.2 kW PV system with battery storage (considering electrical demand of heat pump)	-	3,953 €	22.5
	1800 €	2,153 €	20.6

Taking into account the annual savings from grid electricity consumption, degradation factor of panels, and discount rate, the simple and discounted payback period and return on investment for the designed PV system was calculated. Based on the result tabulated in Table 5.16, the 2.2 KW system with grants has the least payback period with the highest return on investment.

Table 5.16: Payback period and ROI for case study I
Source: Author based on Excel calculation

PV System	Grants (€)	Simple Payback Period (Years)	Discounted Payback Period (Years)	Return on Investment (ROI)
1.48 kW PV system without battery storage	No	20	23.1	1.3%
	Yes	13.6	17.2	3 %
2.2 kW PV system with battery storage (including electrical	No	14	15.4	3.4%
	Yes	6.7	7.1	9.5 %

Case study I

PV System	Grants (€)	Simple Payback Period (Years)	Discounted Payback Period (Years)	Return on Investment (ROI)
demand of heat pump)				

The COCE of the optimized system is sensitive to the cost of grid electricity. In the case study, it is assumed that the grid electricity tariff is 24.70 cent €/kWh referring to the electricity bills of 2020 and 2021. However, the tariff rate changes monthly based on the generation energy mix. Thus, it is relevant to analyse how the cost of the generated electricity and the payback period of the system deviates when the cost of grid electricity is varied. Therefore, for the 2.2 KW system, a sensitivity analysis was conducted. The low-end rate (15 cent €/kWh), the middle range (24.7 cent €/kWh) and the high-end rate (30 cent €/kWh) were considered based on the electricity bill provided by the case study representatives. The result of the sensitivity analysis is presented in Table 5.17.

Table 5.17: Cost sensitivity analysis- Case I
Source: Author based on Homer Simulation

Scenarios	Grants	COCE (cent €/kWh)	Discounted Payback period (years)	ROI (%)
Scenario 1- low end tariff	No	15.97	n/a	-0.3%
	Yes	14.07	16.6	4.6%
Scenario 2- middle range tariff	No	22.5	15.4	3.4%
	Yes	20.6	7.12	9.5%
Scenario 3- high end tariff	No	26.07	12.08	5.3%
	Yes	24.16	12.08	13.2%

For the low-end tariff of 15 cent €/kWh, the investment is not recovered throughout the lifetime of the PV system. Among the scenarios tabulated in Table 5.17, the high-end tariff scenario has the highest return on investment. However, the COCE is also relatively high. A 10 eurocent/kWh decrease from 24.70 cent € /kWh with grants leads to a decrease in COCE by 31.69% and an increase in payback period by 9.4 years. Similarly, a 5 Eurocents/kWh increase in the cost of grid electricity from 24.70 cent € leads to an increase in the COCE by 14.7% and an increase in the payback period by 5 years. With a higher cost of grid electricity, the return on investment is also increased and the COCE also increases. In the COCE calculation, the cost of grid electricity is proportional to the O&M cost. Therefore, increasing grid electricity price leads to higher O&M costs for grid electricity, subsequently leading to higher COCE.

For the 2.2 KW system, a further cost analysis was done considering the annual income from excess electricity sales. The feed-in tariff was considered for 15 years. The regulations on feed-in tariff are described in sub-chapter 4.6.3. Considering a feed-in tariff of 0.09 cent €/kWh, a cost of grid electricity of 0.2407 €/kWh and SEAI grants of 1800 €, the discounted payback period of the system was reduced to 3 years from 7 years and 1 month.

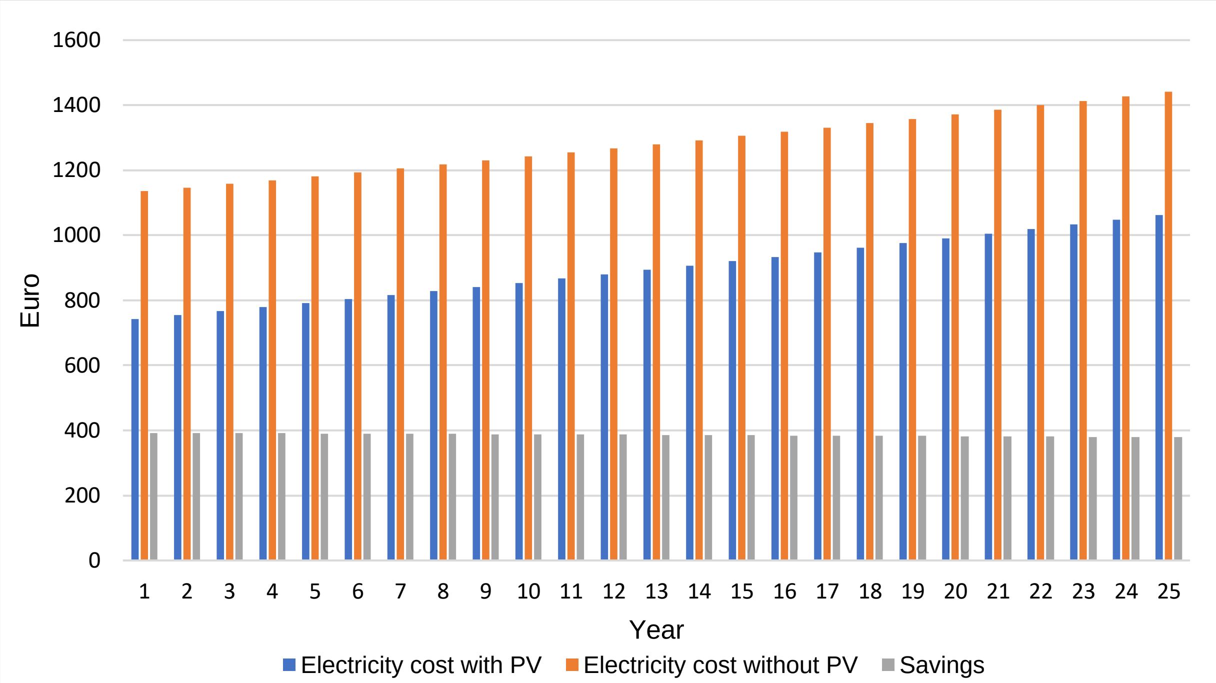


Figure 5.16: Cost savings for case study I
Source: Author based on Excel calculation

The net cost savings due to PV energy for the 2.2 KW system over the lifetime of 25 years was calculated to be around € 5712 after deducting the investment and annual O&M cost of the PV system. The net-saving is sensitive to the cost of grid electricity and feed in tariff. Therefore the change in these parameters lead to change in the net savings. Summarized key findings

The overall PV sizing of case I is done to cater to the maximum household demand at the lowest possible cost. However, due to the high electricity consumption of the heat pump during low irradiance hours, the cost-optimized system could not serve most of the electricity demand. Nonetheless, the cost-optimized system provides considerable renewable penetration. If the homeowner wants a system with a significantly high renewable fraction then the COCE goes higher. Therefore, there would be either technical or cost constraints while system designing.

Case study II

The designed capacity of the heat pump and the optimised Solar PV system as mentioned in sub-chapter 5.3 and 5.1.1 respectively were put to the step of the advanced refurbishment as mentioned in section 5.2.1 to find the potential BER rate via DEAP interface. The analysis of the results from the DEAP interface provided the BER rating of B3.

5.6. Summarized key findings

The overall PV sizing of case I is done to cater to the maximum household demand at the lowest possible cost. However, due to the high electricity consumption of the heat pump during low irradiance hours, the cost-optimized system could not serve most of the electricity demand. Nonetheless, the cost-optimized system provides considerable renewable penetration. If the homeowner wants a system with a significantly high renewable fraction then the COCE goes higher. Therefore, there would be either technical or cost constraints while system designing.

The designed capacity of the heat pump and the optimised Solar PV system as mentioned in sub-chapter 5.3 and 5.1.1 respectively were put to the step of the advanced refurbishment as mentioned in section 5.2.1 to find the potential BER rate via DEAP interface. The analysis of the results from the DEAP interface provided the BER rating of B3.

6. Case study II

6.1. Status quo

6.1.1. Building Envelope

The second case study building is a two-story building constructed in 2005 with a total floor area of 215 m^2 . It has 305 mm concrete block walls with 50 mm of external wall insulation and 50 mm of internal wall insulation. The building has two pitched roofs of 97 m^2 and 40 m^2 respectively including one chimney. A central space heating system is supplied by a geothermal heat pump of 12 KW connected to the underfloor heating. The system also meets the requirement of hot water.

As per the interview with the homeowner, the heat pump operates two hours in the morning and three hours in the evening as per the household's preferences. The domestic hot water requirement is provided by the same heat pump and the water is stored in a 200 liter capacity factory insulated hot water cylinder. The water cylinder is equipped with a 3 kW rated immersion heater. The geothermal heat pump stores 35–40-degree Celsius temperature hot water in the cylinder during the morning operating hours. Then the immersion heater is used to increase the temperature up to the set point of 60 ^{0}C. During the hot summer days, the heat pump is not operated and the domestic hot water is provided by electricity from the grid.There is also the secondary space heating system which is a traditional wood pellet stove.

The dwelling has four bedrooms, three and a half bathrooms, and one bathtub. The common areas include four rooms (kitchen, living room, study, office) and one utility room. The number of occupants in the case study is four. The status quo of building envelope along with the fabric material and the associated U-Value is explained in Table 6.1

Table 6.1: Status quo of case study II
Source: Author

Description		Value	Unit
Floor Area		2157	m^2
Total Door Area		1.54	m^2
Total window Area		29.41	m^2
Number of occupants		4	
Fabric U-Values	305 mm concrete block wall :50 mm internal insulation and 50mm external insulation(Insulation material unknown)	0.27	$W/m^2 \cdot K$
	First floor Pitched roof: insulated on rafter	0.49[d]	$W/m^2 \cdot K$
	Second floor Pitched roof: insulated on rafter	0.25[d]	$W/m^2 \cdot K$
	Ground floor (solid)	0.34[d]	$W/m^2 \cdot K$
	Second floor (solid)	0.37[d]	$W/m^2 \cdot K$
	Windows (double-glazed low -E/ Wood)	2	$W/m^2 \cdot K$
	Door between heated and unheated space (semi-exposed)	1.71	$W/m^2 \cdot K$
	Door between two unheated space (exposed door)	3	$W/m^2 \cdot K$
Appropriate default U-values were used as per the year of construction and as per DEAP Manual are labelled as [d].			

The house is well insulated and only few areas with exceptional heat loss as described were observed during the thermal inspection.

- Improper sealing of windows and doors

The windows of the house are made of PVC with double glazing; however, cold air from the outside is observed around all the windows of the house due to insufficient insulation between the window frame and the wall as observed in Figure 6.1 In order to reduce heat loss, it is recommended to insulate the space between window and wall. Insulating materials like polyurethane-based sealant.

Figure 6.1: Infrared and digital image of the windows.
Souce: Thermal camera

A significant heat loss was also observed from the external doors as seen in Figure 6.2

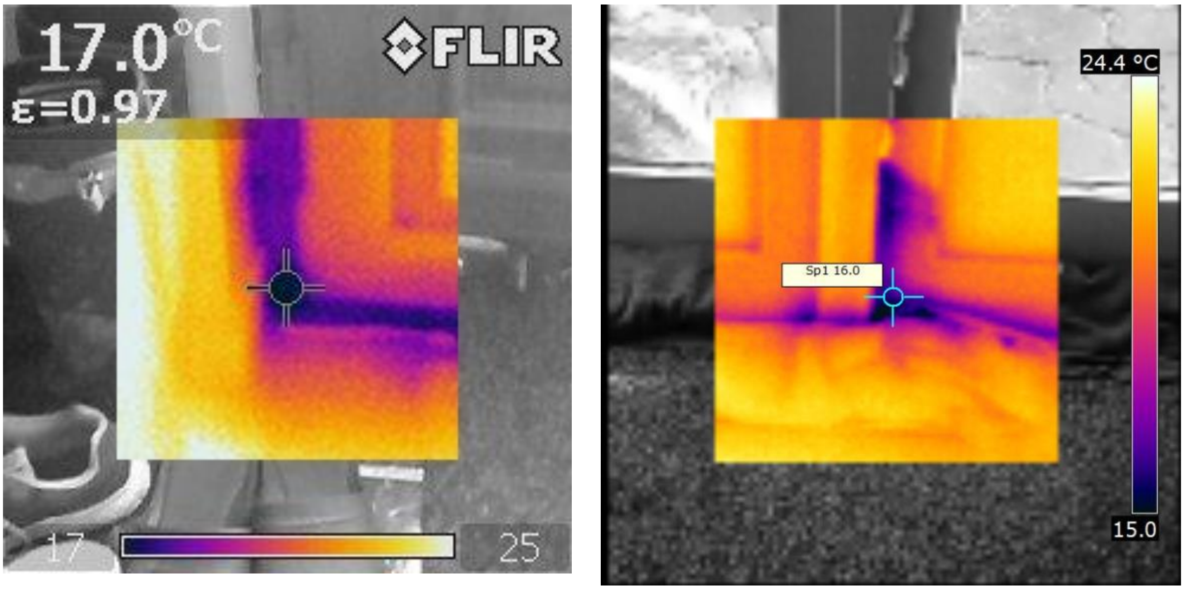


Figure 6.2: Infrared and digital image of the windows.
Souce: Thermal camera

- Attic and roof insulation

During the inspection of the kitchen ceiling, heat losses were identified in the areas of built-in light fittings as seen in Figure 6.3 . Cold air was felt penetrating into the room, perhaps because the installation recess of the light fitting is not air tight. It is recommended to check the insulation and improve it.

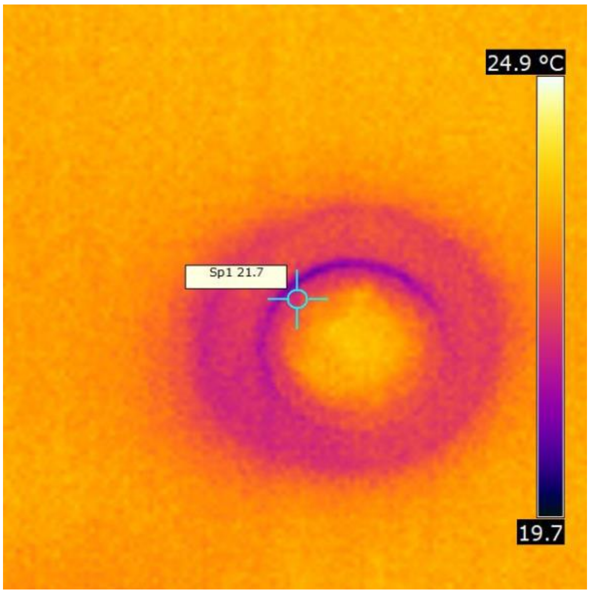


Figure 6.3: Infrared and digital image of the external walls.
Souce: Thermal cemera

- Uninsulated porch

The case study house has an attached porch. The walls of the porch are made of stone and are not insulated. Warm air escapes from the house into the porch as a result of an open or insufficiently insulated door between the porch and the corridor of the house. The infrared image of the house as seen in Figure 6.4 shows heat loss through the uninsulated stone walls of the porch.

Case study II

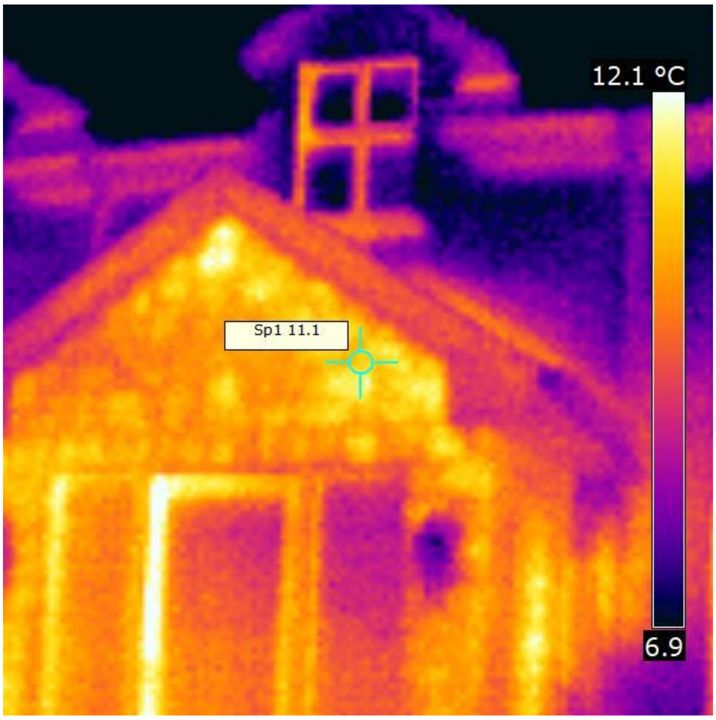


Figure 6.4: Infrared image of the porch.
Souce: Thermal camera

It is recommended to insulate the walls of the porch or, if the porch is not considered as part of the heated area of the house, to separate this space with an energy-efficient front door.

6.1.2. Electricity usage pattern

The annual electricity consumption of Case Study II in 2021 is 17,038 kWh. The Case Study II has high electricity consuming loads such as an electric car and a heat pump. Similar to case study I, case study II pays a fixed electricity bill every month so montly payments may not reflect the variability of electricity consumption throughout the year. The electricity demand profile is illustrated in Figure 6.5.

Case study II

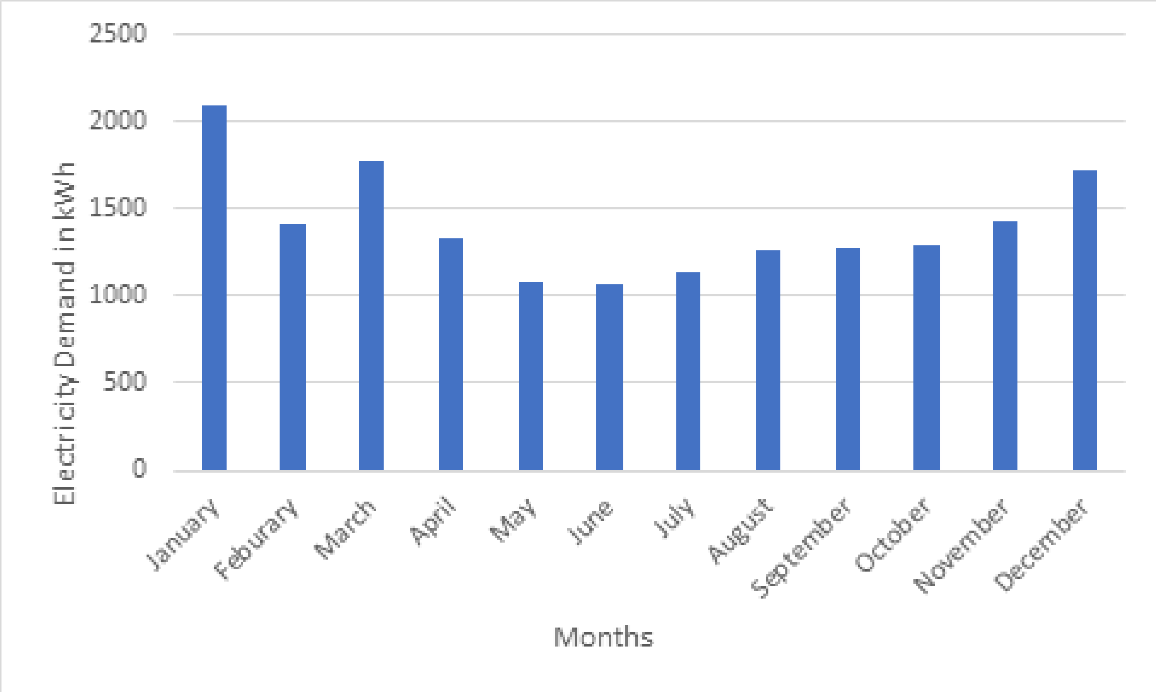


Figure 6.5: Annual estimatedl electricity consumption
Source: author based on own calculation

As per the electricity assessment conducted during the site vist, the end-use breakdown as seen in Figure 6.5 is done to categorize what contributes in the total electricity consumption. As expected, the electric car consumed the maximum amount of electricity, followed by the heat pump.Water heating consumes 9 % and ligting consumes 3 % of the total electricity consumption.

A plumbing issue was observed in the house that connects a booster pump with the toilet flush. This configuration operates the pump every time a toilet is flushed and consumes electricity. A data logger was used for the span of 24 hours and 1.09 kWh of consumption was measured. It should be noted that this is not the maximum energy used by the flush itself as the energy is consumed every time hot water is being used, for example, during a shower. The measured power of the pump during the operation was 662.5 W. It was assumed that the flush is used for 30 minutes every day to calculate the annual energy savings of 120 kWh.

Further, if the cumulative of 340 W of halogen light present in the dwelling is replaced with an equivalent 60 W of LED, 40 kWh of annual saving is achieved. The saving is very insignificant because the lights are not used every day and only for short intervals. The combined annual energy savings then would be 160 kWh resulting in the reduced electricity consumption of 16,918 kWh. The efficiency measures have only considered lighting in this case study as the appliances were found to be efficient. Moreover, the homeowner was wary of the consumption of high energy usage appliances like a dryer (rated 2600 W) and reduced the use of such appliances when possible.

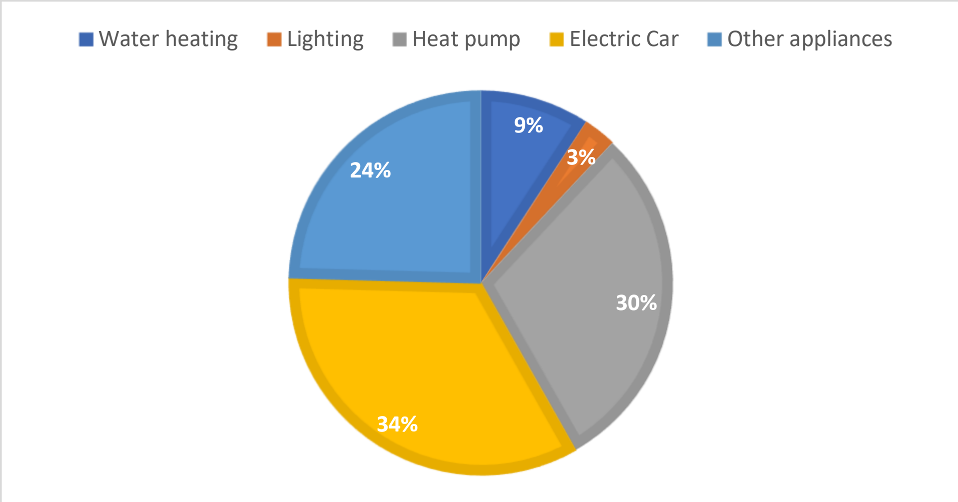


Figure 6.6 End-Use Breakdown of electrical appliances
Source: Author

6.1.3. BER Rating

A BER assessment of the original dwelling was calculated using an online version of DEAP 4.2.0 Online software by SEAI. The building geometry and fabric U-values referred to The second case study building is a two-story building constructed in 2005 with a total floor area of 215 m^2 . It has 305 mm concrete block walls with 50 mm of external wall insulation and 50 mm of internal wall insulation. The building has two pitched roofs of 97 m^2 and 40 m^2 respectively including one chimney. A central space heating system is supplied by a geothermal heat pump of 12 KW connected to the underfloor heating. The system also meets the requirement of hot water.

As per the interview with the homeowner, the heat pump operates two hours in the morning and three hours in the evening as per the household's preferences. The domestic hot water requirement is provided by the same heat pump and the water is stored in a 200 liter capacity factory insulated hot water cylinder. The water cylinder is equipped with a 3 kW rated immersion heater. The geothermal heat pump stores 35–40-degree Celsius temperature hot water in the cylinder during the morning operating hours. Then the immersion heater is used to increase the temperature up to the set point of 60 ^{0}C. During the hot summer days, the heat pump is not operated and the domestic hot water is provided by electricity from the grid.There is also the secondary space heating system which is a traditional wood pellet stove.

The dwelling has four bedrooms, three and a half bathrooms, and one bathtub. The common areas include four rooms (kitchen, living room, study, office) and one utility room. The number of occupants in the case study is four. The status quo of building envelope along with the fabric material and the associated U-Value is explained in Table 6.1

Table 6.1 have been considered to calculate the BER rating of the building. The primary energy use of the building is 161.94 kWh/m^2/yr corresponding to a BER Rating of "C1". The Heat loss of the house is 415.97 W/k with a HLI of 1.94 W/k/m^2.

6.2. Identified energy saving measures

6.2.1. Building envelope

There wasn't a need for the major fabric upgrade of the building. However, based on the thermal camera inspection, the impact of following fabric insulation was assessed.

a) Roof insulation

b) Exposed door replacement

For the added comfort the houseowner is recommended to replace the exposed doors and insulate the kitchen roof. However, this doesn't impact significantly on the energy consumption by the dwelling.

The recommended changes with the upgraded U-values are listed in Table 6.2

Table 6.2: Upgrade Recommendations with their U-Values for case study 2
Source: Based on (Tabula,2014)

Upgrade Recommendation	Upgraded U value
Pitched roof, 300 mm of mineral wool between and over the ceiling rafters and installation of required roof vents	0.13[d]
Munster Joinery GRP premium door	0.8

After employing the recommended changes, the primary energy use was reduced to kWh/m^2/year from 150.32 kWh/m^2/year, i.e., 7 % reduction in the primary energy. The rating of the house remains unaltered as C1. The HLI after this step is 1.72 W/k/m^2

Therefore, in case the houseowner wish to upgrade his BER Rating to B2 or higher, installation of renewable energy technology is recommended. In this case study, a detailed design and system sizing of Solar PV technology is done. The BER rating is accessed at the end considering the impact of Solar PV technology in the dwelling.

6.2.2. Cost analysis of Building retrofit

The range of retrofit measures chosen for the retrofit program is in line with Individual Energy Upgrade grants at the time of analysis. The estimated annual savings after the fabric upgrades along with their cost breakdown is set out in Table 6.3

Table 6.3: Cost Analysis for upgrade recommendation
Source: Author

Upgrade Recommendation	Grant	Estimated Investment Cost (Euro)	Estimated annual savings (Euro/year)	Simple Payback Period (Years)
Roof insulation and doors replacement	Yes	5313	167.415	32
	No	6813		41
he estimated investment cost breakdown is in Annex 13				

Refering the cost estimate classification in sub-chapter 3.2, the uncertainty of the cost analysis was considered by using the accuracy range between a low range of -10 % and a high range of 30 %. Figure 6.7 shows the total investment costs and discounted payback periods, both with and without grant of each step. Giving an example, the total investment cost without grant of is 6,813 euros with the accuracy range between 6,132 euros to 8,857 euros. The discounted payback period of this case without grant is 63 yearswith the accuracy range between 57 to 82year. On the other hand, the applicable “Individual Energy Upgrade” grant for the attic roof insulation of 1,500 euro can reduce both investment cost and discounted payback period. The total investment cost with the applicable grant of roof insulation would be reduced to 5313 euros with the accuracy range between 4,782 and 6,907 euros and the discounted payback period of this case would be 44 years with the accuracy range between 40 to 57 years.

Case study II

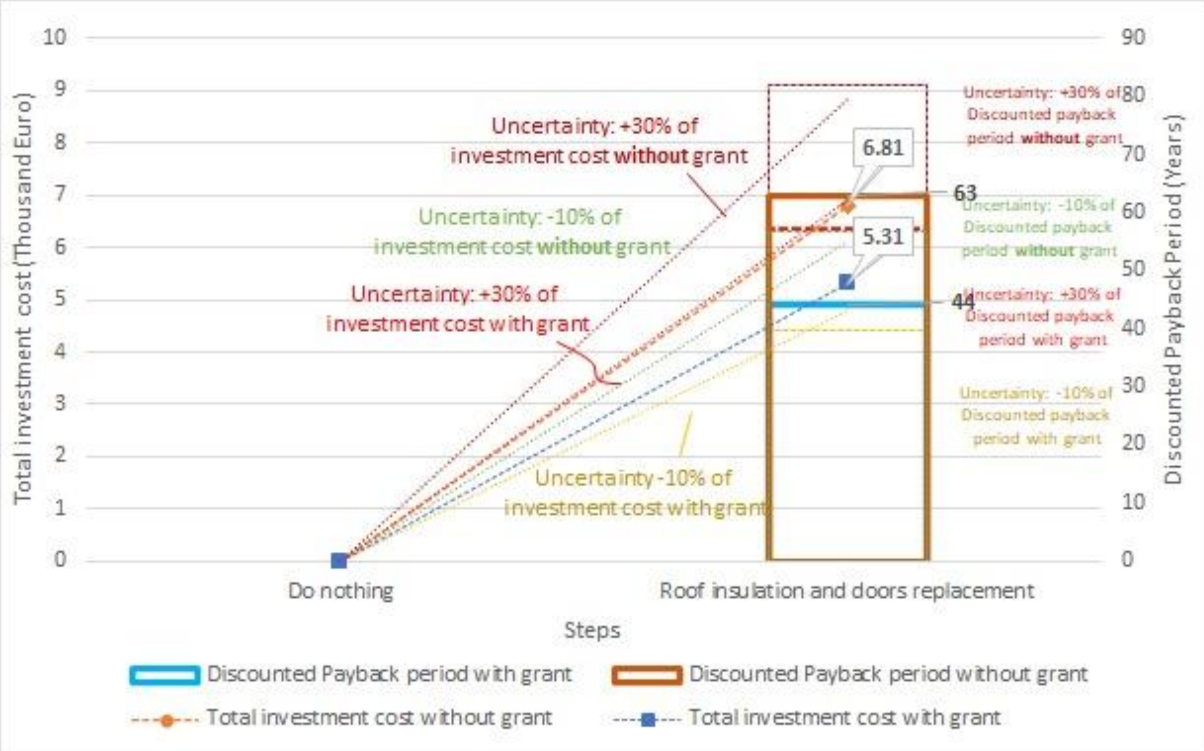


Figure 6.7: Total investment cost and Discounted Payback Period of case study 2
Source: Author

6.3. Existing Space Heating and DHW System

Inspecting the existing space heating and DHW system, it was found that the system depend on a ground source heat pump of 12 kW rated heat output capacity. The system was constructed in 2007; it has 2 vertical GHEs cored into an earth depth absorbing heat units with a total length of 200m, it employs an antifreeze water mixture of Ethylene Glycol at 40% concentration in the first heat transfer circuit. On the other hand, the reverse carnot cicuit employs 2.2 Kg of R-407C refrigerant that transmits heat to the underfloor heat emitters installed at the ground and first floors. The existing space and DHW system depend on 3 time and temperature controls including the 7 rooms in the ground floor, and the 7 rooms in the first floor, and a prioritized DHW tank. The DHW tank is of 500 liters capacity with a 3 kW immersion suplementary heater. The heat pump provides the underfloor heat emitters and DHW tank forward temperature of 44°C, then the immersion coil raise the water temperature to 60°C to avoid bacterial growth. According to the house owner interview, he/she operates the system from 4:00 – 5:00 am and 7:00 – 8:30 pm everyday whether with the timer control or manually. For more information, see Annex 18.

Case study II

6.3.1. Existing Space Heating and DHW System Analysis

Based on the house owner behavioural operation pattern noticed, it was not clear why he/she only operate the system in winter and during fixed hours since depending on the emersion coil to heat the DHW increases his energy costs. Accordingly, it was decided to implement the previously developed excel model in sub-chapter 5.3.2 in order to confirm that allowing the existing automatic temperature control could save the house owner more energy than force stopping the system for prolonged periods. Utilizing the system data as input in the excel model it was found that the automatic temperature control with no human interefence will result in a total of 5752.72 kWhs of electricity consumption at the current thermal mass base scenario, while if the house is further upgraded to a higher energy efficiency level the electricity consumption will be 5,499.82 kWhs. Comparing the 5,752.72 kWhs against the current 6,830 KWhs consumed by the heat pump due to his behavioral patterns; it can be concluded that due to the emersion heater limited efficiency against the high annual average COP of the heat pump at 3, the electricity consumption increases. As a result, it is highly advisable to allow the temperature automatic control all the time without force stopping it in the summer. As shown in Figure 6.8 even if the house owner fully allow his existing thermostatic control to take charge all year round, his electrical consumption in the summer will be just limited to heating DHW at 311 % efficiency. In other words, the heat supplied will be 3.11 times of the electiricty consumed in July.

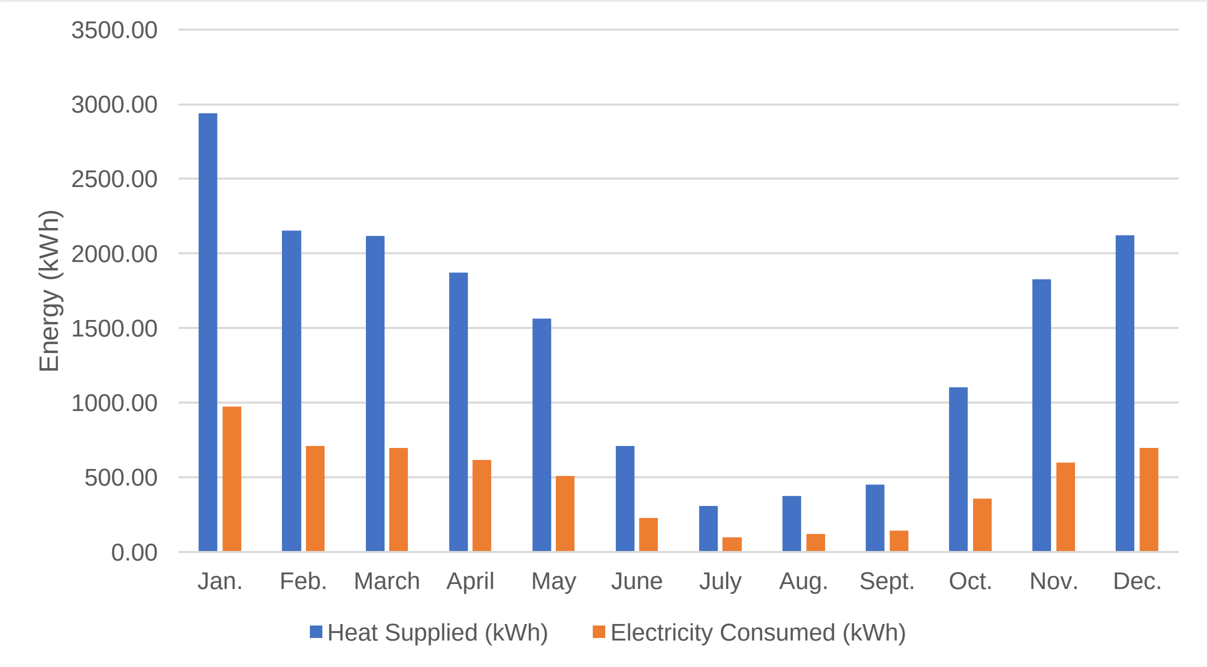


Figure 6.8: Existing geothermal heat pump heat generated against electricity consumed
Source: Author based on (Met Eireann, 2022)

Case study II

6.4. Solar PV system design

6.4.1. Residential electricity demand

The case study II house uses electricity for geothermal heat pump, Electric Vehicle charging, lighting and household appliances, mentioned in sub – chapter 6.1.2. The monthly electricity consumption of the Case study II house according to 2020 electricity bills is 11,143 kWh/year and according to 2021 electricity bills is 17038 kWh/year. The difference between these two years electricity demand is 5,735 kWh/year. According to the conversation with homeowner, the electric vehicle (EV) was purchased in the end of December 2020. And this difference of 5735 kWh/year reflects the presence of EV since 2021. As mentioned in sub - chapter 3.3. the standard national load profile is from the year 1997 that reflelects only the lighting and household appliance electricity consumption only. Therefore it doenot reflect electric vehicle consumption and electrical demand from heat pump in its consumption pattern. Considering this reason separate hourly load profiles developed for electric vehicle charging and electric consumption from heat pump.However for the remaining household electrical load, the synthetic load profile was developed in the similar manner as described in sub - chapter 3.3.

The house owner uses a Nissan Leaf electric vehicle with a 30 kWh battery. The running mileage of the vehicle is 170 km per complete charging of the battery (Electric Vehicle Database, 2021). The owner uses this car during weekdays to commute to his workplace located 78km away from his house. Hence, the total traveling distance is 160km which requires approximately one charge per day after considering battery capacity degradation. As the homeowner explains, the vehicle connects to the home charging port for approximately 10 hours in the evening from around 18:00 every Monday, Wednesday, and Thursday. However the charging of the vehicle happens in day time on Saturday. It was assumed the EV charging on Sunday start from 12 pm noon for consuming PV electrcity. After looking at this EV charging pattern, estimated electricity consumption is 5,790 kWh for EV charging, the vehicle goes for upto 16 full charge per month. In addition, hourly load profile for electrical consumption from heat pump developed in sub-chapter 6.3 was considered for the further calculation. The total annual electrical consumption from heat pump is 5,753 kWh/year. The light and household appliance electricity consumption was estimated as 5,335 kWh/year after introducing energy efficient measures. The estimated total electricity of the case study house is 16,878 kWh/year. Figure 6.9 shows the montly consumption pattern of the house.

Case study II

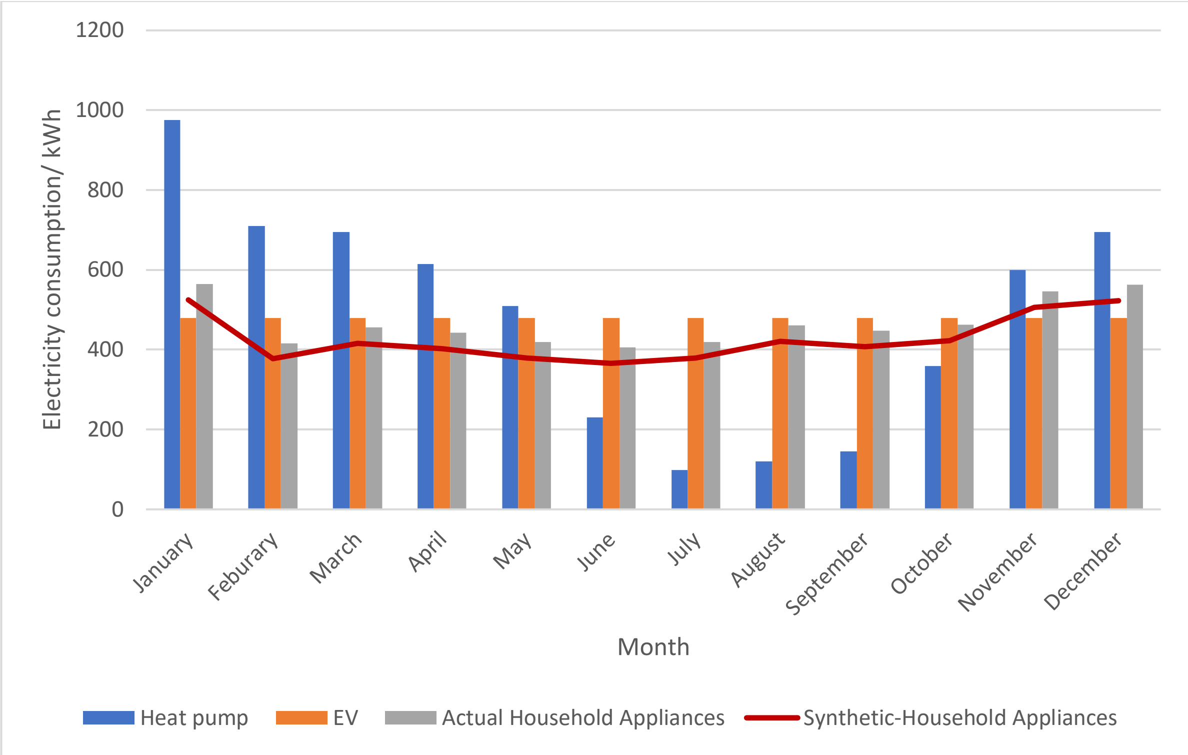


Figure 6.9: Electricity consumption pattern
Source: Author based on (Ricardo, 2020a)

6.4.2. Solar electricity generation

The Global Horizontal Irradiance of the case study II house location is 983.7 $kWh/m^2/year$, and the total electric energy generated by a $1kW_p$ solar PV at 36^0 optimal tilt angle is 943 $kWh/year$

6.4.3. Solar PV System Design

The solar PV system for the case study II house was designed without a battery storage system and with a battery storage system. The best suitable PV system for the case study house II was selected using the Homer Pro optimization tool. The system was optimized based on two criteria. The system is sized based on the lowest Cost of Consumed Electricity (COCE) compared to the considered electricity tariff of 24.70 cent €/kWh. Then, system integration is considered to obtain maximum renewable penetration for house electricity consumption. All possible system configurations based on the market available battery storage capacities are tabulated in Table 6.4 The performance of each system is illustrated in *Figure 6.10* As per the optimization results, a 5.63 kW capacity solar PV system with 2.4 kWh battery storage gives the lowest COCE at 22.54 cent €/kWh. This system can cater 21.3 % of annual electricity consumption using PV electricity. Thus, this system fulfils the cost-optimization and high renewable penetration criteria.

Table 6.4: Least cost PV system configurations

Case study II

Source: Author using Homer Pro optimization tool

System	PV capacity kWp	Battery capacity kWh	Initial investment €	COCE Cent €/kWh	Renewable fraction
1	5.16	-	6,748.00	22.79	17.7%
2	5.63	2.4	8,342.00	22.54	21.3%
3	6.48	3.6	9,690.00	22.90	23.8%
4	6.85	4.5	10,986	23.30	25.4%
5	6.85	6.3	11,658.00	23.40	27%

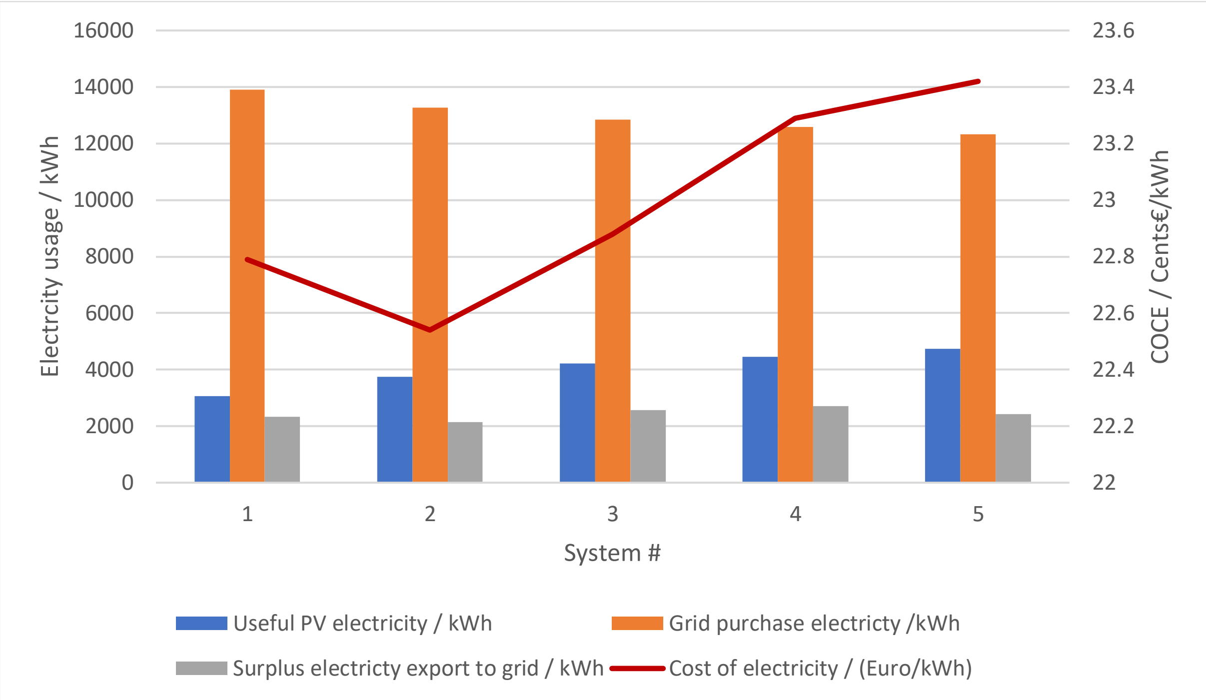


Figure 6.10: Performance comparison for the lowest COE systems

Source: Author based on Homer Pro optimization results

The system can be resized to a 5.92 kWp PV system, allowing 16 “Longi” solar PV panels with 370Wp capacity each. The peak DC power output of the system is 6.5kW on the 21st of August. All other days of the year, DC peak power output is lower than 6.5kW. Hence- the “Solis” two-string MPPT inverter with a capacity of 6kW was selected for the design with a peak DC power rating of 8kW.

Table 6.5: Electricity generation from solar PV system
Source: Author base on Homer Pro results

Case study II

System Configuration	Demand met by PV electricity (kWh/year)	Grid purchase electricity (kWh/year)	Surplus electricity to the grid (kWh/year)
5.16 kWp solar PV without battery	3103	13889	2312
5.92 kWp solar PV with 2.4kWh battery	3834	13195	2354

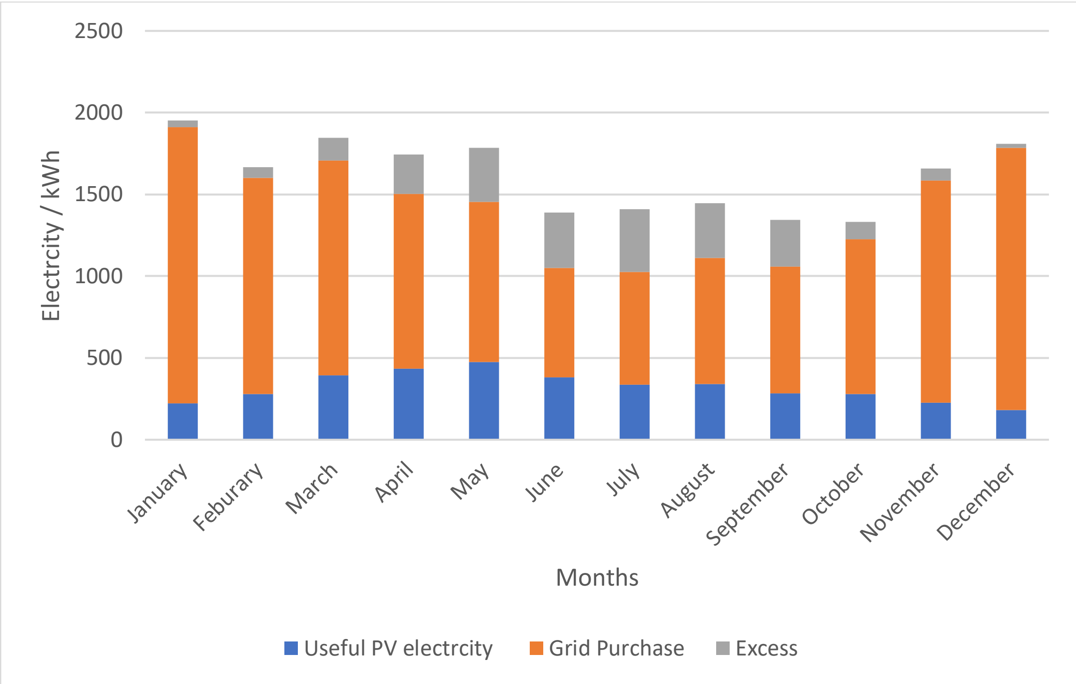


Figure 6.11: Monthly electricity generation by 5.92 kWp solar PV system with battery
Source: Author based on Homer Pro results

As per Figure 6.11 , the highest solar PV electricity penetration is May, with 475 kWh. The lowest PV electricity penetration happens in December in a total of 180kWh. Simultaneously, more than 3 kWh/month of surplus electricity generation happens from April to September..If the system can generate more electricity in winter while reducing surplus energy generation during summer would help to increase more renewable penetration. This requirement can be achieved by fixing the solar panel in deep tilt angle to get the best performance during winter season. Because in winter, the sun is low with respect to the the horizon for the northern hemisphere. In this case, putting the solar panel at deep tilt angle help to incidents the sun rays perpendicularly by increasing energy generation. However, the sensitivity analysis by changing tilt angle upto 45^0 carried out in sub-chapter 5.4.2 reflects that the PV energy yield decreases with the increased deviation from the optimum tilt angle of 37^0 in Loop head.

Case study II

Therefore, it is decided to go with the initially selected panel orientation of the tilt angle of 37º and azimuth angle of 0º from south to west.

Figure 6.12 and Figure 6.13**Error! Reference source not found.** show the time series graphs of electricity generation by solar PV array, state of charge of the battery, grid electricity purchase and electricity demand of two selected time periods of the year. Figure 6.12 show low irradiance days of the year and Figure 6.13**Error! Reference source not found.** show the high irradiance days of the year. During the low irradiance days, all the electricity demand is catered by the grid. During the high irradiance days, the battery is charged fully and start to discharge when the absence of irradiance. The battery can supply electricity to the home during the peak time until 21 hour and then grid purchase starts. As the Figure 6.13**Error! Reference source not found.** show the battery starts to drain faster because of during this time period both the heate pump operation and the EV charging happens.

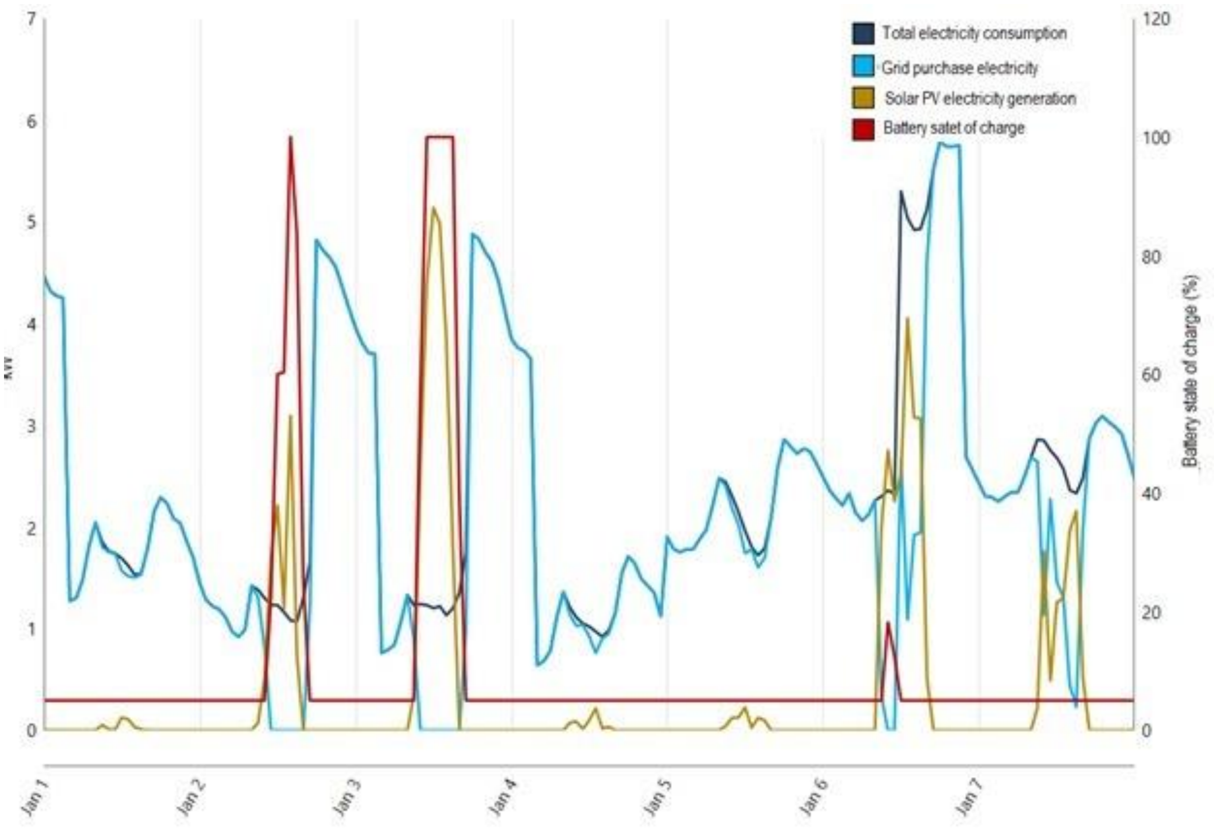


Figure 6.12: Time-series plot of PV system during low irradiation days
Source: Author based on Homer Pro simulation

Case study II

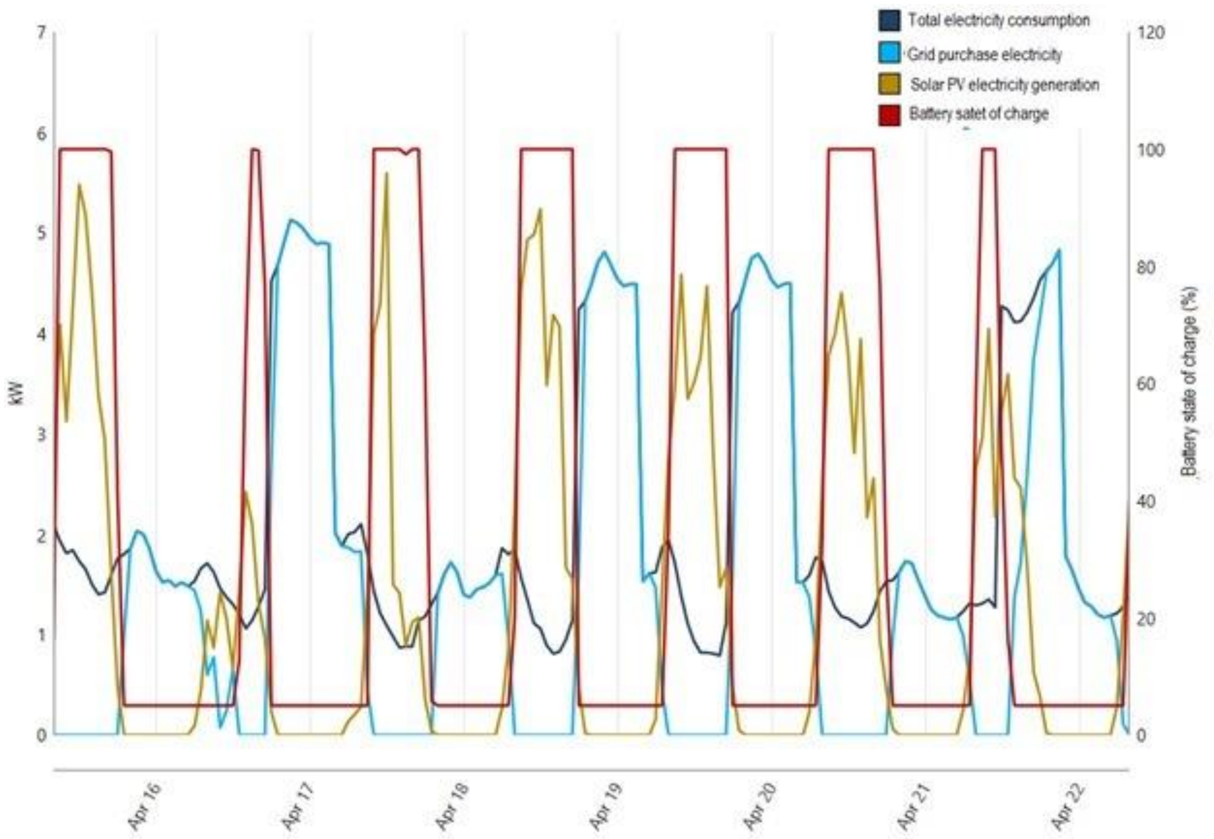


Figure 6.13: Time-series plot of PV system during high irradiation
Source: Author based on Homer Pro simulation

6.4.4. Cost-effectiveness analysis

The detailed cost estimates of the designed solar PV system with battery and without battery are presented in Annex 30 and Annex 31 The capital investment and cost of electricity produced by the design system are summarized in Table 6.6 The calculated tariff rate of the house considering the 2020 and 2021 electricity bills is 24.70 cent €/kWh. The cost of electricity generated by the proposed solar PV system varies from 20.35 cent €/kWh to 21.17 cent €/kWh and the all costs are less than the considered tariff rate of 24.70 cent €/kWh.

Table 6.6: Cost analysis summary of 5.92kWp solar PV system with 2.4kWh battery
Source: Author based on Homer Pro simulation

Grants (€)	Capital Cost (€)	COCE (cent €/kWh)
-	8,675.00	22.54
€ 2400	6,278.00	21.86

The payback period and Return of Investment of the proposed systems were calculated by considering degradation factors of the panel, equivalent annual revenue from PV electricity, system operation and meintence cost, replacement cost of battery and inverter and the discount factor. **Error! Reference source not found.** illustrates the payback period and ROI of the 5.92 kWp solar PV system with battery storage.

Table 6.7: Payback period and return on investment of 5.92kWp solar PV system with 2.4kWh battery
Source: Author based on Homer Pro simulation

Grants	Simple payback period (years)	Discounted payback period (years)	Return on Investment
No	10	11	5.2%
Yes	7	8	8.7%

The cost of generated electricity from the solar PV system changes concerning the cost of grid electricity. In the case study, it is considered the grid electricity cost as 24.7 cent €/kWh by refering the 2020 and 2021 electrcity bills. However the grid electricity price is changing in every month based on the national electricity generation mix. Hence it is meaningful to analyze the sensitivity of the system by changing the grid price within a range. For this sensitivity analysis, the low-end tariff (15 cent €/kWh), the middle range tariff (24.7cent €/kWh) and the high-end tariff (30 €/kWh) was considered based on the electricity bill provided by the case study representatives. The result of the sensitivity analysis is presented in Table 6.8 As per the data the cost of the generated electricity is low when the grid tariff is low and it increase when grid tariff goes up. Also the payback period is high for lower cost of electricity system and the ROI low. The COCE can be reduced by 0.04 cent €/ kWh for the low tariff without grants (worst case) while with a high-end tariff the cost can be reduced by 4 to 5 cent €/kWh. This happens because of lower renewable energy fraction in the system.

Table 6.8: Cost sensitivity analysis for the solar PV system with battery- Case II
Source: Author based on Homer Simulation

Scenarios	Grants	Cost of consumed electricity (cent € /kWh)	Simple Payback period (years)	ROI (%)
Low end tariff	No	14.96	20	1%
	Yes	14.27	13	3%
Middle range tariff	No	22.54	10	5.2%
	Yes	21.86	7	8.7%
High end tariff	No	26.68	8	7.5%
	Yes	26.00	6	11.8%

The same system was further analyzed considering the annual income from excess electricity sales. The feed- in tariff was considered for 15 years. Considering a feed-in tariff of 0.09 €/kWh, cost of grid electricity as 0.2407 €/kWh and SEAI grants of 2400 €. the discounted payback period of the system was reduced to 5 years from 8 years. The net cost savings due to PV energy for 5.92 KWp system with battery storage over the lifetime of 25 years was calculated to be around 13,011 € after deducting the investment and annual O&M cost of PV system.

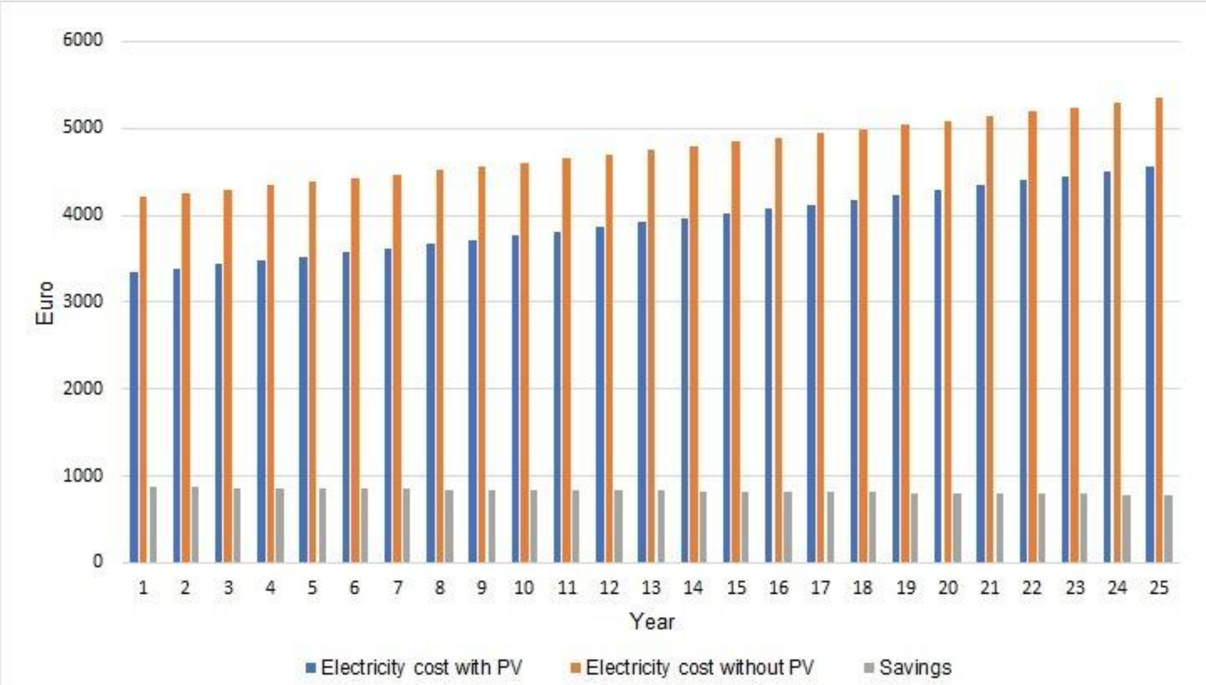


Figure 6.14: Cost savings for case study I
Source: Author based on Excel calculation

The electrical demand considered for the system design includes space heating, hot water generation, and EV charging. Hence, the excess from the PV system is directed to grid.

The overall PV sizing is done to cater to the maximum household demand at the lowest possible cost. However, due to the high electricity consumption of the heat pump and EV charging during low irradiance hours, the cost-optimized system could not serve most of the electricity demand. Nonetheless, the cost-optimized system provides considerable renewable penetration. If the homeowner wants a system with a significantly high renewable fraction then the COCE goes higher.

6.5. Summarized key findings

A finding on the booster pump mentioned in 6.1.2, disconnecting or bypassing this booster pump from the toilet flushing system and replacing halogen light with LED light can reduce the electricity consumption for this particular case study. The designed capacity of the Solar PV system as mentioned in sub-chapter 6.3 was put to the base-case scenario with exiting geothermal heat pump to consider the possible upgraded BER rate via DEAP interface (online tool). The results from the DEAP interface provided that the BER rating could be upgraded from “C1” to “B2”.

In this case, the improvement of building retrofitting could be justified as an option to increase the comfort of living. According to the DEAP interface calculation, the building refurbishment provides fewer impacts to the well-insulated building with the construction year of 2005 onward.

7. Case study III

7.1. Status quo

7.1.1. Building Envelope

The third case study building is a detached dwelling initially constructed in 1930, with a pitched roof without insulation, including a skylight, has two joints built around 1975 with a flat roof and no insulation.

The total internal gross area is 182 m^2. The house has a solid concrete floor with no underground heating and a mixture of two wall types, solid stone with 500mm thickness, concrete block with a thickness of 320 mm.

The primary space heating is an oil condensing boiler with radiators in each room. It also serves domestic water heating demands with a timer control. A wood pellet stove provides secondary heating to the living room, and a small electric heater exists. As per the houseowner , they prefer to use one electric heaters for two hours in the kitchen for added warmt. Also, one heater is used in the study room sometimes during winter. Houseowner emphasizes the lack of insulation in the house to be the casue of additional heating appliance in addition to the central and secondary space heating.

The design of the house is with four bedrooms, for a family of four (two adults and two children), one and a half bathrooms including bathtub, a living room, one storage room and two kitchens (one is of small size). The house has three chimneys and an extraction fan in the kitchen for the ventilation calculations.

Table 7.1: Default U values

Description	Value	Unit
Dwelling Floor Area	143	m^2
Total Door Area	1.85	m^2
Total window Area	25.08	m^2

Case study III

Description		Value	Unit
Fabric U-Values	Wall 1 (Stone walls, 500 mm uninsulated)	2.1[d]	$W/m^2 \cdot K$
	Wall 2 (Concrete block, 320 mm insulated)	1.64[d]	$W/m^2 \cdot K$
	Roof (No insulation)	2.3[d]	$W/m^2 \cdot K$
	Ground floor (uninsulated, solid)	0.61[d]	$W/m^2 \cdot K$
	Windows (Single glazed metal frame)	5.7[d]	$W/m^2 \cdot K$
	Windows (Single glazed wood/pvc frame)	4.8[d]	$W/m^2 \cdot K$
	External Doors (double-glazed)	3[d]	$W/m^2 \cdot K$
Appropriate default U values were used as per the year of construction values are labelled as [d]			

During the inspection of the building, the following deficiencies in the insulation of the building were found:

- Single glazed aluminium windows and doors

When examining the rooms, infrared images show heat losses through windows and doors. These losses occur due to the fact that the windows have an aluminum frame and single glazing, as a result of which they have a high thermal conductivity, which leads to heat losses. To avoid heat loss, it is recommended to replace doors and windows with energy-efficient ones, as is shown in Figure 7.1

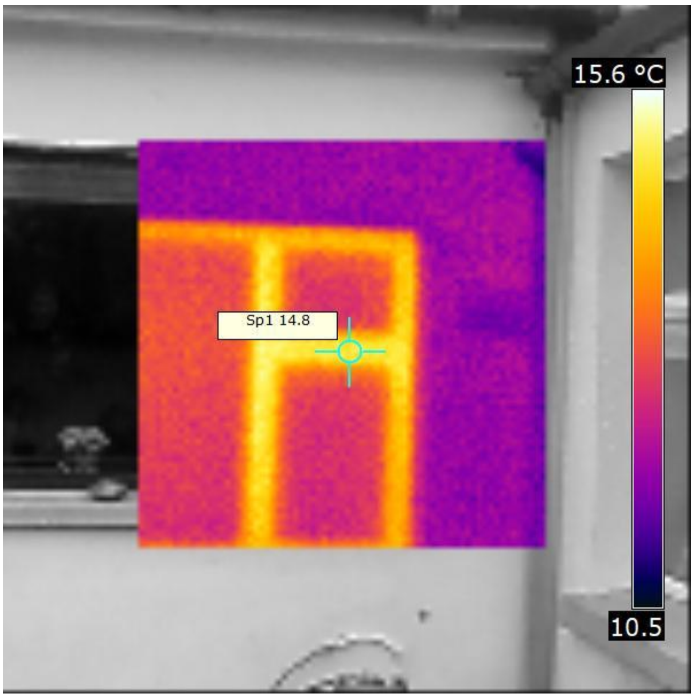


Figure 7.1: Infrared image of single glazed window with aluminium frame. Source: Thermal camera

- Uninsulated roof

Case study III

Figure 7.3 show an increase in the temperature of the roof compared to the main walls. Heat loss occurs due to the lack of roof insulation throughout the house as Figure 7.2. Roof insulation will help to significantly reduce heat loss throughout the house.

Figure 7.2 Digital image of under-roof space
Source: Author

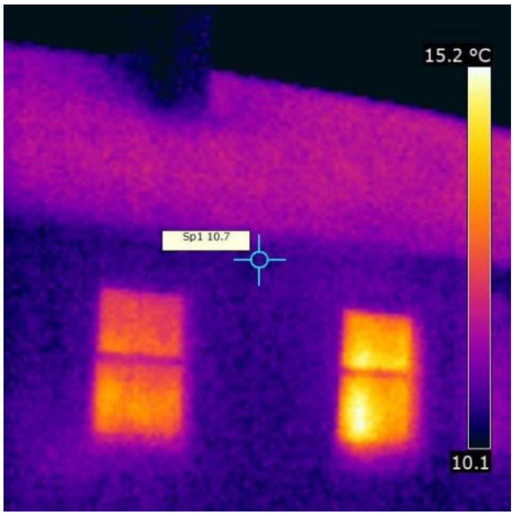


Figure 7.3 Infrared image of the house roof from the outside
Source: Thermal camera

- Uninsulated walls

The Figure 7.4 shows the temperature difference between the inner and outer wall. Insulating the outer walls will help to reduce heat losses in the house.

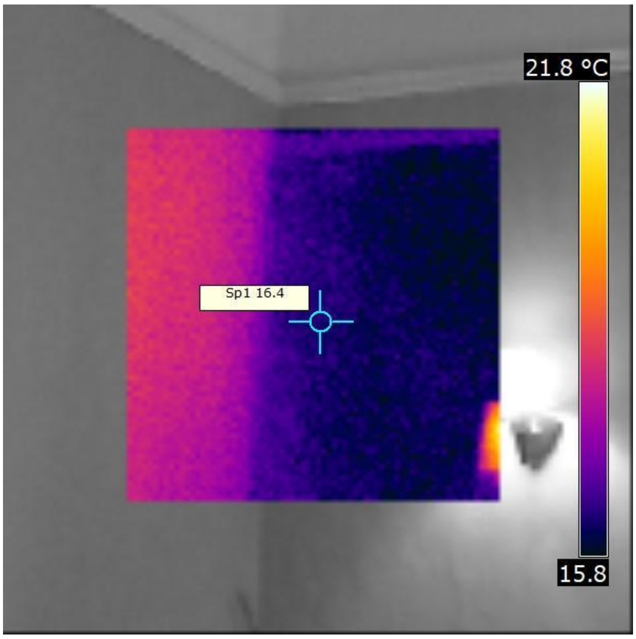


Figure 7.4: Infrared image of an uninsulated external wall.
Source: Thermal camera

Case study III

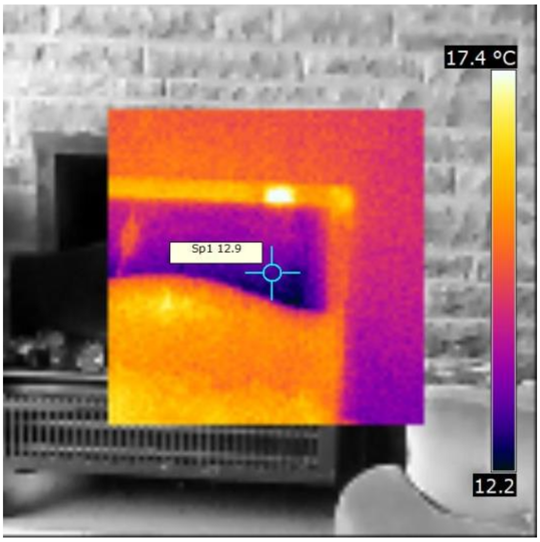


Figure 7.5: Infrared image of the unused fireplace.
Source: Thermal camera

7.1.2. Energy usage pattern

The annual electricity consumption of Case Study III in the year 2021 is 6272 kWh as per the provision of monthly electric bills. The distribution of electricity demand is seen in Figure 7.6It was observed that the highest electricity consumption was seen during winter seasons, as the dwelling relies on electric heaters and electric blankets during winter for the homeowners's comfort level as interviewed.

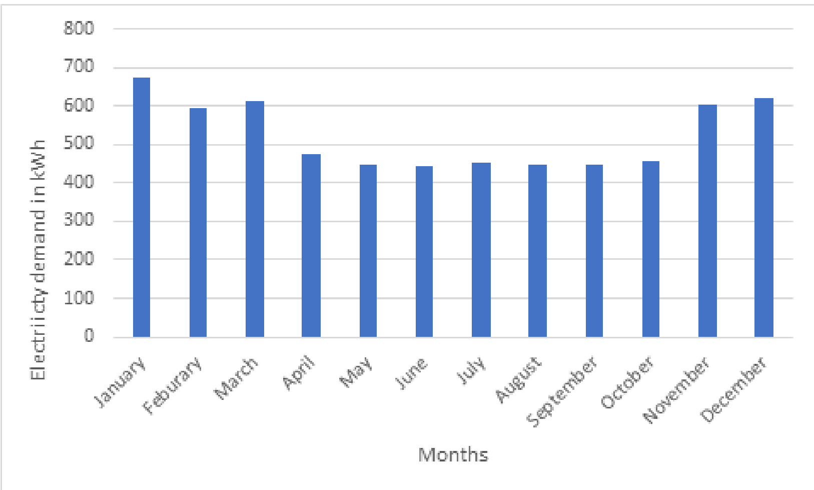


Figure 7.6: Monthly electricity consumption of case study 3
Source: Author

The end use energy breakdown is as seen as Figure 7.7 Lighting consumes 7% of the total electricity, followed by 12% of electric heater.

Case study III

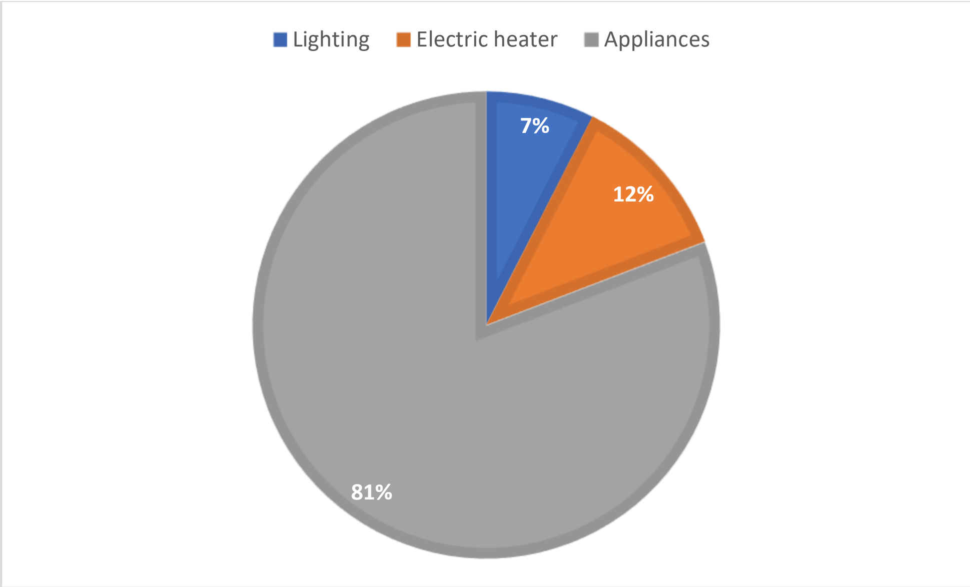


Figure 7.7: End use energy breakdown of case study 3
Source: Author

Energy efficiency measures have been applied for the current electricity demand that includes replacement of 3 Fluorescent light and limiting the use of electric heater in winter, which may reduce the annual electricity demand by 627 kWh.

7.1.3. BER Rating

The BER assessment of the original dwelling calculates in the online version of DEAP 4.2.0 Online software by SEAI. The building geometry and fabric U-values are considered according to Table 7.1: Default U values existing values) to estimate the BER rating of the building. With a primary energy use of 451 kWh/m^2/yr., the current HLI is 8 W/k/m^2 and the current BER rating of the building is “G”.

7.2. Identified energy saving measures

7.2.1. Building envelope

Since the house lacks insulation of any form, the house requires a complete upgrade to improve the energy performance of the building. The objective of the retrofit strategy applied was not only to minimize heat loss but also to increase the rating of the house to a minimum of B2 or to comply with the HLI criteria. Hence the strategies has been presented in the form of steps to present alternatives to the homeowner. The homeowners thus will have a complete picture of where they are at now and how will the insulation impact their annual energy consumption.

Case study III

Individual energy upgrade doesn't necessitate to reach a B2 level BER rating. If the homeowners wish to only improve the comfort level, the insulation of roof and walls can be done with an application for a grant from SEAI.

However, if the homeowers wish a deep retrofit strategy, it is recommended to apply the One Stop Solution Service grants. In this case, however, the house should reach a minimum B2 level after all the upgrades have been carried out.

Both alternatives are presented for the homeowners to make an informed decision.

Individual energy upgrade

Insulation of attic and walls have been considered in this case.

a) Wall insulation: Wall insulation with 100 mm of rockwool insulation will result in a U-value to 0.27. It is the standard refurbishment step of the wall as defined by TABULA (Tabula, 2014). With this step, the HLI is reduced to 6 W/k/m^2 which is 23% of the total heat loss of the base case. The BER rating of the building after wall insulation could be improved to "E2".

b) Roof insulation: As there is zero insulation in the roof, insulating the roof has the maximum savings. There is separate insulation employed for pitched roof and flat roof. According to TABULA (Tabula, 2014), the pitched roof insulation with 300 mm of mineral wool will result in a U-value to 0.13 and the flat roof insulation with 150 mm of hardrock underlay slab will result in a U-value to 0.22. These U-values were used in each case.

   By insulating the roof, the HLI is reduced to 5 W/k/m^2 and the heat loss is reduced by 37%. The BER rating after roof insulation could be "E1".

The summary of the investment cost with the simple payback is shown in Table 7.2

Table 7.2: Energy Cost Savings and payback period of insulation

Type of insulation	Grants	Total Investment Cost (Euro)	Total energy saving* (kWh/y)	Estimated annual savings (Euro/y)	BER rate	Simple Payback Period (Years)
Wall insulation	No	31,484	11,518	891	E2	36
	Yes	23,484				26
Roof insulation	No	6256	19,141	1481	E1	5
	Yes	3256				3

Case study III

* Total energy saving is delivered energy saving from primary and secondary space heating energy systems. **Replacement of doors and windows is not recommended under this scheme as there is no available grant. The annual savings is only 2,381 kWh/year with a payback period of and the payback period is more than 80 years.

It was observed that investing in roof insulation is a better option for the homeowner than investing in the walls if he/she has to choose between one of the alternatives. Insulating the roof has lower investment but the highest energy cost savings.

One-Stop-Shop Service

The One-Stop-Shop Service mandates the post- refurbishment BER rating of B2. Hence the above-recommended measures are not enough to achieve that level. Therefore, to assess the reduction in heat loss and increase in the dwelling rating, step-by-step fabric improvement was done.

Base Case: "Do Nothing" Scenario: No fabric upgrades have been considered in this scenario.

Step 1: Roof and External wall insulation

The recommendation as summarized in Table 7.2 was combined in this step. The heat loss was decreased by 62% from the base case scenario. Further, the two dormant chimneys are recommended to be sealed in this step. HLI was improved to 3.08 W/K/m^2 and the BER rating of the house could be upgraded to "C2".

Step 2: Doors and windows replaced in addition to roof and external wall insulation

The dwelling presently has thirteen single glazed windows. Therefore, it should be replaced with a windows with lower U-Values preferably highly efficient double glazed or triple glazed windows. With this step, the heat loss reduced by 67 % in total. HLI was improved to 2.68 W/K/m^2 and the BER rating of this step would be upgraded to "C1".

Advanced Refurbishment 1: 200 mm wall insulation thickness with with better material grade in addition to roof insulation, doors and windows replacement

Since Step 2 could not meet the criteria for getting heat pump grant, the wall insulation was changed to 200 mm with better material grade to see its impact on the heat loss. However, this step does not reflect considerable difference in the HLI. The final HLI of the advanced refurbishment 1 was 2.53 W/K/m^2. The BER rating of the house is still at "C1".

Case study III

Further improvement was considered to recheck HLI as lowest as possble to be eligible for heat pump grant by another advanced refurbishment as follow.

Advanced Refurbishment 2: 125 mm floor insulation thickness in addition to 200 mm wall insulation thickness with with better material grade, roof insulation, doors and windows replacement

After improved by floor insulation, the heat loss reduced by 73% in total. HLI was improved to 2.2 W/K/m^2 which now is eligible to get the heat pump grant. The BER rating of this advanced step could bring the house upgrading to "B2".

The recommended changes with the upgraded U-values are listed in Table 7.3

Table 7.3 Upgrade Recommendation with their U-Values of case study III
Source: (Tabula,2014)

Upgrade Recommendation	Upgraded U value (W/m^2·K)
300 mm of mineral wool insulation for pitched roof insulation	0.13
150 mm of hardrock underlay slab for flat roof insulation	0.22
100 mm of Grey EPS external wall insulation	0.27
200 mm of Silver EPS external wall insulation	0.15
Triple glazed Argon Low E (0.15, hard) - Wood/PVC – 16mm Gap Window	1.4
Munster Joinery GRP Joinery Door	0.8
125 mm of White EPS floor insulation (Solid Concrete Ground Floors – Insulation Below the Floor Slab) (KORE, 2022)	0.21

7.2.2. Cost analysis of Building retrofit

The range of retrofit measures chosen for the retrofit program is in line with available grants as of the current analysis time. The estimated annual savings after the fabric upgrades along with their cost breakdown is set out in Table 7.4

Table 7.4 Cost Analysis for different retrofitted steps of case study 3
Source: Author

Steps	**Grants**	**Estimated Investment Cost (Euro)**	**Total energy saving* (kWh/y)**	**Estimated annual savings (Euro/y)**	**BER rate**	**Simple Payback Period (Years)**
Step1	No	39,152	33,468	2,590	C2	15
	Yes	28,152				11

Case study III

Steps	Grants	Estimated Investment Cost (Euro)	Total energy saving* (kWh/y)	Estimated annual savings (Euro/y)	BER rate	Simple Payback Period (Years)
Step2	No	54,463	36,844	2,851	C1	19
	Yes	37,863				13
Advanced Refurbishment1	No	57,035	38,021	2,942	C1	19
	Yes	40,435				14
Advanced Refurbishment2	No	98,561	40,908	3,166	B2	32
	Yes	78,461				25
The estimated investment cost breakdown is in Annex 13						

With the advanced refurbishment 2 the dwelling can lower down the original heat demand by 76.4%. However, this holds true only when the house is actually heated to the comfort level of the house, that is have an actual demand of 53,550 kWh/year as calculated by DEAP in the base case scenario. DEAP calculation is based on standardized conditions anddoesn't account the behaviour of occupants, hence the total energy savings might differ based on the consumption behaviour of the occupants.

Considering the uncertainty by the cost estimate classification as described in sub-chapter 3.2, the uncertainty range is between a low range of -10% and a high range of 30%.Figure 7.8 **Error! Reference source not found.**shows the total investment costs and discounted payback periods, both with and without grant of each step. Giving an example, the total investment cost without grant of advanced refurbishment 1 is 57.04 thoudsand euro with the accuracy range between 51.33 to 74.15 thousand euro. The discounted payback period of this case is 23 years with the accuracy range between 21 to 30 year. On the other hand, the applicable "One Stop Shop Service" grant help reduce both investment cost and discounted payback period. The total investment cost with the applicable grants could be reduced to 40.44 thoudsand euro with the accuracy range between 36.39 to 52.57 thousand euro and the discounted payback period of this case would be 16 years with the uncertainty range between 14 to 21 year.

Case study III

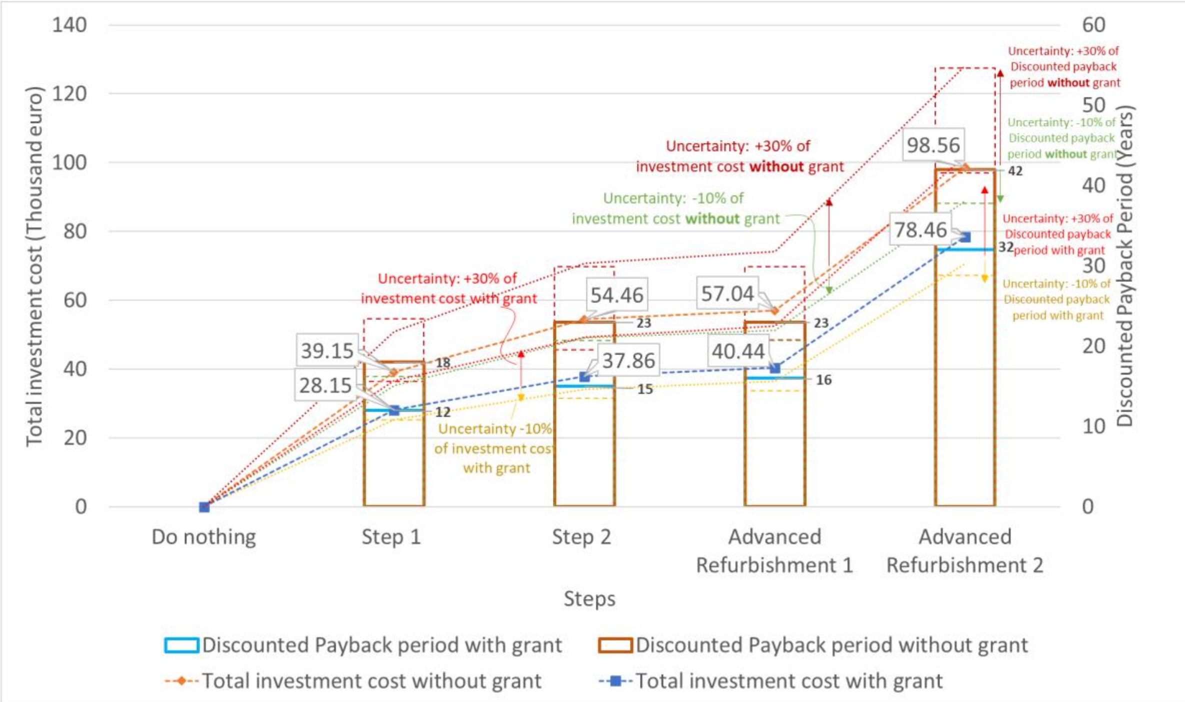


Figure 7.8: Total investment cost and Discounted Payback Period of case study 3
Source: Author

In this case study, insulating floor is an additional option for the homeowners if they wish to replace the exising condensing oil boiler to be heat pump with applicable grant for heat pump. The estimated total investment cost with grants of the advanced refurbishment 2 is the highest one among all steps between range of 70.61 to 102 thousand euro. Also, the discounted payback period with grants is the longest period which is 42 years with the uncertainty range between 38 to 55 year.

7.3. Solar PV

7.3.1. Residential Electricity Demand

After energy efficiency measures (EEM) are applied as described in sub-chapter 7.1.2 the electricity demand is reduced to 5645 kWh per year. As mentioned in methodology sub–chapter 3.3 this electricity consumption per year was used to calculate a scaling factor. Then, the scaling factor and the standard national hourly load profile based on (Ricardo, 2020b) was used to develop the synthetic hourly load profile Figure 7.9. compares the synthetic monthly load profile and actual monthly load profile. As a similar demand pattern was observed between the two load profiles, the developed synthetic load profile was used for sizing the PV system using Homer. The electricity consumption for this house is higher during the winter months from November to March at above 500 kWh per month.

Case study III

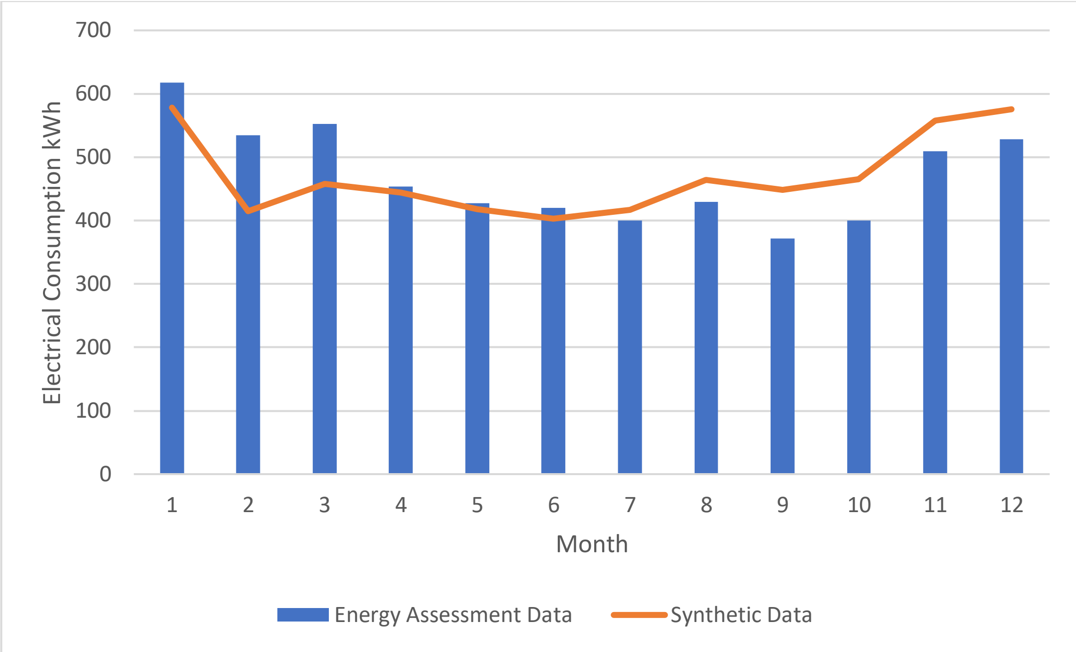


Figure 7.9: Comparison of the synthetic and monthly demand profile
Source: Author based on monthly bills and (Ricardo, 2020b)

7.3.2. Solar PV System Design Using Homer Pro Software:

The solar PV system for Case study III was designed for two different scenarios using Homer Pro. One system is without a battery, and another one is with a battery. The Homer optimizer was used to optimize the system for the given electricity demand and to calculate the profitability for each of the options for the owner. The system was optimized based on the two criterias. The selection is based on lowest COCE compared to the considered electricity tariff of 24.70 cent €/kWh and system integration is obtained for maximum renewable penetration. All possible system configurations based on the market available battery storage capacities are tabulated in Table 7.5 and the performance of each system is illustrated in Figure 7.10 As per the optimization results, a 4.37 kWp capacity solar PV system with three 2.4 kWh (7.2 kWh) battery storage gives the lowest COCE at 20.3 cent €/kWh with renewable energy penetration of 56.1%. However, the initial investment cost is high and this system requires three numbers of battery storage. Therefore this system is not considered for the futher calculation. A 2.83kWp capacity solar PV system without a storage has COCE of 21.4 cent €/kWh. This system can cater to 29.9% of annual electricity consumption using PV electricity. Further, combining battery energy storage of 3.6 kWh with 4.4 kWp panel capacity, the renewable energy fraction (self-consumption) increased upto 47.1%.The integration of a battery in the system will ensure reliability during the power outage at night time and increase self-consumption.

Table 7.5: Least cost PV system configuration
Source: Author based on Homer Pro Optimization tool

Case study III

System	PV capacity kWp	Battery capacity kWh	Initial investment €	COCE cent €/kWh	RE Share
1	2.83	-	3,566.00	21.17	29.9%
2	4.37	7.2	8,270.00	20.3	56.1%
3	4.4	3.6	6,449.00	22.07	47.1%
4	4.4	4.5	7,311.00	23.14	50.6%
5	4.4	6.3	7,983.00	23.59	55.0%

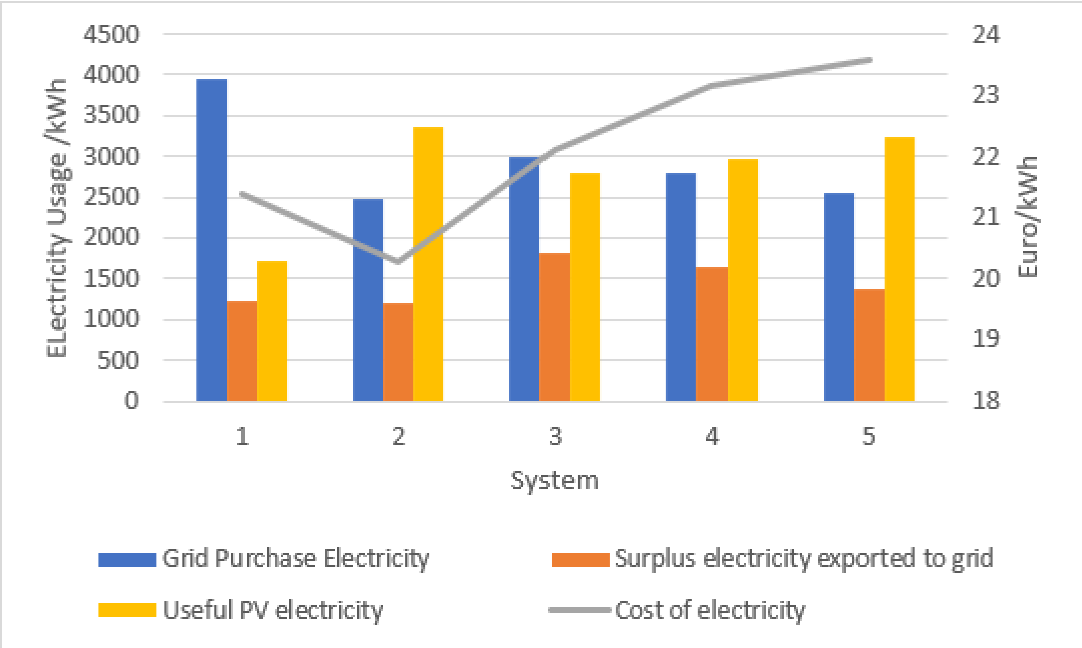


Figure 7.10: Performance comparision for the lowest COE systems
Source: Author based on Homer Pro Optimization results

The selection of the appropriate system depends upon the preference of homeowner. If the homeowner prefers the least COCE with the lower initial capital investment to cater the household demand then the solar PV system of 2.83 kWp capacity without battery storage and 3 kW inverter can be selected. The system was resized to a 2.96 kWp PV system, allowing 8 “Longi” solar PV panels with 370Wp capacity each. The peak DC power output of the system is 3.2kW on the 21st of August. All other days of the year, DC peak power output is lower than 3.2kW. Hence- the Solis mini inverter with a capacity of 3 kW was selected for the design with a peak DC power rating of 3.5 kW. The total area required for 2.96 kWp system is 17.15m^2. Using this system, the daytime household demand is covered by the solar PV electricity generation but during nighttime, when there is no output generated from the PV system, the demand is met from electricity purchased from the grid. In this case, as a battery is not used, excess electricity is being directly fed into the grid. Moreover, if homeowners want to increase renewable energy penetration and add battery backup system to the house, then 4.4 kWp solar PV system (12 solar panel with 370 watt each) with 3.6 kWh battery storage can be selected. The resized system with battery storage ensure the optimum use of all the electricity generated by the PV system. The Solis Single Phase Dual MPPT inverter of 3.6 kW was selected for the design. The selected inverter has a peak DC power rating of 7 kW. The total area required for this system is 25.48m^2. The datasheet for the panel, battery and the inverter is in Annex 19, Annex 20, Annex 21, Annex 22, and Annex 23 In this case, at first, the household requirement is served, after which the excess goes to the battery. When the battery is fully charged, the remaining electricity is diverted for domestic water heating. Finally, after all this, the remaining power is fed to the grid. Table 7.6 elucidates the output of the designed PV system, and Figure 7.11 shows the monthly electricity generation by the 4.4 kWp selected system.

Table 7.6: Electricity generation from selected solar PV system
Source: Author based on Homer Pro Optimization results

System Configuration	PV generation (kWh/year)	Demand met by PV electricity (kWh/year)	Grid purchase electricity (kWh/year)	Surplus electricity to the grid (kWh/year)
2.96 kWp solar PV system without Battery	3093	1713	3932	1335
4.4 kWp solar PV system with 3.6kWh Battery	4598	2794	2988	1804

The amount of grid-purchased electricity after including battery storage is reduced from 3,932 kWh/year to 2,988 kWh/year. The renewable fraction has increased from 30.4% to 47.1%. At the same time, excess electricity generation increased from 19% to 23.8%.

Case study III

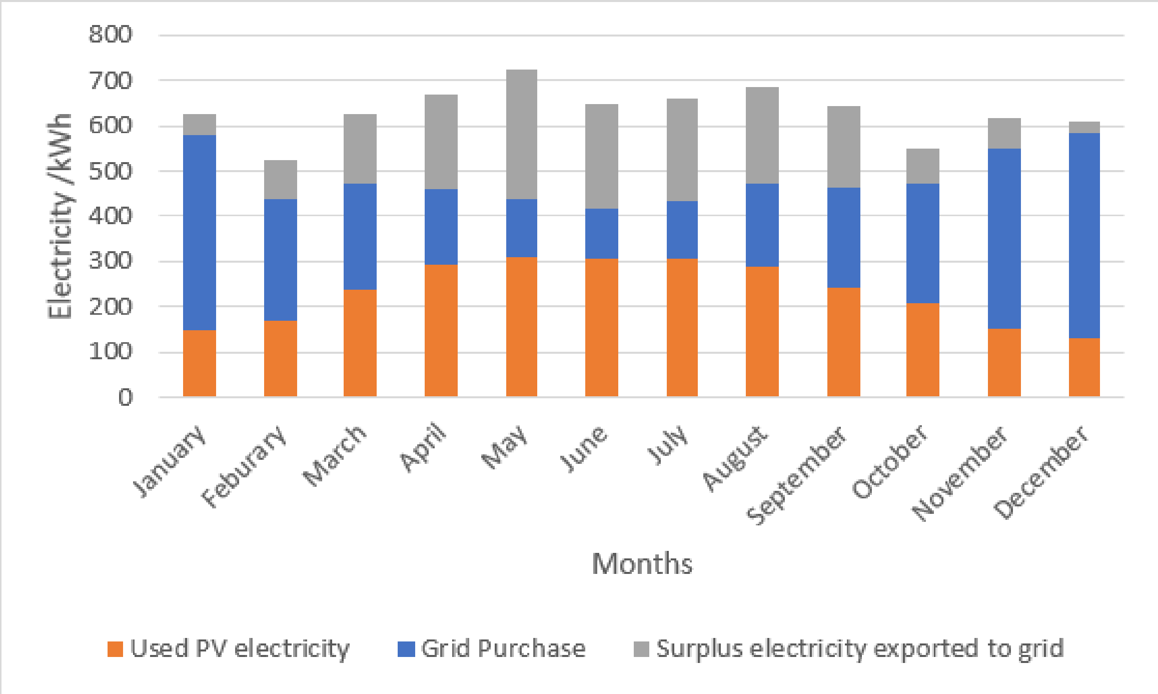


Figure 7.11: Monthly electricity generation by 4.4 kWp solar PV system
Source: Author based on Homer Pro results

As per Figure 7.11 the highest solar PV electricity penetration of 310.22 kWh is in May followed by June and July with 307 kWh and the lowest PV electricity penetration happens in December with a total of 129.3 kWh. For this case study III sensitivity analysis by changing the tilt angle was done. But as already mentioned in case study I and II the increased deviation from the optimal angle reduced the PV yield. If the system tilt angle increased from 37º to 45º, the system renewable fraction percentage decreases from 47.1% to 46.7%. And if we reduce the tilt angle from 37º to 25º, the system renewable fraction is same 47.1% but the generation from PV is less compared to 37º. Based on the sensitivity analysis concerning the tilt angle and azimuth angle, it is decided to go with the initially selected panel orientation of the tilt angle of 37º and azimuth angle of 0º from south to west.

As shown in Figure 4.14, the highest irradiance is in May. Figure 7.12 shows most of the household demand is served by the PV system and during nighttime, when there is no output generated from the PV system, the demand is met from battery storage. When the battery is completely drained demand is met by electricity purchased from the grid.

Figure 7.13 shows the load served by the solar PV system, grid purchases and the excess electricity generated throughout the year. The excess is high during the summer months (March to September) and low during the winter months (October to February).

Case study III

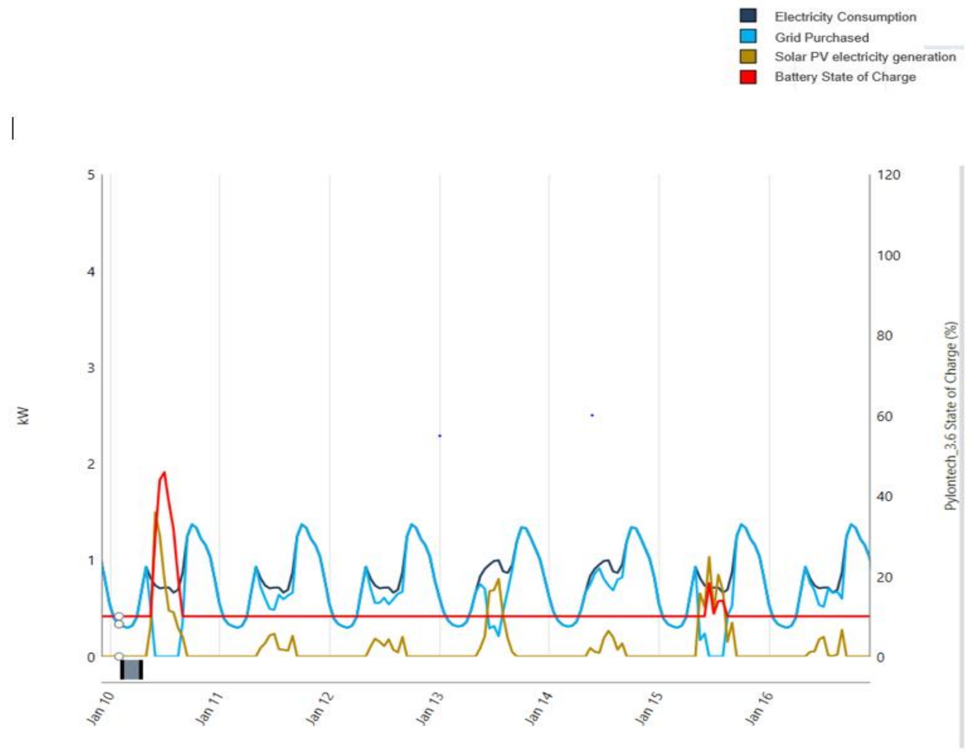


Figure 7.12: Time series plot of electricity generation and demand during lowest irradiation day
Source: Author Based on Simulation in Homer

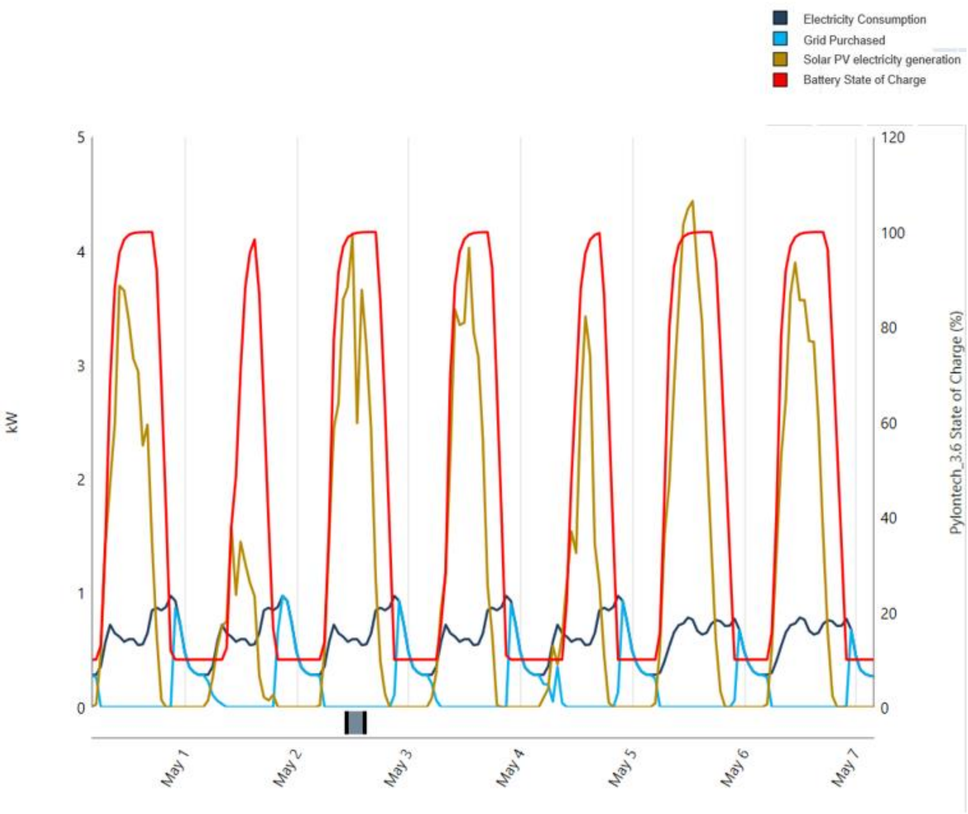


Figure 7.13: Time series plot of electricity generation and demand during highest irradiation day
Source: Author based on simulation in Homer

Case study III

Domestic hot water

Currently, the house is using a condensing oil boiler and stove for space heating and domestic hot water heating purposes. The stove is on from 9 am to 10 pm 4 days a week and for approx. 5 hours for the remaining 3 days of the week throughout the year. The water cylinder tank is equipped with a 3 kW rated immersion heater and the immersion heater is used once or twice a week to increase the temperature up to the setpoint for 30 minutes. According to this behaviour the annual electricity consumption for water aheating is 117 kWh/year. But it is a good approach to store the excess electricity generation from PV in form of thermal storage in the hot water tank. Installing a hot water diversion control will be an effective solution for operating the immersion heater during the excess electricity generation time. As mentioned in sub – chapter 3.3, for a family of four members an approximate estimate of 120 L of water at 50 ^{0}C daily consumption is assumed. The diverted power was used to heat water up from water mains temperature of 10^{0}C to 50^{0}C from the water mainstemperature.This study aims to replace the fuel for the domestic hot water purpose and utilize the excess PV generation to cater the demand. The calculated electricity requirement for hot water is 2213.57 kWh/year. If the excess from the PV generation is not sufficient to cater the hot water demand then hot water storage tank draws electricity from the grid. With a PV system of 4.4 kW, 916.28 kWh/year of excess electricity can be used for hot water diversion. The remaining 888.53 kWh/year will be finally diverted to the grid.

7.3.3. Cost effectiveness analysis

The cost analysis for the above-mentioned system was carried out without grants and with grants. The cost of each component and balance of system is detailed in Annex 28 and Annex 29. All the economic parameters used for the calculation are mentioned in sub-chapter 3.3. A considered tariff rate for the electricity from the grid as mentioned in sub-chapter 3.3. is assumed for the calculation. The COCE generated by the above proposed PV system varies from 19.34 cent €/kWh to 21.12 cent €/kWh and all the costs are below the considered tariff rate of 24.70 cent €/kWh.

Table 7.7: Cost Analysis – Case Study III
Source: Author based on simulation in Homer

PV System	Grants (€)	Capital Cost (€)	COCE) (cent €/kWh)
2.96 kW (~ 3 kW) PV system without battery	-	3,706	21.12
	2,100	1,606	19.34
4.4 kW PV system With Battery	-	6,449	22.07
	2,400	4,049	20.34

Case study III

Taking into consideration the annual savings from grid electricity consumption, the degradation of the panels and a discount rate of 1.47%,the payback period and return on investment for the both the PV system without battery and with battery was calculated. Table 7.8 presents the payback period and ROI for the case study III. Based on the result,the 2.96 kW PV system with grants has the least payback period with highest return on investment.

Table 7.8: Payback period and ROI for case study III
Source: Author Based on Excel Calculation

PV System	Grants (€)	Simple Payback Period (years)	Discounted Payback Period (Years)	Return on Investment (ROI)
2.96 kW (~ 3 kW) PV system Without battery	No	9	10	6.2%
	Yes	4	5	19.7%
4.4 kW PV system With battery	No	14	16	3.1%
	Yes	7	7	7.3%

For both the system, a sensitivity analysis was conducted to investigate the different outcomes when above-mentioned assumptions vary. The grid electricity price varies everyday based on the national electricity generation mix. Therefore, it is important to identify how dependent the COCE and payback period are on the cost of electricity. To conduct the sensitivity analysis, three different scenarios were assumed. A low-end rate (15 cent €/kWh), a middle rate (24.7 cent €/kWh) and a high-end rate (30 cent €/kWh) were considered based on the electricity bill provided by the homeowner. Table 7.9 shows the results of the sensitivity analysis for 2.96 kW system without Battery storage. The COCE goes high when the cost of grid tariff increased high. The payback period is lower and ROI is higher with the increase in tariff rate. A 5 cent €/kWh increase from 24.70 cent €/kWh with grants leads to increase in COCE by 18.8%, a decrease in payback period by one year and an increase in ROI from 15.9% to 20.7%. And a 10 cent €/kWh decrease from 24.70 cent €/kWh with grants leads to decrease in COCE by 35.5%, a increase in payback period by 4 years and decrease in ROI from 15.9% to 7.2%.

Table 7.9: Sensitivity Analysis for the 2.96 kWp system
Source: Author Based on Calculation with Homer

Scenario	Grants	COCE (cent €/kWh)	Payback Period (Years)	ROI (%)
Scenario 1 (Low-end rate)	No	14.43	21	1.7%
	Yes	12.84	9	7.2%

Scenario 2 (Middle range rate)	No	21.18	10	6.2%
	Yes	19.60	5	15.9%
Scenario 3 (High-end rate)	No	24.88	8	8.6%
	Yes	23.29	4	20.7%

Table *7.10* shows the results of thesensitivity analysis for the 4.4 kW system with battery storage.

Table 7.10: Sensitivity Analysis for the 4.4 kWp system
Source: Author Based on Calculation with Homer

Scenario	Grants	LCOE (cent €/kWh)	Payback Period (Years)	ROI (%)
Scenario 1 (Low-end rate)	No	16.93	n/a	-0.9%
	Yes	14.90	25	1%
Scenario 2 (Middle range rate)	No	22.07	16	3.1%
	Yes	20.34	7	7.3%
Scenario 3 (High-end rate)	No	24.87	12	5.3%
	Yes	22.83	6	10.8%

If the LCOE is higher than the cost of electricity from the grid, then the investment in the system is not viable. When the cost of electricity is low, the investment takes a longer time to be recovered whereas when the cost of electricity purchased from the grid is high, the investment takes a short period of time to be recovered. A system with a high renewable fraction for catering the demand and a low LCOE is considered as an attractive solution.

The government of Ireland has announced the introduction of a feed-in tariff as mentioned in sub – chapter 4.6.3. Therefore, the solar PV system cost analysis was done with feed-in tariff consideration as well. The feed-in tariff is assumed to be applicable for 15 years.With a feed-in tariff of 9 cent €/kWh and grants, the payback period of the 2.96 kWp system is reduced from 5 years to 3 years. Figure 7.14 shows, the total cost saving for this system is 8,251 € and the net total saving for the system is 4,545 € over the life time of the PV system. Figure 7.15 shows the total cost saving for 4.4 kWp system is 12,359 € over a lifetime of 25 years. If the investment cost and operation and maintenance cost are deducted, the net savings from the 4.4 kWp PV system is 5,952 € over a 25 years period. The payback period is reduced from 7 years to 5 years.

Case study III

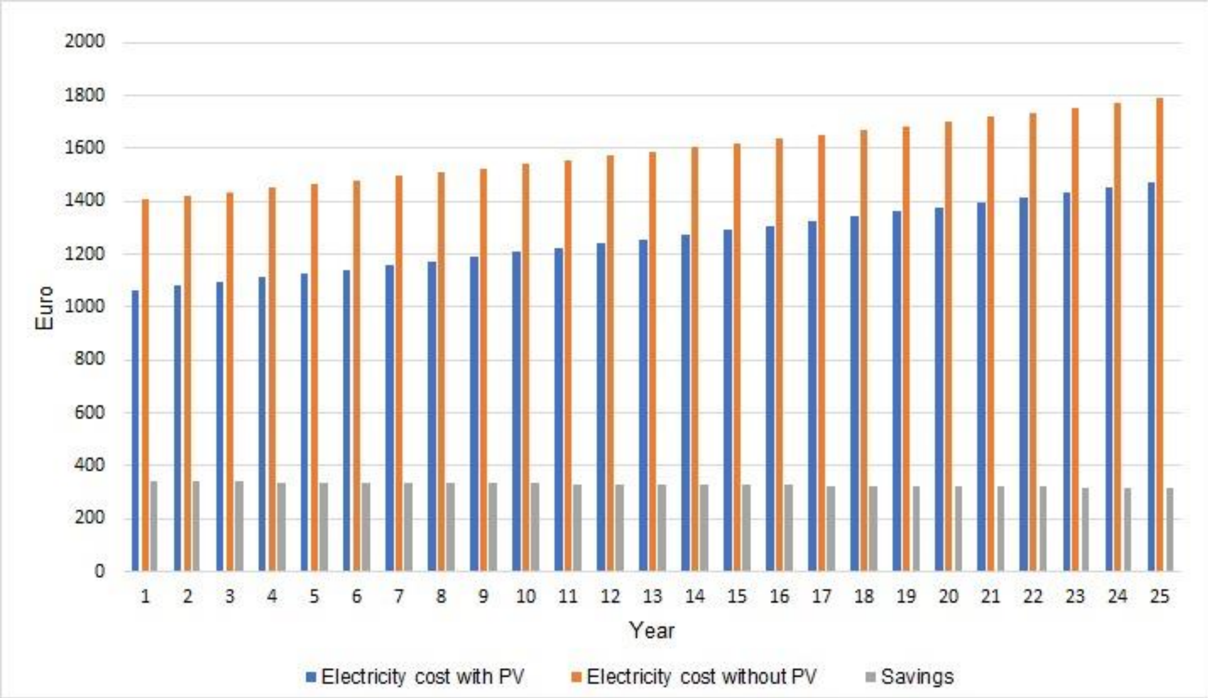


Figure 7.14: Cost saving for 2.96 kWp PV system without battery case study III
Source: Author

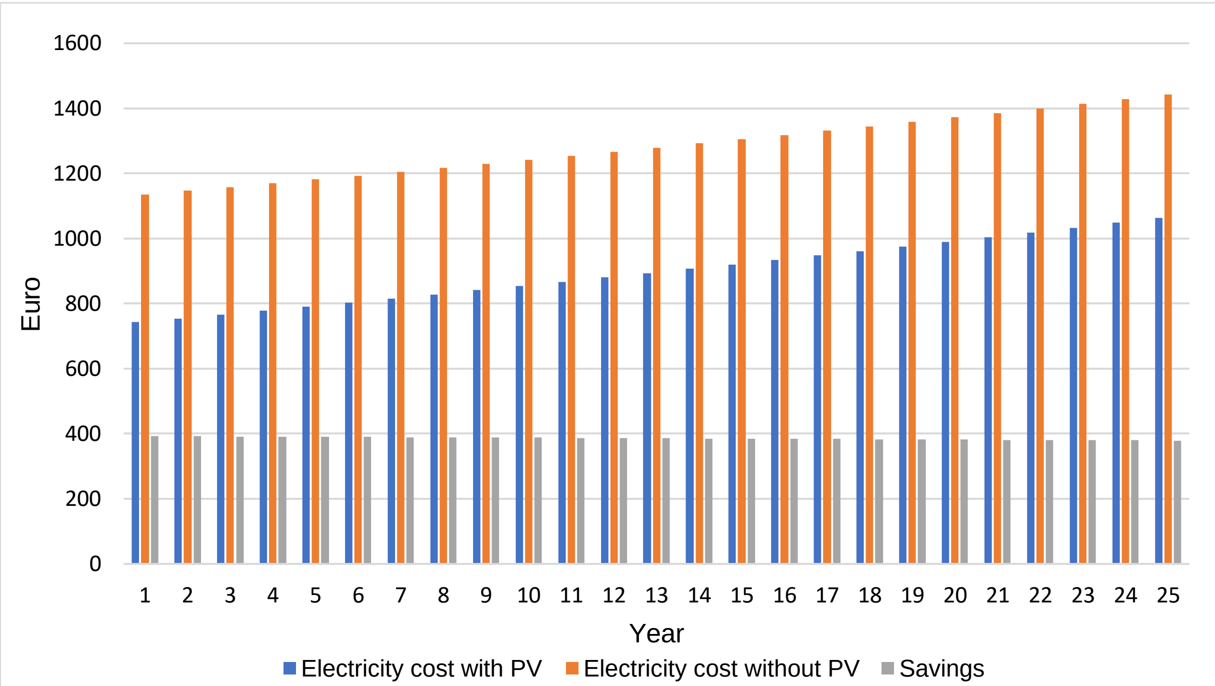


Figure 7.15: Cost saving for 4.4 kWp system with battery case study III
Source: Author

The overall PV sizing for the case study is done to cater the maximum household demand and to increase the renewable energy penetration. The net-saving is sensitive to the cost of grid electricity and feed in tariff. Therefore the change in these parameters lead to change in the net savings. The choice PV system without and with battery energy storage depends upon the preference of the homeowner based on cost and renewable energy penetration mentioned in the Table 7.7.

7.4. Summarized key findings

The designed capacity of the Solar PV system as mentioned in section 7.3 was put to the step of the advanced refurbishment as mentioned in section 7.3.1 to consider the possible upgraded BER rate via DEAP interface (online tool). The analysis was simulated based on the existing condensing oil boiler as a space heating system. The results from the DEAP interface provided that the BER rating could be upgraded from "G" to "B2" that is from 451 kWh/m^2/yr to 115.09 kWh/m^2/y with addition to Solar PV System together with Step 2 fabric upgrades. With solar integrated with Advanced Refurbishment 2 the BER rating could be further upgraded to B1 with the final primary energy of 82.80kWh/m^2/y. However,after the advanced refurbishment Step 2, the dwelling is eligible for heat pump installation, the integration of which might decrease the dwelling rating. However, heat pump sizing wasn't considered for this particular Case study.

8. Local environmental and socio-economic impacts

8.1. Life cycle assessment

8.1.1. Goal and scope

By Saleheh Rahimi

The life cycle assessment (LCA) analysis provides a clear and specific understanding of the environmental impacts of a product throughout its life cycle (Vácha et al., 2021). This chapter investigates the environmental performance of the Solar PV technology in Loop Head by focusing on analyzing solar PV technology.

The majority of life cycle assessment studies of solar PV systems show that the biggest environmental impact happens during the extraction and manufacturing phases (Ludin et al., 2018a). Therefore, a "cradle to grave" approach was set as the boundary of the system in this study. "Cradle to grave", as a partial product life cycle, is performed on a residential solar system: starting from the extraction of the raw materials phases up until the usage phase. Therefore, environmental impacts were assessed from raw material extraction and processing (cradle), product manufacturing, distribution, the operation and usage of the solar PV system, until the end of its life cycle (grave).

Local environmental and socio-economic impacts

In addition, the carbon footprint of electricity generated from the current Irish generation mix as per (SEAI, 2022e) statistics, 52% of electricity generation in Ireland rely on natural gas and 42 % comes from renewables energies including a high penetration of Wind energy around 37 %, however, solar technology accounts for just a small fraction of electricity mix.) compared to the electricity generated from the solar PV system (on a household level) will be investigated.

According to the standard protocol of ISO 14044:2006, to define the goal and scope of the LCA, supply chain's processes and system boundaries should be defined (ISO, 2006) as well as a description of the functional unit and other assumptions which affect the final result (Zendehdel et al., 2020). To define the goal and scope of this LCA study, the diagram in Figure 8.1 was created to illustrate the central framework of the LCA, starting from the initial stage of the module production to the manufacturing and usage of the solar system.

In this case, the goal of the LCA is to evaluate different environmental impact categories of Solar PV systems and services in Loop Head on a household level. The analysis will investigate various impact categories which are global warming potential, acidification, and land use by quantifying all inputs and outputs of material and energy flows in each life cycle stage. Additionally, assessing the environmental impacts of such low-carbon technology is a pre-requisite step to prove and show its comparative sustainability. The aim is to inform the local community about the ultimate impact of their energy-related choices on the environment. The LCA will also highlight the carbon footprint of the PV system and its potential to contribute to CO_2 reduction when compared to the Irish grid.

In the case of manufacturing solar modules and the balance of system (BOS), the first step was to identify all the processes involved in primary and natural resources and direct and indirect energy sources. To achieve this, after the definition of the goal and perspective of the life cycle assessment, the next step was to define the scope and boundary of the system as seen in Figure 8.1.

Local environmental and socio-economic impacts

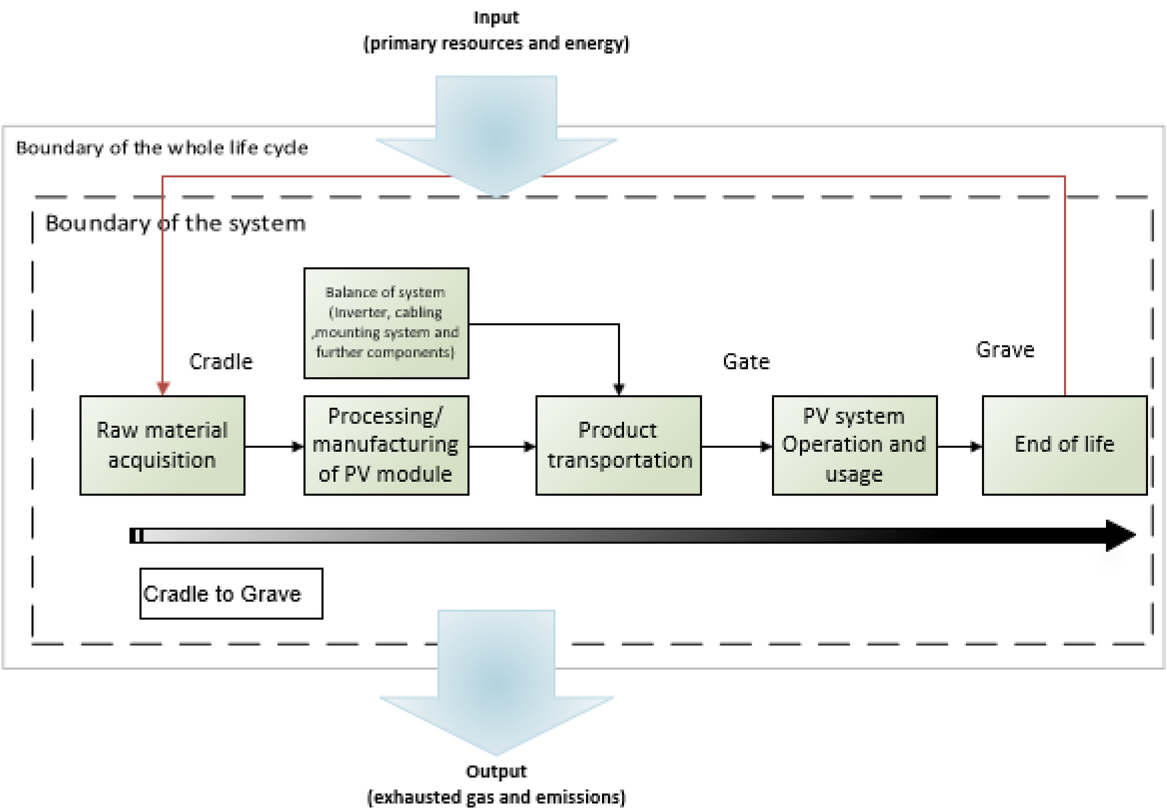


Figure 8.1: The scope and system boundaries of the solar PV life cycle analysis
Source: Author based on (Ludin et al., 2018)

While defining the scope of the LCA, the materials and energy used for the production of the PV panel, inverter, cabling, mounting system, and battery were taken into account. The recycling and disposal of the panels and other components (after end-of-life) are not considered in this study. In addition, it was assumed that after the manufacturing and packaging processes of PV panels and other components, they are transported from China to Ireland as a separate process. Other marginal and subsequence transportation such as flows between factories (e.g., between inverter and mounting system) in China were not taken into account. According to the scope of the PV system, the initial process starts from the raw material acquisition. During this process, the extraction and insertion of natural resources and energy supply are analyzed. Then, within the process of manufacturing PV modules, all the raw material acquisition, the manufacturing of silicone base PV module product, and the corresponding energy consumption are considered. Other auxiliaries such as water demand are also considered. After the production process of the PV module, manufacturing of all components in the balance of system (BOS) including inverter, cables and wires, mounting system and battery that are needed to make the PV system ready to produce electricity from sun irradiation is included in the system boundaries.

Local environmental and socio-economic impacts

Additionally, other supply chain processes including transportation of the PV products to the place of installation of the PV system, as shown in Figure 8.2, was evaluated in the final stage of the life cycle.

Figure 8.2: Transportation of solar system components from China to Ireland
Source: Author based on (Sea-route, 2021)

The scope of this work includes the LCA study of the two recommended solar PV systems from case study III (Chapter 7) and a comparison with the Irish electricity grid. This comparison helps stakeholders to analyze and interpret the environmental impacts of conventional (grid) and renewable energy resources (solar PV systems) in a comprehensive way. The following items form the boundaries of the LCA system:

- Case study III as described in Chapter 7, including solar PV system (Mono-Si panel) of 2.96 kWp without battery and solar PV system (Mono-Si panel) of 4.4 kWp with 3.6 kWh battery
- Electricity from the Irish grid

To determine the functional unit as a measurement of the system's performance, various functional units were selected based on each process output. For example, the unit of a square meter (m^2) is used to define the area of the solar module while the unit of a kilogram (kg) is used to describe the production of potteries. Also, when comparing the performance of different projects with different units, a unified unit was selected. In this case the unit of energy generation (kWh) was used for comparing the environmental impact of different configurations of the solar PV systems to the grid.

8.1.2. Methodology

By Fitri Wulandari

The LCA approach is standardized in ISO 14040:2006 Environmental Management – Life Cycle Assessment – Principles and Framework (ISO, 2006). The LCA carried out during the International Class 2022 follows this standardized approach. Figure 8.3. presents the overall methodology of this study.

Figure 8.3: LCA methodology
Source: Author

The study started with a **literature review** to understand the concept of LCA and state of the art of LCA of a PV system. The LCA was conducted using the open-source software, OpenLCA, as it does not require an additional cost for licence. Although it has a larger database and is perceived to be more user-friendly by the author, GaBi software was not chosen as it can only be utilized without charge for 30 days.

The next step was to collect qualitative data through a **site visit** to a household that already has a solar PV installed to understand the typical system in Loop Head. This phase was needed to build the LCA prototype while waiting for the calculation result from the case study presented in Chapter 7. Key parameters such as PV technology, type of system, the lifetime of solar PV, and the balance of system (BOS) were identified during this phase. In addition, the electricity production from the installed solar PV in one household was calculated and the expected electricity production for the 25 years of PV lifetime period was calculated. These key parameters were later updated using the details of the proposed technology designed for Case Study III (Chapter 7)

The **LCA study** was carried out as the last step. This step was done based on the conceptual framework of life cycle assessment defined by the International Organization for Standardization (ISO). The LCA was performed for three solar PV systems: the prototype, one system with a battery, and one system without a battery. Case study III was chosen as the representative of the systems with battery and without battery. ISO (n.d.) defines four phases for the LCA study: the goal and scope definition phase, the inventory analysis phase, the impact assessment phase, and the interpretation phase.

The goal and scope definition phase defines the stages of the life cycle included in the LCA study, which would affect the system boundary (aspects that are included and excluded from the study). The level of detail of an LCA depends on its intended use.

The life cycle inventory phase is very crucial as it determines the accuracy of an LCA study. In this phase, the inputs and outputs for the solar PV system throughout its life-cycle stages, as defined in Figure 8.1 were quantified. This includes all the materials and energy flows (inputs) as well as the waste discharged into the environment during the manufacturing process (output). For the input-output tables, this study used generic data (not directly measured or collected) as specified by the IEA PV Power Systems Programme (Heath et al., 2015) based on the specification of the Solar PV system identified during the site visit and case study III. The Ecoinvent Consequential LCI database was used as it complies with ISO 14040 and 14044. The database includes international industrial life cycle inventory data on agriculture, mining, manufacturing, energy supply, and transportation.

The life cycle impact assessment phase aimed to understand and evaluate the significance of the impacts of the Solar PV system throughout its life cycle. This study focused on two LCA indicators, which are climate change and cumulative energy demand (CED). These two indicators will be further explained in sub-chapter 8.1.5. Two impact assessment methods were used to assess the desired indicators. The first one was ILCD 2011 Midpoint+, which corresponds to the ILCD, version 1.0.9, May 2016 (European Commission, n.d.) and focuses on environmental life cycle impact assessment. The second method used was Cumulative Energy Demand by EcoInvent version 2.0. To run the calculation, the reference flow and functional unit needed to be defined. (ISO, 2006) defined reference flow as a measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit, whereas the functional unit specifies the quantified performance of a product system.

Local environmental and socio-economic impacts

In the **data interpretation phase**, the value from the climate change and the CED indicators were compared with literature values for the two solar PV systems, with battery and without a battery. The environmental impact was analysed based on units of electricity produced over the solar PV lifetime of 25 years and the total CO_2 emissions embodied in the solar PV system, measured in gCO_2/kWh. The resulting two impact indicators were further processed into energy payback times (EPBT) and energy return on investment (EROI). Furthermore, this phase would also include a system comparison of the CO_2eq between electricity generated by a solar PV system versus electricity generated by the Irish grid, measured in gCO_2/kWh to assess the potential of carbon saving by installing solar PV at the household level.

Limitation

Due to time and resource constraints, the study faced limitations and undertook assumptions that will be described in the following paragraphs. This study emphasized the impact at the production stage. The construction and installation process as well as operation and mainteinance were not considered to be negligible for household systems. The main limitation of this study is related to data uncertainties. The quality of an LCA relies on the compiled data from various sources during the lifecycle inventory phase. It is not possible for the collected data to be accurately representative of the specific two cases (with battery and without battery) that were being analysed. This study assumed that all manufacturing processes of the different solar PV system components happen in one place in China, hence transportation during the manufacturing process was not considered. In addition, this study also did not include infrastructure during the manufacturing stage as an input as it is considered to be negligible.

Possible replacements of the components as well as impacts related to the operation and maintenance during the lifetime of the installation, were not considered. The electricity mix used in the manufacturing process is based on the available electricity generation mix available within the database; hence, this study did not use the specific electricity generation mix from when the components were manufactured. Furthermore, the calculation of electricity produced did not include losses reported by the panel manufacturer. Losses caused by other components within the solar PV system were also not included. Some inputs, such as integrated circuit, sewage, PV cell production effluent, were defined as new flows as they were not available within the database. Sub-chapter 8.1.6 will discuss how to address these limitations in the future.

8.1.3. Life cycle inventory analysis

By Philip Miltrup

Local environmental and socio-economic impacts

To achieve the objectives of the study defined in chapter 8.1.1, a collection of all necessary data is required. This data collection is also defined as inventory, more precisely as lifecycle inventory (LCI). According to ISO 14040:2006, LCI is an inventory of input and output data related to the system studied, in this case, the PV system. For the LCA, all environmental inputs and outputs that occur during the life cycle of the PV system must be considered. These inputs/outputs can represent, for example, the energy required for the manufacture of products or the demand of raw materials for production. Furthermore, the LCI analysis requires input/output elements such as emissions. These are, for example, emissions to air, emissions to water, or emissions to soil. Additionally, other releases to the environment are considered in the inventory.

To determine the PV inventory, a flowchart was created first to define the individual processes of the system and the system boundaries. A simplified flowchart of the analyzed processes and their inputs and outputs is shown in Figure 8.4

Local environmental and socio-economic impacts

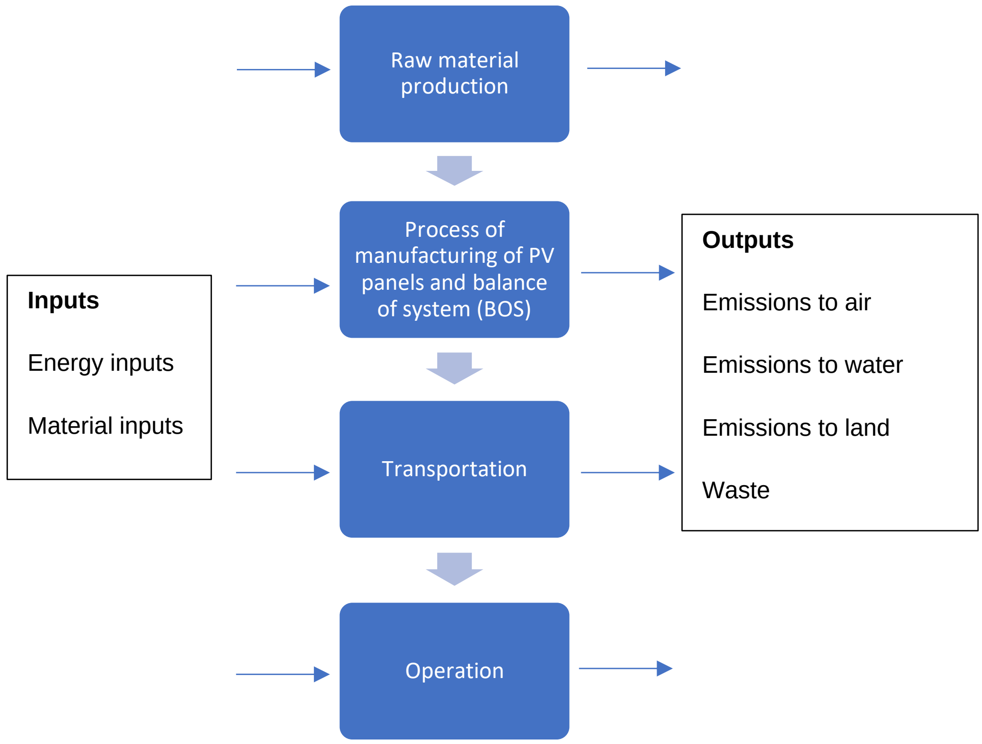


Figure 8.4: Simplified process flow diagram of an LCA for a PV system
Source: Author

PV modules

Case study III (Chapter 7) consists of two different system sizes. The system without a battery consists of a total of 8 monocrystalline Longi solar panels with 370 W each and has a capacity of 2.96 kWp. The system with a battery has a capacity of 4.4 kWp and consists of a total of 12 solar panels with the same rated power, from the same manufacturer. For the manufacturing of the PV modules, the process steps in Figure 8.5 were taken into account. Since the case studies conducted exclusively use monocrystalline PV modules, only the input/output data of this module type was used. Module production essentially consists of five process steps, which are carried out in China for module manufacturer Longi. However, in the OpenLCA software, the basic silicon products have been divided into further sub-processes, as these

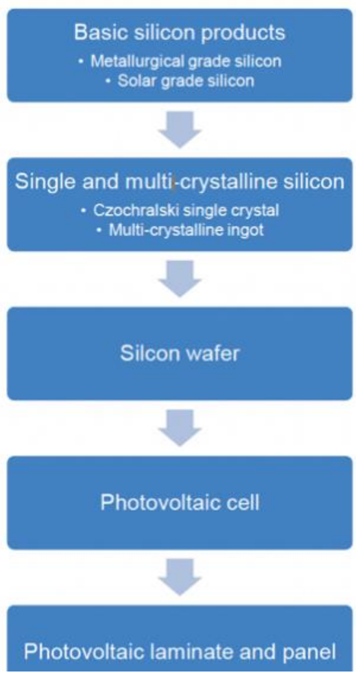


Figure 8.5: Supply chain of sillicon-based PV electricity production
Source: (Frischknecht et al., 2020)

products are divided into three sub-processes according to (Frischknecht et al., 2020). This includes the production of metallurgical (MG) silicon and solar grade (SG) silicon as well as the silicon production mixes for China.

Figure 8.6 shows an example of the input/output data for the production of SG silicon for monocrystalline PV modules. To produce 1 kg of SG silicon, 1.13 kg of MG silicon is required from the preceding process. For the MG silicone to be processed in the example, energy in form of electricity (49 kWh) and heat (28 MJ) is used to produce the desired end product of this process with the addition of hydrochloric acid, liquid hydrogen and sodium hydroxide. It can be seen in the outputs that most of the emissions for the production of SG silicon are emitted to air and water. Based on this approach, the input/output data for all processes of the PV life cycle were defined, except the battery manufacturing.

Inputs

Flow	Category	Amount	Unit
electricity, medium voltage	351:Electric power ge...	49.00000	kWh
heat	Energy carriers and te...	28.80000	MJ
hydrochloric acid, without...	201:Manufacture of b...	1.60000	kg
hydrogen, liquid	192:Manufacture of r...	0.05010	kg
MG Silicon (module stage 1.1)		1.13000	kg
sodium hydroxide, without...	201:Manufacture of b...	0.34800	kg

Outputs

Flow	Category	Amount	Unit
AOX, Adsorbable Organic H...	Emission to air/unspe...	1.26000E-5	kg
BOD5, Biological Oxygen De...	Emission to water/fossil-	0.00020	kg
Chloride	Emission to air/unspe...	0.03600	kg
COD, Chemical Oxygen Dem...	Emission to water/fossil-	0.00202	kg
Copper	Emission to air/high p...	1.02000E-7	kg
DOC, Dissolved Organic Car...	Emission to water/fres...	0.00091	kg
Heat, waste	Emission to air/high p...	176.00000	MJ
Iron	Emission to air/high p...	5.61000E-6	kg
Nitrogen	Emission to air/high p...	0.00021	kg
Phosphate	Emission to air/high p...	2.80000E-6	kg
SG Silicon (module stage 1.2)		**1.00000**	**kg**
Sodium, ion	Emission to water/gro...	0.03380	kg
TOC, Total Organic Carbon	Emission to air/high p...	0.00091	kg
Zinc	Emission to air/high p...	1.96000E-6	kg

Figure 8.6: Input/output data in OpenLCA for solar grade silicon production in PV module manufacturing. Source: (Frischknecht et al., 2020)

As the output product in the last module production stage (PV laminate and panel), the total module area of the respective system is finally entered as the target amount. The dimensions of the module data assumed for Case Study III (Chapter 7) are 1755 mm x 1038 mm for a 370 W module. This results in a total module area of 21.86 m^2 for the system with a battery and a total module area of 14.74 m^2 for the system without a battery.

Balance of System

BOS includes all components of the PV system, except the PV array (Irwan et al., 2016). For the BOS, the following components were considered in the case study III (Chapter 7) and added as processes in OpenLCA:

- Inverter
- Battery storage
- Electrical cables and wiring
- Mounting system

Inverter:

The input/output data for the inverter is based on the respective inverter capacity. The capacities in the IEA report range from 2.5 kW to 20 kW and are thus within the scope of the inverter capacities used for case study III. The higher the capacity of the inverter, the more materials have to be used and the more emissions are released, hence the input/output values increase. Since the case study includes a PV system with a battery and without a battery, the inverter capacities in the PV lifecycle must be adjusted accordingly. For the system without a battery, an inverter with a capacity of 3 kW was assumed and for the system with a battery, an inverter capacity of 3.6 kW was assumed. Therefore, the input/output data for these inverter dimensions were used. Since the output product is an inverter unit, i.e., a complete inverter, weight and dimensions can be neglected in the result calculation. Only the number of items has to be entered, in the case study, this is one inverter.

Battery storage:

Since case study III (Chapter 7) also includes a PV system with a battery, the battery described in (Chapter 7) was added to the PV life cycle. This is a lithium-ion battery with a capacity of 3.6 kWh. For the battery production, a predefined process from the Ecoinvent database was used in OpenLCA. The default output product is 1 kg of a lithium-ion battery. The provided Pylontech battery weighs 32 kg. Therefore, this value was entered as the target amount when calculating the results.

Electrical cables:

The wiring was defined based on the system requirements of the design defined for Case Study III (Chapter 7). A cable length of around 100 m with a diameter of 4 mm was assumed for the PV systems. This takes into account the distance between the plant and the connection point between the battery and the inverter. According to (Fouad et al., 2017), the most commonly used cables for PV cabling are made of copper. Therefore, the input/output data from (Frischknecht et al., 2020) was used for the production of copper cables in OpenLCA. However, the length of the cables can be adjusted depending on the system studied.

Mounting system:

The mounting system in the respective system of case study III (Chapter 7) is based on a ground mounting. This type of installation requires more materials compared to a roof installation since the stand must be considered as well as the concreting. In the case of roof mounting, the roof serves as a substructure for the aluminum strips, which saves material. The required input/output data were again used from IEA and include materials, packaging and transportation of mounting systems, and disposal of packaging materials. The inputs entered in OpenLCA subsequently result in an output of 1 m^2 of mounting system.

Transportation:

As mentioned in chapter 8.1.1, the transportation route of the modules is from China to Ireland. The production facilities of the Longi modules are located in Jiangsu, China, a neighboring province of Shanghai. Jiangsu's production base mainly consists of five plants, Wuxi Hydrogen Production Equipment Plant, Wuxi Wafer Plant, Taizhou Cell Plant, Taizhou Module Plant, and Jiangsu Module Plant (LONGi, 2022). The Solis inverters used are produced in Xianshan, also close to Shanghai. Therefore, for the transportation inventory, it was assumed that the modules and inverters are shipped from the port of Shanghai to Dublin. According to (SEA-DISTANCES, 2022), an online tool for calculating distances between seaports, the shipping route between the two locations is approximately 19.186 km, passing through the Suez Canal. This value is used as an input parameter in the predefined container ship transport process from the Ecoinvent database. Therefore, the consumption of the container ship, as well as the inputs/outputs do not have to be calculated or entered. According to (Pérez-López et al., 2017), transportation has already been identified as a marginal contribution (maximum 5%) to the total environmental impact of PV systems in previous LCA studies. Therefore, only the transport route from China to Ireland is considered and not the transport of raw material to the production company or transport within Ireland.

Electricity requirements

Since the production of the PV modules and inverters are executed in China, energy in form of electricity and heat from China is required for the manufacturing process. For this purpose, the predefined process of the Ecoinvent database in OpenLCA was used. The dataset describes the electricity available at the medium voltage level of the State Grid Corporation of China for the year 2014. Therefore, the transmission of 1 kWh of electricity on the medium voltage level is represented by default in the process. To ensure that the available electricity and the associated emissions from generation are as current as possible, China's generation and emissions data were compared using available data from the International Energy Agency (IEA).

China's electricity generation in 2019 was approximately 7.505 TWh, of which nearly 65 % (4.875.5 TWh) was attributable to coal (IEA, 2019). Electricity generation from oil and gas account for only a comparatively small share of 0.15 % and 2.84 %, respectively. Chinas heat generation in 2019 was approximately 1,300 TWh, of wich 85% (1300 TWh) was attributable to coal, 11.2 % (171 TWh) to gas and just under 3 % (44TWh) to oil (IEA, 2019). According to the IEA, China's CO_2 emissions from electricity and heat generation are mainly based on coal, gas, and oil emissions. In 2019, electricity and heat generation from coal emitted about 5,078.1 $MtCO_2$, representing nearly 97.5 % of total emissions from this energy source. Therefore, CO_2 emissions from oil and gas are neglected in this case. Hence, the production of 1 TWh results in around 1.04 $MtCO_2$. According to (IEA, 2019), the electricity and heat generation from coal in 2014 was about 4.246.9 TWh and emissions from this energy source are reported as 4.272.1 $MtCO_2$. This results in a value of 1.01 $MtCO_2$/TWh for the year 2014.

Therefore, the increase in CO_2 emissions in electricity and heat generation from coal from 2014 to 2019 is only about 3.5 %. For this reason, when considering the electricity required for the processes, the Ecoinvent dataset of available electricity from the State Grid Corporation of China from 2014 is used.

8.1.4. Life cycle impact assessment

By Munzer Osman

According to (Kun-Mo Lee, 2004a) the Life Cycle Impact Assessment (LCIA) stage is where the potential environmental effects of all the elements and flows collected during the inventory analysis are calculated. In general, the LCIA is carried out in four steps: classification, characterization, normalization, and weighting. However, the last two elements are considered optional.

In classification, as explained in (Kun-Mo Lee, 2004b), the data from the inventory analysis according to their prospective environmental impact are assigned under specific impact categories based on the cause-effect relationship (some inventory flows and elements could have multiple effects, thus classified under more than one impacts category). Based on the impact assessment used typical impact categories are defined (see Table 8.1).

Local environmental and socio-economic impacts

The second crucial stage for the LCIA is the characterization, in this step, the pre-classified inventories under different impact categories are quantified, however, to measure the potential environmental impact from different inventory parameters a unified unit is required. This unit is identified as a “categorization factor” which measures the contribution of each inventory parameter in its assigned impact category (Kun-Mo Lee, 2004a). The equivalency principle is a typical approach to define a characterization factor, for example, the environmental impact is assessed based on CO_2 equivalent, which means the effect of each of the other elements and parameters in the inventory are translated in terms of CO_2 equivalent (for instance the environmental impact of 1 g of Methane is reported as equivalent to 23 gCO_2) (Kun-Mo Lee, 2004a).

For the modeling in OpenLCA, the International Reference Life Cycle Data System (ILCD 2011 MIDPOINT+) which was released by the European Commission and the Joint Research Centre in 2012 as a lifecycle impact assessment method was used (OpenLCA, 2022). Table 8.1 illustrates the impact categories that are covered in this method:

Table 8.1: ILCD 2011 MIDPOINT+ impact categories
Source: Author based on (OpenLCA, 2022)

No	Impact category	Unit
1	Acidification	molc H+ eq
2	Climate Change	kg CO_2 eq
3	Freshwater eutrophication	kg P eq
4	Water Resource Depletion	m^3 water eq
5	Ecotoxicity, Freshwater	CTUe
6	Terrestrial Eutrophication	molc N eq
7	Human Toxicity, Cancer Effects	CTUh
8	Human Toxicity, Non-Cancer Effects	CTUh
9	Ionizing Irradiation, human health effects	kBq U235 eq
10	Land Use	kg C deficit
11	Mineral, Fossil and Renewable Resource Depletion	kg Sb eq
12	Ionizing radiation E (interim)	CTUe
13	Ozone Depletion	kg CFC-11 eq
14	Particulate Matter, Respiratory Effects	kg PM2.5 eq
15	Photochemical Ozone Formation	kg NMVOC eq
16	Marine eutrophication	Kg N eq

Local environmental and socio-economic impacts

For this case study, the environmental impact for two scenarios of PV systems mentioned in section 8.1.1 will be investigated (both installed in the same location). The following impact categories will be addressed in further detail:

Climate Change

sometimes referred to as the “Greenhouse effect”, during the various processes of the PV lifecycle, various inventory parameters release emissions to the atmosphere. Such emissions contribute to raising the temperature of the earth's surface by trapping and reflecting the radiation emitted from the earth’s surface (capturing the heat) which eventually results in raising the planet’s temperature (Brockway et al., 2019a). The global warming potential (GWP) is expressed as kilogram equivalent of CO_2 (kg CO_2 eq). Figure 8.7 shows the results from the OpenLCA modeling for the 2.96 kWp system (without a battery), the total estimated CO_2 emissions over its lifecycle were 3,108 kg CO_2 eq.

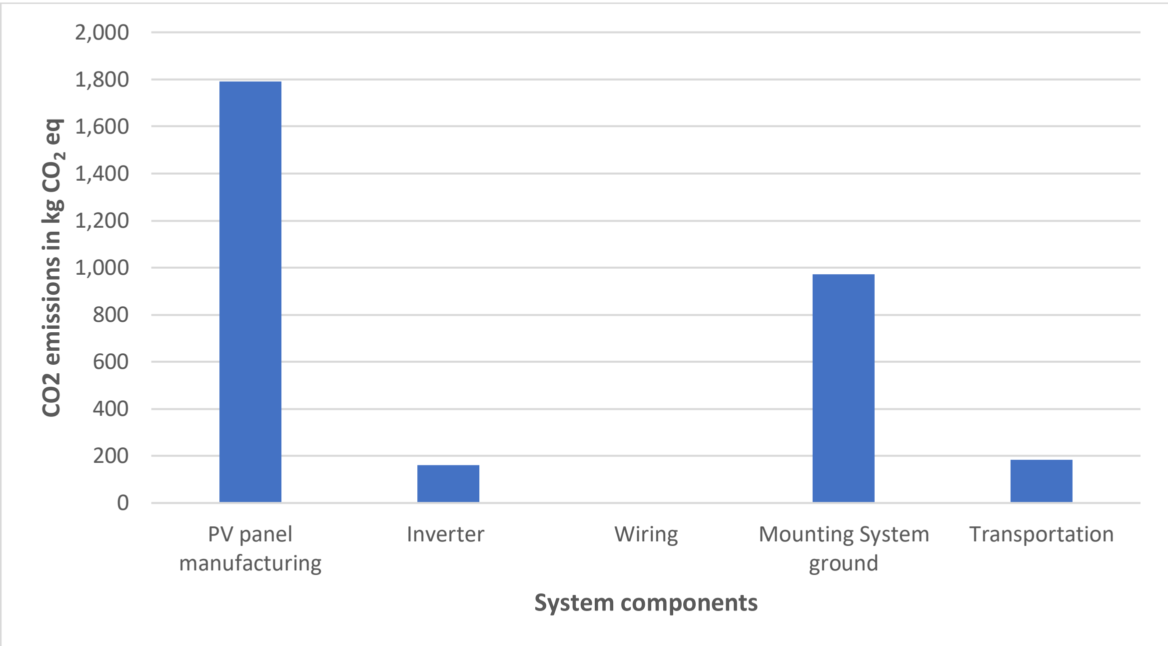


Figure 8.7: Lifecycle CO_2 emissions for the 2.96 kWp PV system components
Source: Author

As illustrated in Figure 8.7, PV manufacturing has the highest carbon footprint with 1,792 kg CO_2 eq, mainly attributed to flows of energy in the forms of coal, natural gas, and electricity required during the initial processes such as the manufacturing of the Metallurgical-grade silicon (MG silicon). According to (PV production, 2022), the MG silicon is extremely purified (98% purity) silicon that is essential in building solar cells. The process of producing MG silicon includes reaction with carbon in the forms of coal, charcoal under extreme heat in an arc furnace. The second most intensive component in terms of CO_2 emissions is the mounting system with 972 kg CO_2 eq mainly attributed to emissions from the upstream processes required to produce the necessary materials for constructing the mounting structure such as reinforced steel, concrete, and steel sections. For the inverter, the most intensive process is the manufacturing of the integrated circuits (IC), however, in this case study, the IC flows are considered as a final product at the plant, without looking at the upstream manufacturing processes. Considering the small size of the inverter the total emissions were 161.3 kg CO_2 eq. Finally, for the transportation process of the PV modules from the location of production in China to Ireland (as sea cargo), the total emissions were 182 kg CO_2 eq, mainly attributed to the fossil fuels burned in the ship engine (transportation was responsible for less than 6% of the total emissions).

Similarly, Figure 8.8 shows the carbon emissions for the second PV system (4.4 kWp, with a battery). The total CO_2 emissions from the battery used are 65.41 kg CO_2 eq, and the total emissions from the entire components of the system (including transportation) throughout its lifecycle are 4,898.37 kg CO_2 eq.

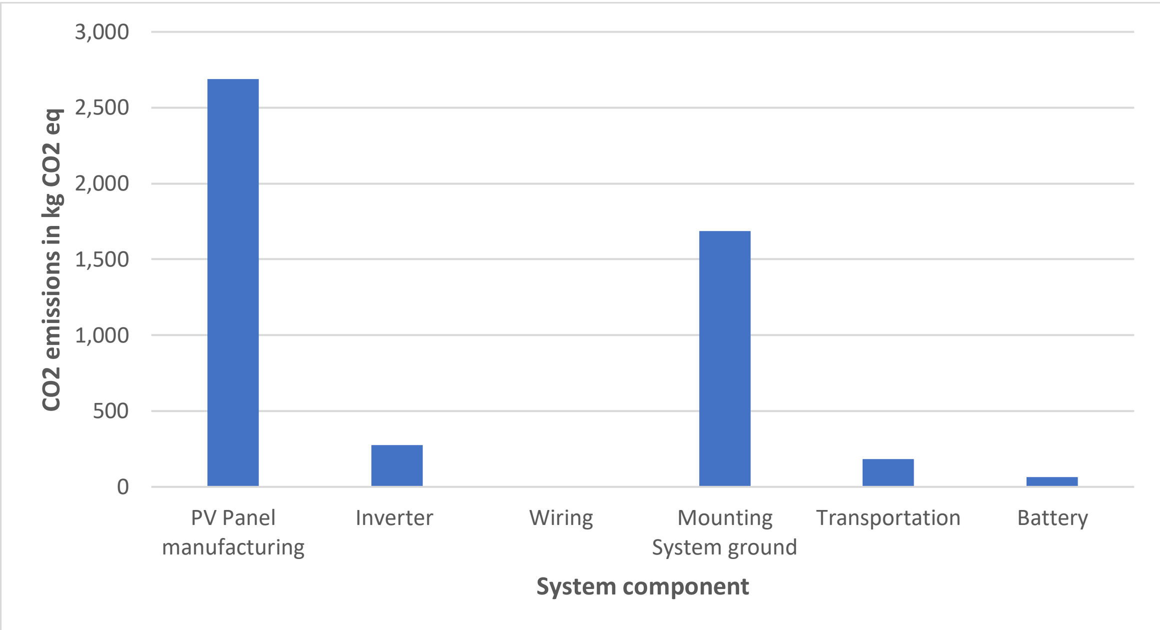


Figure 8.8: CO_2 emissions for the 4.4 kWp PV system components
Source: Author

When comparing the two PV systems, a pattern could be noticed, the PV panels manufacturing process still accounts for the largest share of the carbon footprint, followed by the mounting system and then transportation and inverter, with zero emissions from the wiring and cables. Additionally, a linear relationship could be seen. With the increase in the system size and the system components, the system boundaries changes, hence more emissions are obtained (especially for the PV panels and the mounting system).

Figure 8.9 depicts the total emissions from each of the two PV systems when compared to the Irish grid, for the same amount of electrical energy generated (assuming a 25-years lifecycle for the PV system). As shown below, in the first case (2.96 kWp), the grid emissions are 10,590 CO_2 eq which is higher when compared to the 3,108 kg CO_2 eq resulting from the 2.96 kWp PV system. The comparison is based on the amount of emission resulting from the electricity generated by the solar PV system (a total of 33,725 kWh electricity generation over the 25 years) and the total emissions to generate the same amount from the grid. In the second case, when increasing the PV system size to 4.4 kWp with 3.6 kWh battery the total renewable electricity generated is 114,950 kWh in 25 years, then the emission from the grid equivalent to generate the same amount of energy is 15,744 kg CO_2 eq compared to only 4,898 kg CO_2 eq from the PV system.

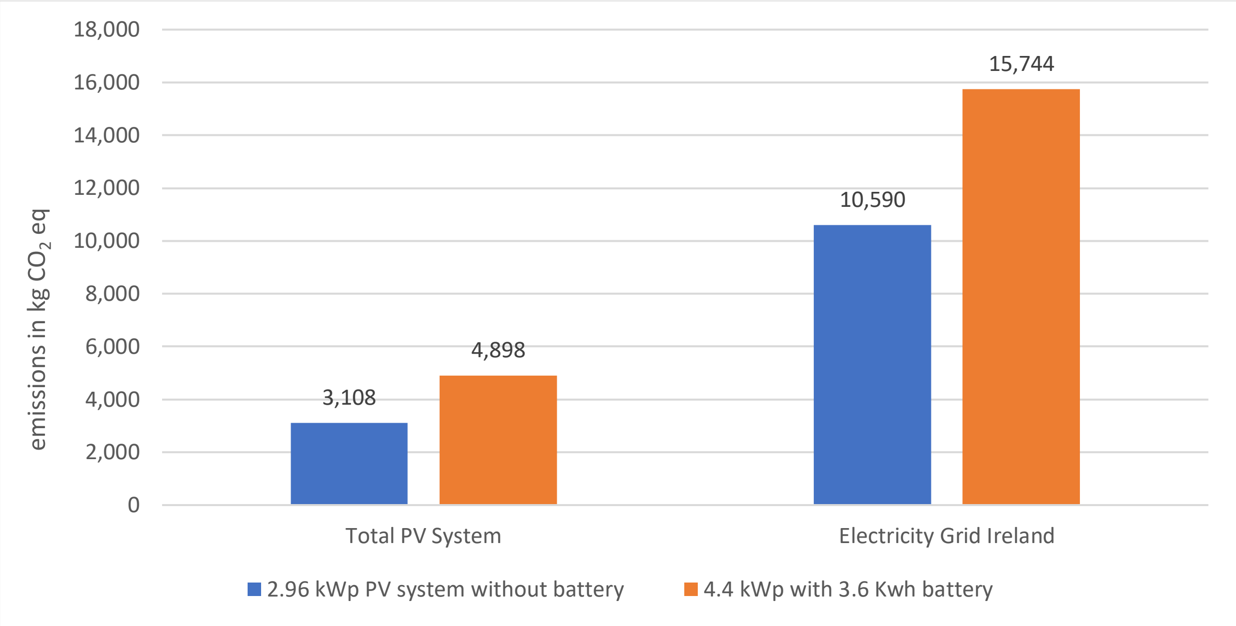


Figure 8.9: Total emissions comparison between the two PV systems and the Irish grid
Source: Author

Figure 8.9 implies that more differences in the carbon footprint between the grid and the PV system appear at larger sizes: the higher the capacity installed, the more energy obtained from the PV system, and, to produce the same amount of energy using the grid, higher emissions will be obtained.

By: Philip Miltrup

Land use

The impact category "land use" describes in the methodology of life cycle assessment (LCA) the environmental impacts of the use, transformation, and management of land for human purposes (Frank Brentrup et al., 2002). Furthermore, the land use indicator describes the impact of land use and how it is used (Aitor P. Acero et al., 2005). Consequences of land use are, for example, the reduction of landscape elements, impairment of the naturalness of used areas or the decrease in the diversity of animal species. The naturalness of an area can be defined as the sum of the areas not influenced by humans and the remaining naturalness of the used areas (Frank Brentrup et al., 2002). The ILCD 2011 MIDPOINT+ methodology used in OpenLCA uses "kg C deficit" as its reference unit and describes the deficit of soil organic carbon in kg. Equation 8.4 shows the land use comparison between a 2.9 kWp PV system without a battery and the Irish grid. As illustrated Figure 8.10, the land use of the Irish power grid is about twice as high compared to the PV system. The land use of the power grid is 7.775 kg C deficit and of the PV system 3.338 kg C deficit. The highest influencing factor on land use in the Irish grid is the conversion of mineral extraction areas. This amounts to about half of the total land use and is mainly due to the gas extraction required for electricity generation, as gas-fired electricity generation accounts for the highest share in the Irish grid. Extraction degrades the naturalness of land in use. Large areas of land are crossed by pipelines, putting a long-term strain on them for agricultural use, for example. In the entire PV system, PV module manufacturing has the highest proportion of land use with a 1.152 kg C deficit followed by the ground mounting system with a 1.071 kg C deficit. In PV module manufacturing, the largest influencing factor is the electricity from China required for the process. This is based, as described in sub-chapter 8.1.3, mainly on coal. During coal mining, large land masses are moved, which leads to a reduction of landscape elements. In addition, the mining of raw materials such as aluminum and silicone, as well as the production of solar glass, has one of the greater impacts on land use.

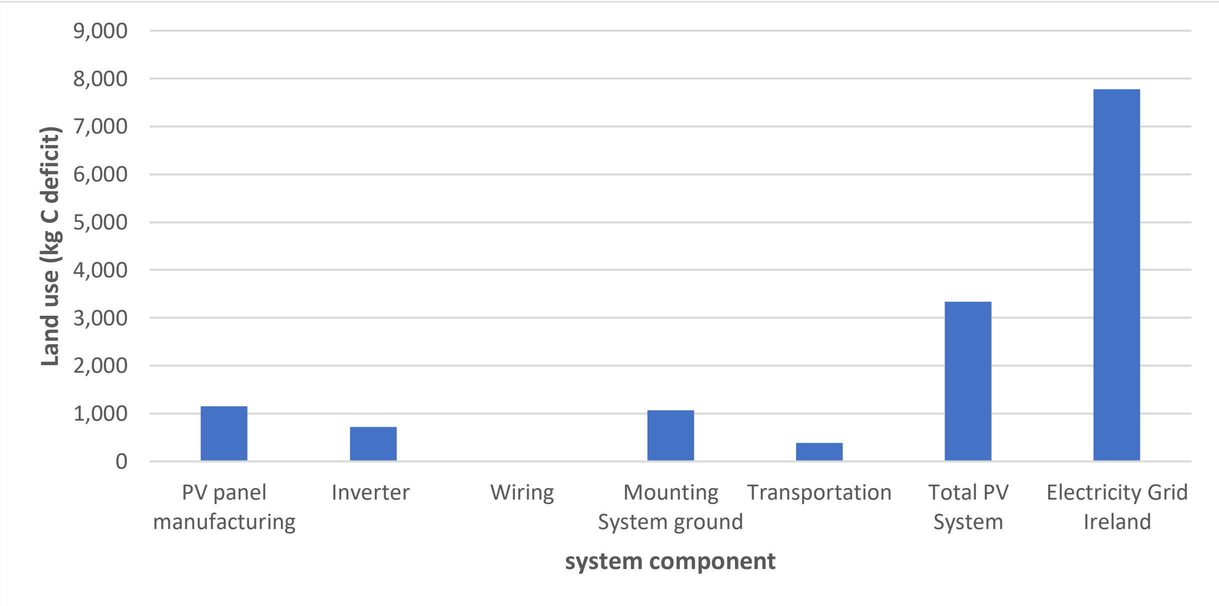


Figure 8.10: Land use comparison, 2.9 kWp without battery and Irish electricity grid
Source: Author

Local environmental and socio-economic impacts

Figure 8.11 shows the land use comparison between a 4.4 kWp PV system with a battery and the Irish power grid. It can be seen that the overall PV system has more than twice the land use relative to the electricity grid in Ireland. The land use of the PV system is 26,800 kg C deficit and the power grid is about 11,600 kg C deficit. The trigger of the high land use in the PV system is the added 3.6 kWh battery. The high land use is associated with the raw material extraction for battery production. The extraction of lithium has significant environmental impacts. According to (Joseph Zacune, 2014), the extraction process leads to water pollution and depletion. Water scarcity in turn affects land use negatively, as neighboring land areas lose fertility and food production is restricted (Joseph Zacune, 2014).

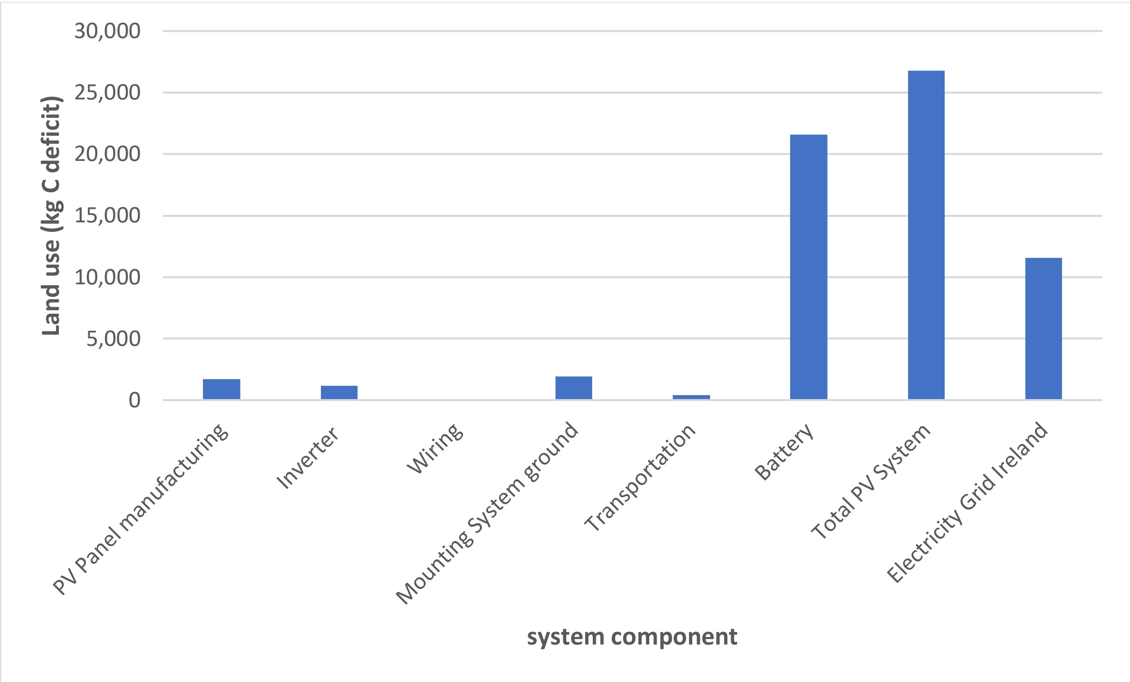


Figure 8.11 Land use comparison, 4.4 kWp with battery and Irish electricity grid
Source: Author

Acidification

During the combustion of fossil fuels, emissions are released into the air. According to the National Oceanic and Atmospheric Administration (NOAA, 2020), about 30 % of these emissions are absorbed by the ocean. Through a series of chemical reactions, sulfur oxide (SOX) and CO_2 cause the acidity of the oceans to increase. In addition, the release of acidifying exhaust gases leads to acidification of cloud water, causing precipitation to contain these acids and damage the soil. Millions of tons of SOX and CO_2 are absorbed by the ocean and land surfaces every day. Two other main contributors to acidification are ammonia (NH_3) and nitrogen dioxide (NO_2). Other compounds are of minor importance and are not considered in the recommended LCIA method. Acidification potential is expressed by the ILCD 2011 Midpoint + methodology in the reference unit "molc H+ eq." and describes the ability of substances to form H+ ions (Khalid Raouz, 2018).

Figure 8.12 shows a comparison between the acidification impact from a 2.9 kWp PV system without a battery and the Irish power grid. As illustrated, Ireland's power grid (17.12 molc H+ eq) has slightly lower acidification compared to the overall PV system (22.72 molc H+ eq). In the PV system, module production has the highest contribution to acidification with about 11.26 molc H+ eq. Aluminum alloys in particular cause high emissions of nitrogen oxide, ammonia and sulfur dioxide. According to (Hassellöv et al., 2013), international shipping has been identified as a significant contributor of SOX and NOX to the atmosphere at local, regional, and global levels. When sulfur-containing fuels are burned by container ships, SOX is produced, which is absorbed by the water and thus contributes to ocean acidification.

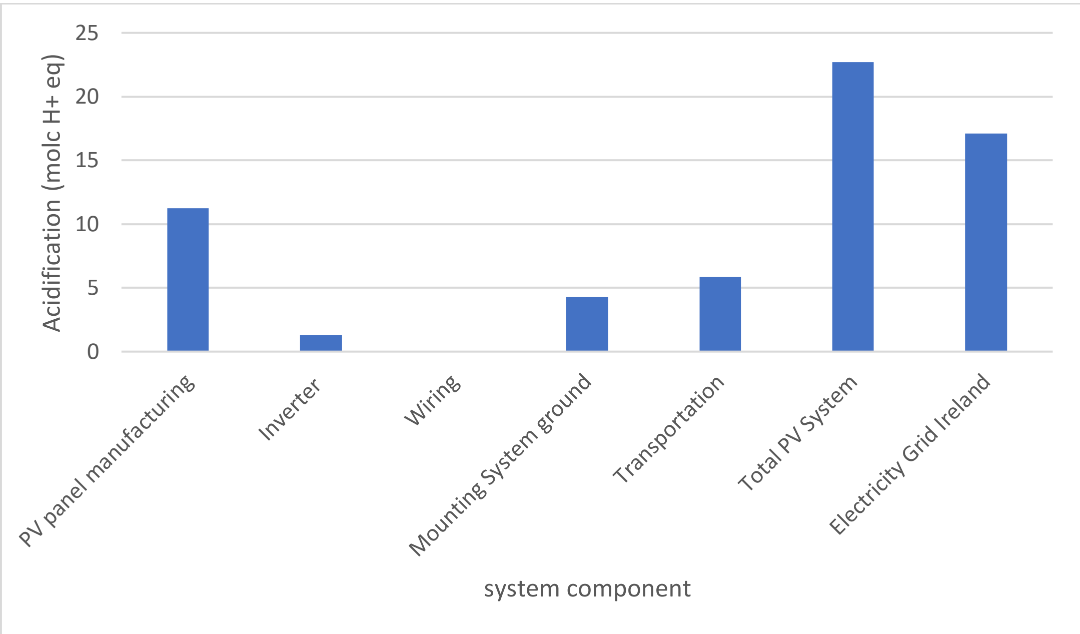


Figure 8.12 Acidification comparison, 2.9 kWp without battery and Irish electricity grid
Source: Author

Figure 8.13 shows a comparison of acidification between a 4.4 kWp PV system with a battery and the Irish electricity grid. It can be seen that in this case study, the acidification of the entire PV system is significantly higher than the Irish electricity grid. With 72.78 molc H+ eq, the acidification caused by the PV system is almost three times higher than in the case of the power grid (25.46 molc H+ eq). The main contributor is the lithium-ion battery added in the case study. The entire battery production causes significantly high acidification which is mainly due to the cathode production and the copper foil which is used as current collector (Chordia et al., 2021). However, acidification from the Chinese power grid is not negligible. Since all system components of the entire PV system are produced in China, the Chinese electricity grid contributes considerably to acidification.

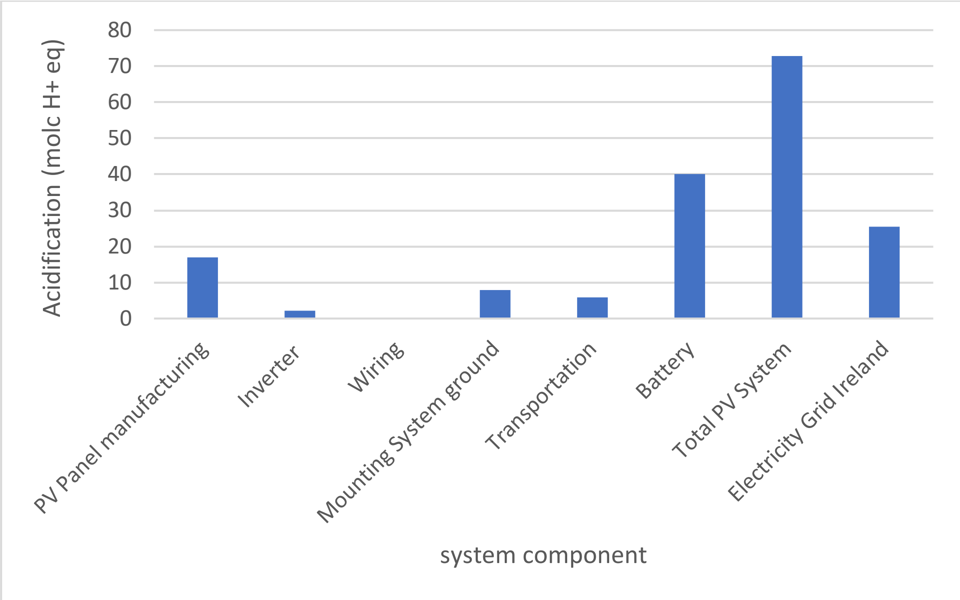


Figure 8.13 Acidification comparison, 4.4 kWp with battery and Irish electricity grid

Source: Author

8.1.5. Data interpretation

By Munzer Osman

As illustrated in sub-chapter 8.1.2, the fourth step of the lifecycle assessment study is the LCA data interpretation. The LCA interpretation is a comprehensive stage that considers all the three previous steps (goals & scope, lifecycle inventory, lifecycle impact assessment). According to (Zampori L., 2016), the LCA results interpretation provides answers to the questions raised during the first steps of the LCA study, questions such as which phase or stage of the life cycle of the PV system has the largest environmental footprint. This will help in identifying the hotspots of the system under investigation. The LCA data interpretation also discusses the limitations and constraints that might occur during the LCA inventory phase. It also discusses whether data collected to describe the different processes flows are accurate and comprehensive enough or not, because such limitations affect the final results of the life cycle assessment. Regarding the lifecycle impact assessment, the data interpretation also highlights the impact assessment method used, the different impact categories, and the process contribution trees.

Local environmental and socio-economic impacts

For the two PV systems investigated in this case study, four lifecycle interpretation indicators will be investigated:

- Cumulative Energy Demand (CED)
- Energy Pay Back Time (EPBT)
- Energy Return on Investment (EROI)
- Global Warming Potential (GWP)

Cumulative Energy Demand (CED)

The method of CED is used to assess the total primary energy consumption throughout the life cycle of the PV system (Acero et al., 2015a). Considering the stages of PV manufacturing, significant amounts of energy are utilized during the extraction and processing of raw materials, manufacturing of different components (wafer, cells, panel), transportation, and other auxiliaries related to the balance of the system (BOS). The CED method contains eight different impact categories. These categories describe the exact type (source) and amount of primary energy used, including renewable and non-renewable sources of energy to manufacture the PV system. Table 8.2 summarizes these different categories.

Table 8.2: The impact Categories of Cumulative Energy Demand (CED) method
Source:(Acero et al., 2015a)

Method: **Cumulative Energy Demand (CED)**		
Impact category group	**Name of the impact category in the method**	**Reference unit**
Non-renewable resources	Fossil	MJ-eq
	Nuclear	MJ-eq
	Primary forest	MJ-eq
	Biomass	MJ-eq
Renewable resources	Geothermal	MJ-eq
	Solar	MJ-eq
	Wind	MJ-eq
	Water	MJ-eq

The CED results differ according to the type of system assessed for the lifecycle, also it is affected by the location of production, the availability of energy sources, and the technology of production. By using the CED method, it is possible to define the hotspots of the supply chain for the system under assessment and highlight the processes that consume the most energy.

Local environmental and socio-economic impacts

For this report, the focus will be on estimating the non-renewable primary energy demand for both of the introduced PV systems (the 2.96 kWp and the 4.4 kWp with a battery).

For the 2.96 kWp system, Figure 8.14 shows the amount of the non-renewable primary energy consumption for each component of the PV system.

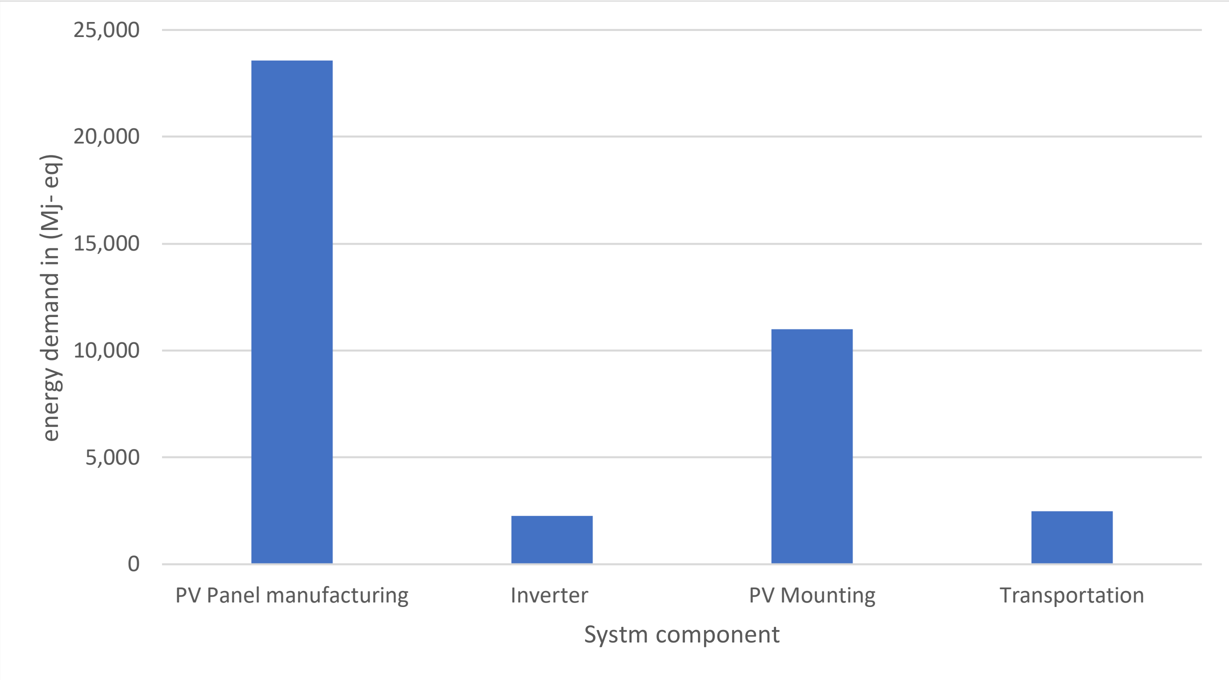


Figure 8.14: Non-renewable primary energy demand for the 2.96 kWp PV system
Source: Author

Currently, the majority of the PV modules in the market are crystalline silicon (same as the system under study is single crystalline). Both single-crystal, and multi-crystalline silicon PV panels manufacturing require using large wafers of purified silicon. The process of purifying and crystallizing the silicon are the most energy-intensive phases of the solar-cell manufacturing process (Renfrow, 2004). To obtain 77,325 kWh of electricity from the 2.96 kWp PV system, 39,320.32 MJ-eq of non-renewable primary energy is required (about 60% of this energy is required to manufacture the PV system and 27% is consumed to manufacture the mounting system). The energy is mainly consumed during the different production phases and processes, for example, the hard coal consumption during the production of the MG silicon stage as seen in the inventory flows, also the required electricity (which comes from the Chinese energy mix) to power-up the factories for the PV production, and also the energy needed for the transportation.

As a comparison, to generate the same energy from the Irish grid,195,751MJ-eq of non-renewable primary energy is required. For the 4.4 kWp PV system with a 3.6 kWh battery, the non-renewable energy demand is illustrated in Figure 8.15. Similarly, the top three energy-intensive components could be identified: PV manufacturing is consuming most of the energy with 35,374 MJ-eq, followed by the mounting system with 19,068 MJ-eq then inverter and transportation as shown below, the battery production consumes only 0.25 MJ-eq of non-renewable primary energy.

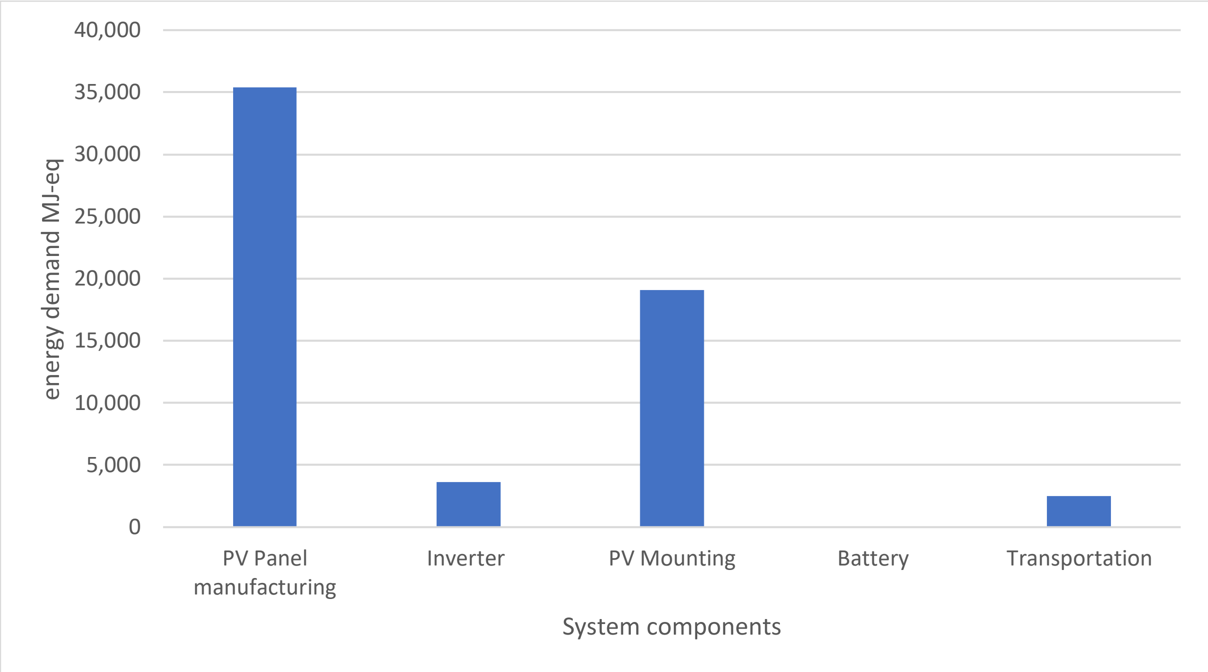


Figure 8.15: Non-renewable primary energy demand for the 4.4 kWp PV system
Source: Author

Energy Pay Back Time (EPBT)

While the CED indicator illustrated that the production of PV systems requires significant amounts of energy, the term Energy Pay Back Time (EPBT) describes how much time is required for the PV system to generate energy that is equivalent to the energy utilized to produce the system in the first place (Renfrow, 2004). The energy generated from the PV system is a crucial factor in determining the energy payback time, the higher the energy generated from the PV system the less time is needed to pay back the energy invested during the production of the PV system.

Another crucial factor in EPBT is grid efficiency (Tariq, 2019a). It indicates the conversion efficiency of primary energy to electricity (basically describing how efficient the Irish grid is in converting the various primary energy sources of the current energy mix as an input to useful electricity energy as an output). For Western Europe the grid efficiency is considered to be 31% in 2015 (Frischknecht, 2015), however, for Ireland, it is estimated to be 49.1% in 2020 according to (SEAI, 2022e).

Local environmental and socio-economic impacts

By applying Equation 8.1, the EPBT could be calculated for the two PV systems investigated in this section of the report.

Equation 8.1: Energy Pay Back Time
Source: (Tariq, 2019b)

$$EPBT = \frac{PEinv}{\frac{Epv_{gen}}{T}\ /\eta national\ grid}$$

Where:

- EPBT is the energy payback time in years
- PE_{inv} is the primary energy invested in producing the PV system
- E_{pv_gen} is the energy generated from the PV over its lifetime (electricity generated)
- T is the lifetime of the PV system
- $\eta_{national\ grid}$ is the national grid efficiency (the national power sytem for Ireland)

The total electricity generated from the PV system over 25 years of a lifetime is estimated to be 77,325 kWh for the 2.96 kWp system, and 114,950 for the 4.4 kWp system, and from the OpenLCA simulation results the total required energy to build these two PV systems are 42,029 MJ-eq and 66,525 MJ-eq respectively. By applying the EPBT equation, the EPBT for the 2.96 kWp system is 1.85 years and for the 4.4 kWp system is 1.97 years (based on the LCA results, when using the CED impact assessment method negative values/numbers for certain CED impact categories were obtained, these negative results suggested an avoided impact or saving in energy rather than consumption (Carvalho et al., 2021). Thus, these values were not considered in calculating the EPBT).

Energy Return on Investment (EROI)

EROI is a useful way to evaluate and compare energy inputs, output, and energy yield for various technologies (world nuclear association, 2020). The EROI indicator evaluates the profitability of technologies, not in terms of monetary value, rather using energy itself as an evaluation criterion. EROI could be obtained by simply dividing the energy output from the specific technology to the energy input (energy invested to obtain useful energy from the corresponding technology). A higher value of EROI implies better technology in terms of net energy profitability.

Certain technologies require a small amount of energy to extract fuels or raw materials, and to build systems that convert these fuels to useful energy, when the resulting output energy from these fuels is significant, such technologies would have a high EROI. In general, technologies such as hydroelectric and wind power plants require relatively low energy investment to construct a complete system and facilities to produce electricity when compared to other technologies that are energy-intensive during the manufacturing or the extraction of fuels such as natural gas, or oil which usually have lower EROI (CARBON BRIEF STAFF, 2013). Equation 8.2 was applied to calculate the EROI for the PV systems under study.

Equation 8.2: Energy Return On Investment
Source: (Tariq, 2019a)

$$EROI = \frac{EPV_{gen}/\eta\text{national grid}}{PEinv}$$

Similarly, as the total electricity produced by the 2.96 kWp PV system over its lifecycle is 77,325 kWh, the national grid efficiency is 49%, and the total primary energy invested is 42,029 MJ-eq. Then, the EROI is estimated to be 13.5. And for the 4.4 kWp, the total electricity produced over its lifetime is 114,950 kWh, total primary energy invested is 66,543 MJ-eq; then, the EROI is 12.3.

In general, solar PV systems have lower EROI when compared with other renewable technologies such as wind which has a high EROI value, with a mean value of 18:1 and 20:1 (Hall et al., 2014) or even 30:1 (Brockway et al., 2019b), however, for electricity generated from fossil fuels resources such as electricity generated from coal, the typical EROI is ranging between 4 and17, and for gas, it is ranging between 6 and 14 (Brockway et al., 2019b). This places renewable energies as strong competitors for traditional fossil fuels when it comes to the net profitability of energy.

Climate change potential

Increasing penetration of renewables in the Irish electricity generation mix will significantly reduce the GHG emissions in this sector. Between 2005 - 2020, Ireland increased its dependency on renewable resources from 6% to 42% (SEAI, 2022f), along with the adoption of more efficient technologies and improved conversion rates in the electricity generation sector. This led to a reduction in the carbon intensity of the Irish electricity from 636 g CO_2/kWh in 2005 to only 296 g CO_2/kWh in 2020 (SEAI, 2022f). Similarly, each kWh generated from the solar PV system placed on Loop Head will replace kWh of electricity from the Irish grid, which will further reduce GHG emissions.

For the two PV systems in this case study, and considering the different stages over the PV lifecycle, the total GHG emissions per unit generated (emission factor) could be calculated by dividing the total emissions produced over the lifecycle of the PV system (emissions released during material extraction, processing, manufacturing, and transportation) by the total electricity produced over its lifecycle as illustrated in Equation 8.3.

Equation 8.3: Emission factor
Source: (Tariq, 2019a)

$$Emission\ factor = \frac{total\ GHG\ emissions\ in\ CO2\ eq\ over\ its\ life\ cycle}{total\ electriciy\ produced\ by\ the\ PV\ system\ over\ its\ life\ cycle}$$

By applying Equation 8.3, considering total emissions of 3,107.8 kg CO_2 eq for the 2.96 kWp system, the total CO_2 intensity (emission factor) calculated is 40.2 g CO_2 eq/kWh, which is fewer emissions when compared to the Irish grid. Similarly, for the 4.4 kWp system, the carbon intensity factor is 42.6 g CO_2 eq/kWh.

In 2020, 52 % of electricity generated in Ireland came from natural gas and about 37% from wind energy (SEAI, 2022f). By introducing the PV system into the Ireland generation mix (the republic of Ireland generation mix), it is expected to contribute to reducing the CO_2 emissions in the electricity generation sector. To further illustrate the process of carbon reduction as a result of introducing solar energy in electricity generation, a sample day will be analyzed (this date is randomly selected and is not completely representative for the whole year, however, for the sake of understanding the carbon saving from PV system the general approach will be the same). Figure 8.16 shows the hourly CO_2 intensity from the electricity generation sector in Ireland on February 17th, 2022.

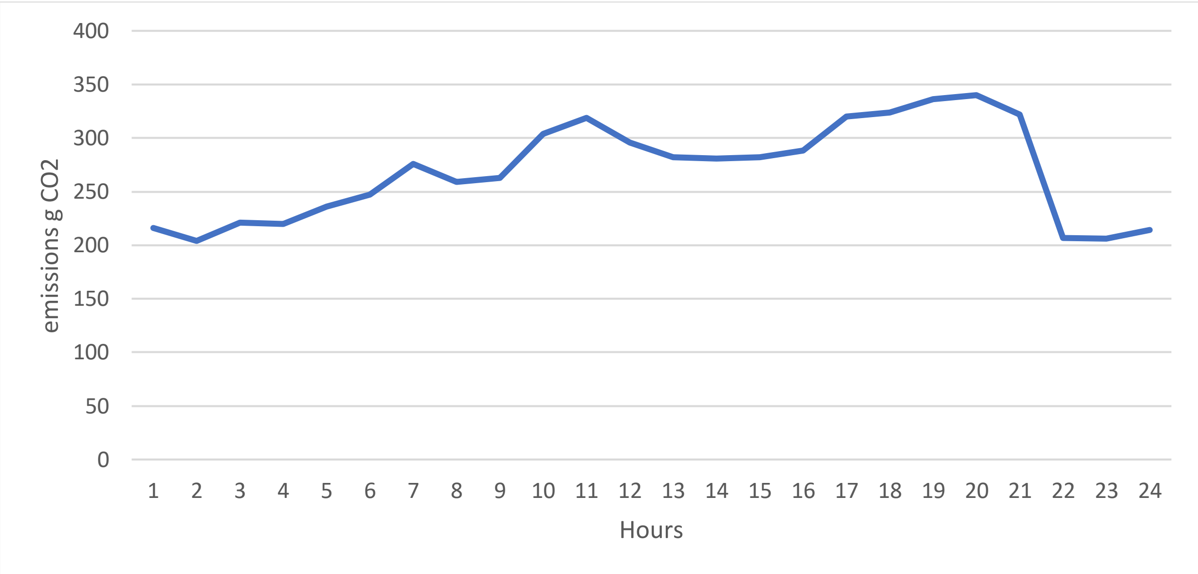


Figure 8.16: Electricity generation carbon intensity in Ireland, February 17th, 2022
Source: Author based on (EirGrid, 2022)

Considering the Irish electricity generation mix on that day, these emissions are mainly attributed to natural gas and coal as illustrated in Figure 8.17, which shows the contribution of different fuels in the electricity generation on the same day.

Local environmental and socio-economic impacts

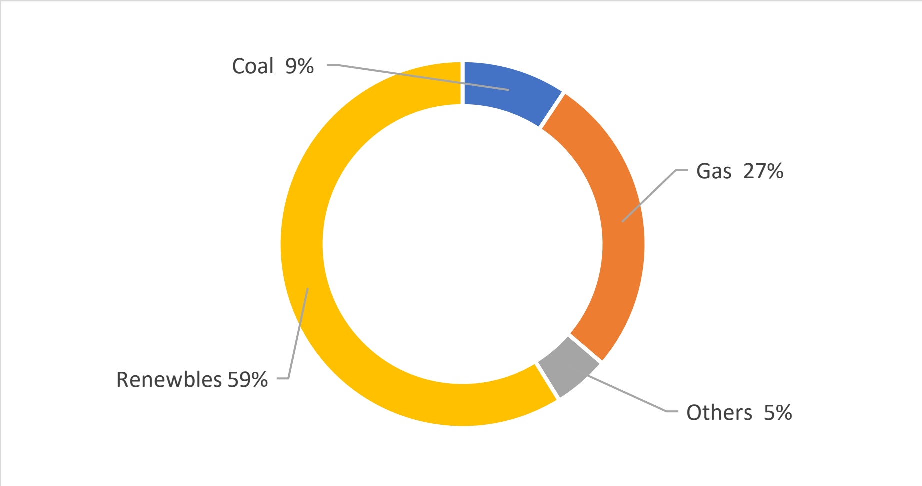


Figure 8.17: Irish system generation fuel mix, February 17th, 2022
Source: Author based on (EirGrid, 2022)

Figure 8.18 depicts the positive impact of the 2.96 kWp PV system contribution in the generation mix (on the household level), the total electricity withdrawn from the national grid will be reduced by an amount equal to the generation of the PV system. As the generation from solar is only during the daylight hours, and considering a 2.96 kWp PV system without battery storage, the PV system contribution in CO_2 emissions reduction will approximately be between 8:00 to 18:00 (slight fluctuation might occur depending on seasonality). Considering the electricity demand in this case study and the household hourly load curve, if the entire demand is covered from the electricity generated by the grid, the total CO_2 emissions will be 4.3 kg, however, by introducing the PV system the total electricity purchased from the grid is reduced by the equivalent amount of electricity generated by the PV system. As a result, the total emissions are reduced to 2.2 kg CO_2 (approximately a 50% reduction).

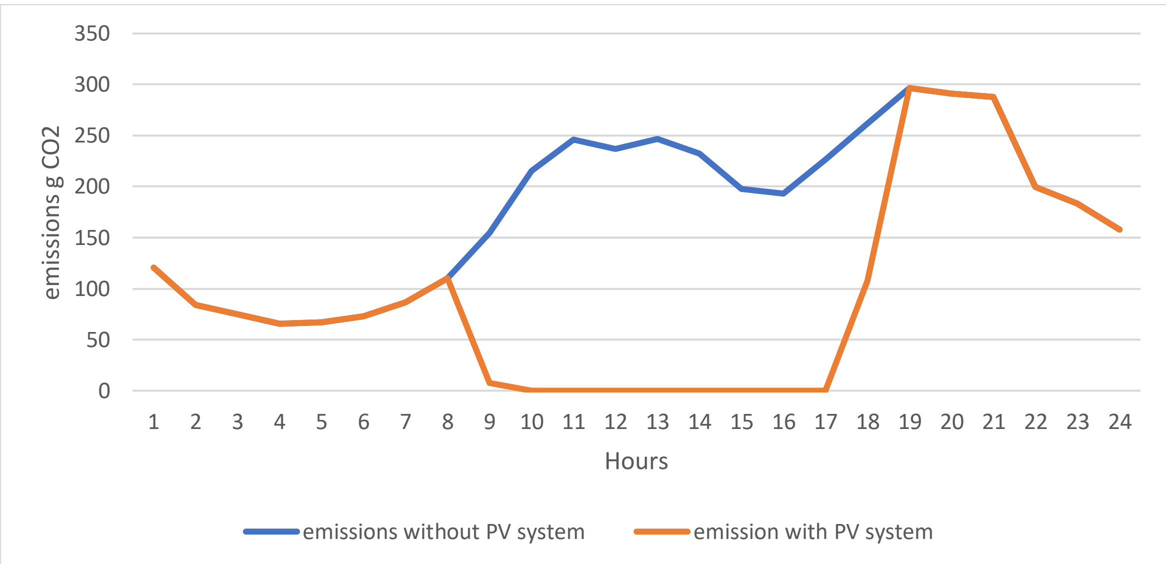


Figure 8.18: The effect of the 2.96 kWp PV system on CO_2 reduction, February 17th, 2022
Source: Author

Similarly, Figure 8.19 shows the results for the 4.4 kWp system with a battery, the battery prolongs the hours of solar penetration to cover the household demand (for certain hours when there is no sun) which will further reduce the electricity purchased from the grid. The total emissions without a PV system are 4.3 kg CO_2, reduced to 1.17 kg of CO_2 as an effect of introducing the PV system (3.1 kg CO_2 reduction).

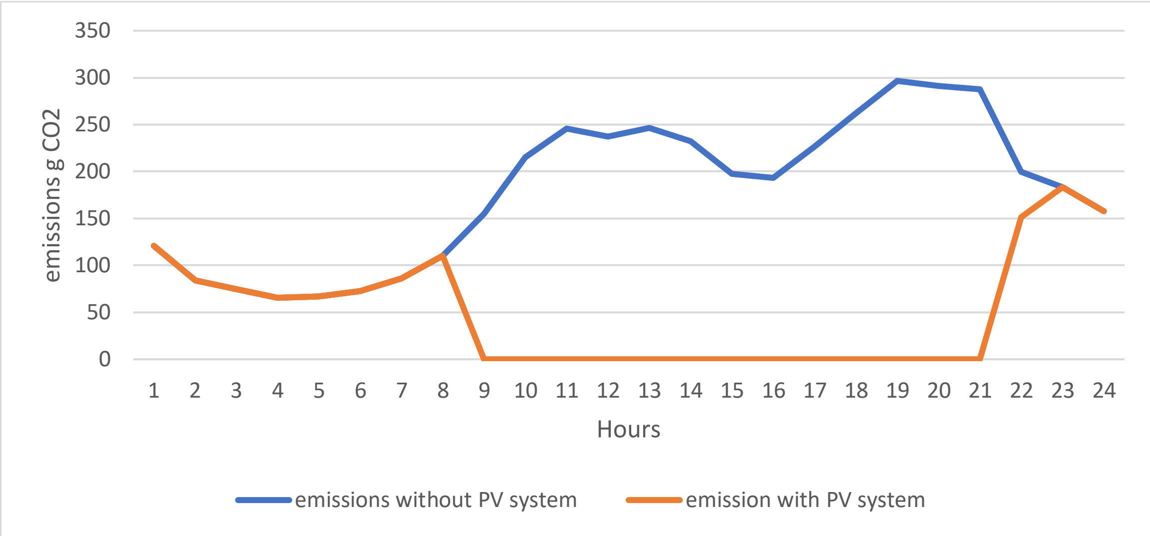


Figure 8.19: The effect of the 4.4 kWp PV system on CO_2 reduction, February 17th, 2022
Source: Author

According to (Renewable Ninja, 2022) statistics, in July and May Ireland has the lowest capacity factor of wind energy (approximately 25% - 26%), hence the penetration of wind energy will be low during these months and the Irish grid would have different fuel mix. Figure 8.20 shows the CO_2 intensity of electricity generation on July 14th, 2021, where the wind conditions are relatively low.

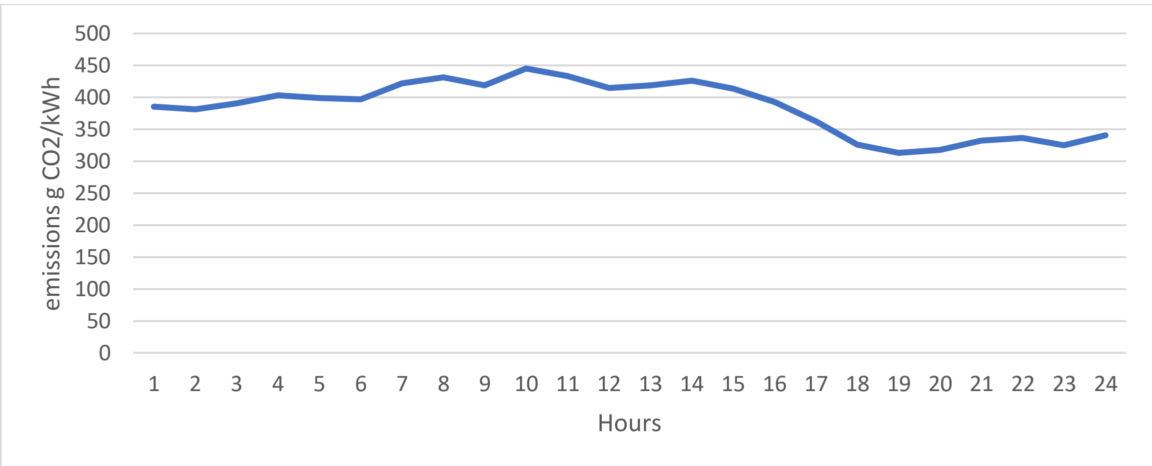


Figure 8.20: Electricity generation carbon intensity in Ireland, July 14th, 2021
Source: (EIRGRID, 2022)

Local environmental and socio-economic impacts

By following the same approach earlier (for the February 17th case), the hourly CO_2 savings for the 14th of July for both 2.96 kWp and 4.4 kWp systems are illustrated in Figure 8.21 and Figure 8.22 respectively.

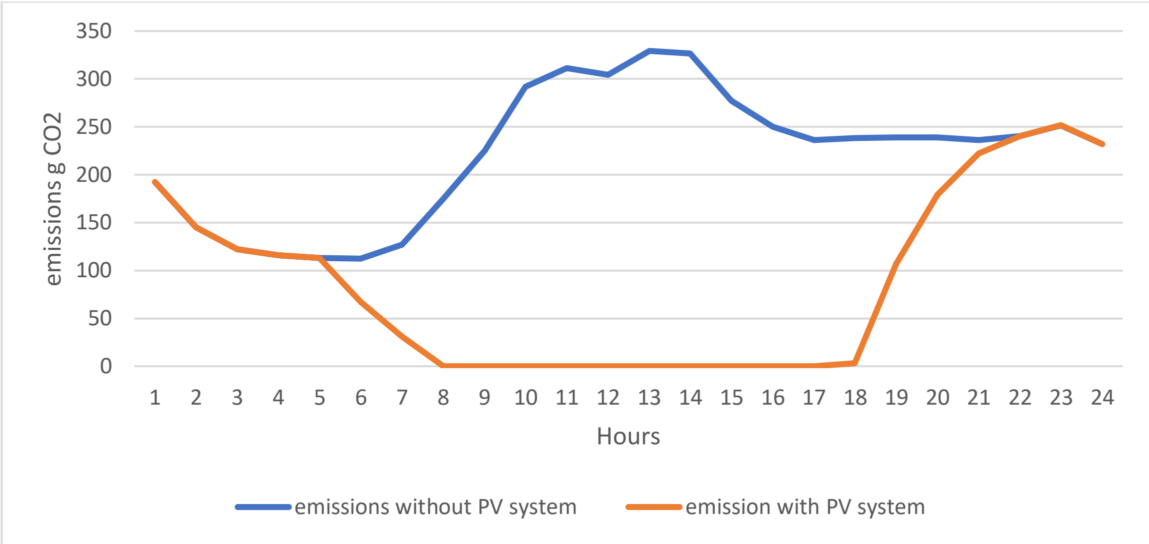


Figure 8.21: The effect of the 2.96 kWp PV system on CO2 reduction, July 14th, 2021
Source: Author

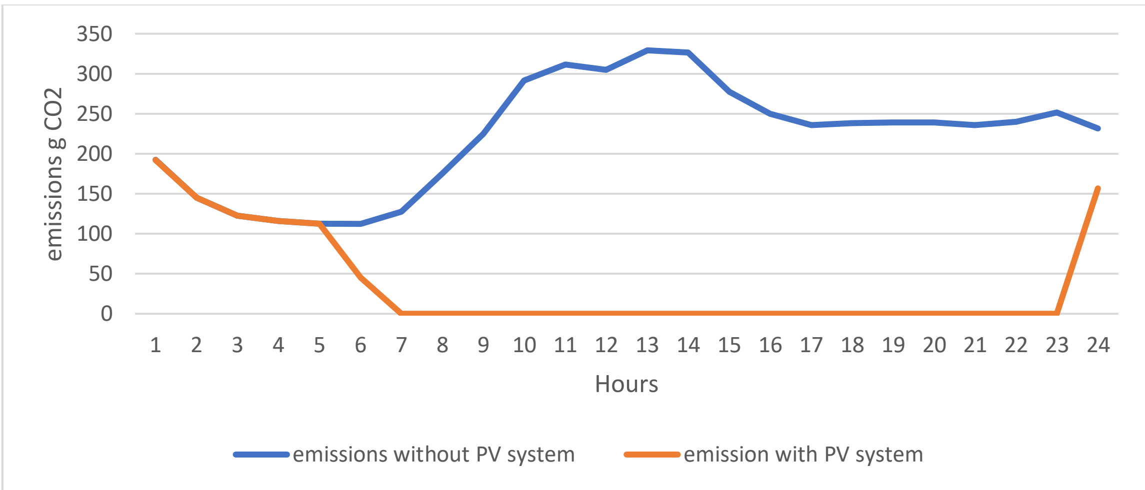


Figure 8.22:The effect of the 4.4 kWp PV system on CO2 reduction, July 14th, 2021
Source: Author

The carbon savings on July 14th is 4.4 kg CO_2 (in the case of 4.4 kWp system) which are higher than the carbon savings on February 17th. This difference could be explained by the nature of the energy replaced from the grid (based on the fuel mix on that day) and the operation of the PV system as it is generating electricity since 5:00 and feeding the household up until 23:00, because of the battery and the sunny summer hours.

Local environmental and socio-economic impacts

It should be mentioned that the CO_2 reduction is affected by several factors, for example, the hourly grid CO_2 intensity is continuously fluctuating according to the share of each fuel type in the generation mix. Additionally, the seasonality and fluctuation in the wind generation in Ireland is an important factor as it is considered the second-largest generation source after natural gas. Ffor a windy day with high renewable penetration in the Irish grid the carbon intensity of the grid will be low, and the carbon savings by the PV system will be less. On the contrary, for a day with lower renewable penetration, the carbon intensity of the grid is high and then the carbon savings by the PV system will be higher. Moreover, the PV system size and configuration (e.g., with battery or without a battery) is also an important factor because it affects the time (day/ night) at which the electricity generated from the PV system is replacing the electricity from the grid.

Finally, as introduced earlier and according to (SEAI, 2022e), the Irish electricity CO_2 intensity is 296 g CO2/kWh, by applying this value over the whole year (as an average), the total annual carbon savings from the 2.96 kWp and the 4.4 kWp PV systems placed in Loop Head will be about 507 kg CO2 and 787 kg CO_2 respectively.

8.1.6. Critical discussion

By Philip Miltrup

One of the most important elements of a successful life cycle analysis is the existence of reliable data for the product under investigation. The IEA data used for module, inverter, cable and mounting system production of PV systems can be evaluated as reliable since the individual system components can be found with their exact wording in the Ecoinvent database. However, the existing flows and processes of the database for the corresponding processes (cradle to grave PV LCA) need to be evaluated in detail before use. It is of paramount importance to understand what lies behind predefined flows or processes, otherwise, it is possible that a predefined database process includes sub-processes such as disposal or even recycling, which is not considered in this study. This not only misrepresents the results but also misinterprets them if, for example, the subsequent energy required for recycling is also included in a flow or process.

The goals and scope phase also defines, among other things, the motivation for conducting a project. One of the purposes of the PV systems analyzed in this LCA is to illustrate to members of the Loop Head community that there are also emissions associated with renewable energy technologies such as PV systems. However, more importantly, these emissions are significantly lower than those associated with energy generated from conventional, non-renewable technologies. In addition, the analysis serves to illustrate how much emissions can be saved on a household basis by a PV system.

The scope describes very well that this project is limited to a certain time and space. In the scheduled project duration of five weeks, restrictions have to be accepted. Therefore, a cradle to cradle analysis would have exceeded this scope. In addition, one of the key findings of LCA is that it is iterative, meaning that it continues for years, with data quality improving as measurement improves and the scope and goals of the project are better understood.

8.2. Socio-economic impact assessment

8.2.1. Introduction

By Philip Miltrup

According to the IC2021 results, the total energy demand in Loop Head is composed of heat, electricity, and transportation, with the main energy sources for heating being oil, LPG, coal, peat, and electricity. Most households in Loop Head still rely on fossil fuels as their primary heating fuel. In order to initiate a transition to greener energy production in Loop Head, active citizen participation in renewable energy generation is an important success factor. According to (Claudia Fruhmann & Nina Knittel, 2016), renewable energy production offers common benefits to people and communities. These include, for example, the use of local natural resources, building social capital and counteracting energy poverty. Additionally mentioned, and considered in more detail in this chapter, is how employment can increase at the regional level through the deployment of PV systems and what impact the implementation of PV systems could have on the Loop Head economy. The consequences of these changes are examined, including the effects on total and sectoral output and on employment levels. According to (Ronald E. Miller & Peter D. Blair, 2009), an input-output analysis (IO analysis) is considered as a suitable method to be used in this context as it captures the interdependencies between different sectors of the economy and since Ireland publishes official IO tables. Sub-chapter 8.2.2 discusses the methodology of the socio-economic analysis. Sub-chapter 8.2.3 describes the data collection procedure for the analysis.

Among other things, the system components in Case Study III (Chapter 7) are included in the data collection. OPEX assumptions and CAPEX breakdowns are outlined and leakage assumptions are explained. Chapter 8.2.4 presents the results of the examined topics in terms of gross value added (GVA) and job creation. The results of the GVA essentially represent the GVA of the respective (economic) sectors involved and the economic benefits of a PV system implementation. The following qualitative analysis of resulting jobs through the installation of

PV systems and the discussion of potential business models such as social enterprises or cooperatives is presented in the last part of this section. A critical discussion of the results follows in sub-chapter 8.2.5.

8.2.2. Methodology

By Munzer Osman

To measure the socioeconomic impact of installing a PV system on Loop Head, the method of input-output analysis is used. The approach of input-output analysis is widely utilized in understanding and measuring the direct, indirect, and induced impact of renewable resources (Acero et al., 2015b). The Input-output tables for Ireland were obtained and examined to identify the main economic sectors and their interdependencies and the different economic transactions among different sectors. In general, the implementation of the PV system in Loop Head could have three different effects. A direct effect which is the immediate expenditure associated with such a project (for example, for the process of constructing the PV system, equipment such as PV panels, inverters, and the mounting system should be spent on). The second type of effect is indirect such as the expenditure on hiring the installation engineers, technicians, and consultants to perform the job. The third effect is induced such as the benefit that reflected on the economy from the further expenditure of the working team in installing the PV system (for example, workers buying drinks and snacks from a local shop in Loop Head is an induced impact. Additionally, the positive image of a green and sustainable energy community of Loop Head would enhance the tourism activities and attract higher number of visitors, this could be considered as an induced effect as well).

After screening all potential expenditures for the PV system (cost per kW installed then calculating for the whole PV array), a unique Standard Industrial Classification (SIC) was assigned to each of the expenditures for system components. Then, all items with similar SIC were grouped under one category (to identify the main economic sectors). Then, a leakage factor was applied. A leakage factor is an indicator that could be used to describe the strengths of a certain economy, a lower leakage value indicates a strong supply chain, which means all the spending on production inputs is within the country borders and no significant imports are required. Conversely, a high leakage factor indicates a weak supply chain, and the production elements are being imported from outside the country, which means the country's expenditure is leaving its borders (Charlotte Cochrane, 2021). This leakage describes how much of the spending remains in Ireland's economy. Additionally, "GVA output multipliers" were calculated, and the GVA output multiplier type II was considered as a way to account for all the potential socioeconomic effects (direct, indirect, and induced). The output obtained from this process is the Gross Value Added (GVA) per unit kW installed capacity of the PV system which reflects the economic value from this activity (installing of PV systems).

8.2.3. Data collection

By Saleheh Rahimi

Primary data collection is a systematic flow of gathering observations or measurements. It helps to gain first-hand knowledge and original insights into the research problem, whether it is performing research for business, governmental or academic purposes (Shanks & Bekmamedova, 2018). This section presents the collection of data in order to calculate the contribution of implementing a solar PV system to the Irish economy. Two main indicators including Gross Value Added (GVA) (which decribed in following part) and employment factor are determined to evaluate the socio-economic impacts of implementing a solar system based on characteristics of the case study III described in Chapter 7. The data collected are mainly quantitative (numeric values) in calculating the GVA but also some qualitative (words and meaning) data is used to describe some linguistic variables which are described in more detail in chapter 8.2.4. to evaluate the job creation. The methods used to gather the data for estimation of expenditures and investment cost for installing solar PV system are interviews (face-to-face) with a group of experts and engineers who were directly involved in the process of installing the solar PV system. Secondary data collection to calculate the GVA variables are based on Ireland's Industry and Service Statistics provided by Organization for Economic Co-Operation and Development (OECD.stat, 2021) and regarding job employment creation, data collection is based on literature review and country's statistical data (KMPG Ireland, 2015). All the data and assumptions which influence the result are explained in this section.

Gross Value added (GVA)

One of the main inicators to measure the economic impact of Solar PV system on the region is GVA, which is calculated through the Input Output-Tables (IOTs) method described in chapter 8.2.4. GVA represents the value generated by selling goods and services as an output in the economy. it measures the contribution of each activity in industry or sector to the Gross Domestic Product of a nation, GDP. Therefore, the summation of all GVA from different industries and services subtracting product taxes but adding subsidies is equal to the GDP of a country as the total economic output (SSE, 2018a). This indicator shows how many products (goods and services) are brought into an economy (either as a result of domestic production or imports from other countries) and how many of those same products (intermediate consumption by industry and final consumption by a household or any sector and exports) are used in the economy (UNITED NATIONS, 2018). Many economists believe that GVA can be a better indicator for measuring the country's economic growth than GDP since GVA does not take into account the taxes paid by people. Sometimes GDP increases solely because of growth in taxes, however, it does not necessarily mean that more goods and services are produced (The Economic Times, 2017).

Each country has its own Output-Input table which has become an essential tool to inform policy and decision-makers. The table which is used to calculate the GVA output is Ireland's Input-Output 2018 prepared by Organization for Economic Co-operation and Development (OECD) (OECD.stat, 2021) According to Equation 8.4 industry output is calculated by summation of intermediate consumption of a product by industry (manufacturing and selling the PV system) and GVA output from final consumption by customer (households).

Equation 8.4: Industry output
Source: (UNITED NATIONS, 2018)

$$Output = Intermediate\ consumption + GVA$$

The GVA output for an industry is defined as the total value of production in all industries of the economy that is necessary for all stages of production in order to produce one unit of the product for final use (UNITED NATIONS, 2018).

Equation 8.5: GVA output
Source: (SSE, 2018b)

$$GVA\ output = GVA\ effects / GVA\ multiplier$$

In Equation 8.5, GVA effects show the total change in GVA as a result of one unit change in product demand. GVA multiplier also identifies the effects of 1 euro of GVA in each industry on the whole Irish economy which consist of two types, Type I and type II(SSE, 2018a). Type I multipliers sum together direct and indirect effects while Type II multipliers also include induced effects which are defined in section 8.2.2. In this study, GVA multiplier type II (including direct, indirect and induced impacts) is considered.

Leontief methodology

The methodology used for calculating the GVA multiplier is based on the Leontief inverse in a linear model from the input-output model. Then, for each industry category, GVA multipliers are calculated based on the Input-Output table.

Leontief model a is methodology used for calculating the production level of each industry for the whole country or region. It defines the relative value of each specific industry for associated GVA. Basically, in this model, there are n industries with n products. It is assumed that production is equal to consumption. In general, $x_1 \dots \dots \dots x_n$ is the total output of the respective industry (see Equation 8.6)

Equation 8.6:The total output of each industry
Source: (Kansas State, 2020)

$$Industry\ 1: \quad x_1 = a_{11}x_1 + a_{12}x_1 + \cdots + a_{1n}x_1 + b_1$$
$$Industry\ 2: \quad x_2 = a_{21}x_1 + a_{22}x_1 + \cdots + a_{2n}x_2 + b_2$$
$$Industry\ n \ : x_n = a_{n1}x_1 + a_{n2}x_1 + \cdots + a_{nn}x_n + b_n$$

And $a_{ij}x_j$ is the number of units generated by industry *i* and consumed by industry *j*. Then, the input-output matrix (A) is obtained from Equation 8.7.

Equation 8.7: Input-output matrix
Source: (Kansas State, 2020)

$$A = \begin{pmatrix} a_{11} \dots & a_{1n} \\ & \vdots \\ a_{n1} \dots & a_{nn} \end{pmatrix}, \quad B = \begin{pmatrix} b_1 \\ b_2 \\ \cdot\cdot \\ b_n \end{pmatrix}, \quad X = \begin{pmatrix} x_1 \\ \cdot \\ \cdot \\ x_n \end{pmatrix}$$

In this equation, B is the external demand vector and X is the production level of each industry. Thus, Equation 8.8 is defined as follows.

Equation 8.8: Linear equation in Leontief model
Source: (Kansas State, 2020)

$$X = AX + B$$

To determine the X as the solution from this matrix, it can be transformed to Equation 8.9.

Equation 8.9 Leontief Inverse
Source: (Kansas State, 2020)

$$I_nX - AX = B$$
$$(I_n - A)X = B,$$
$$X = (I_n - A)^{-1}\, B$$

Then $(I_n - A)^{-1}$, which is called the Leontief inverse, defines the amount of output in each industry.

According to (UNITED NATIONS, 2018), International Standard Industrial Classification (SIC) is the international reference for the classification of all economic activities. The fourth revision, ISIC Rev. 4, was published by the United Nations in 2008 and it consists of 21 sections, 88 sub-section, 238 groups and 419 classes. It aims at providing a standard classification of products and services used for gathering and providing economic statistics for further economic analysis by each industry. Section level defined the main industries and businesses involved in producing the products and activities, then in the next level, sub-section, it described the main characteristics of industry's outputs such as products and services. At the class level, it classifies the products and services based on their associated process and technology.

Table 8.3 shows the GVA multiplier Type II as a result of Leontief method used to build the model for each main SIC category assumed to be involved in the implementing of a PV system in Loop Head.

Table 8.3: GVA multiplier II
Source: Author based on (OECD.stat, 2021)

SIC category	SIC Code	GVA multiplier II
Manufacture of electronic industrial process control equipment	26.51/2	0.4002
Manufacture of electrical equipment	27.00	0.4419
Manufacture of machinery and equipment	28.00	0.5204
Electrical installation	43.21	0.5504
Repair and installation of machinery and equipment	33	1.0301

According to the environmental life cycle assessment of a solar PV system, the technical cost breakdown structure is identified from the first LCA stage, manufacturing of solar system including solar panels and balance of system. In this study, the assessment of socioeconomic impacts of the PV system is aligned with the supply chain stages in LCA. To calculate the economic impact of the solar PV system, the first step is to define the cost of the material and services involved in utilizing the solar panels as the final consumption by the consumer. As it is already mentioned in chapter 8.1.1, PV life cycle assessment consists of extraction of raw material, manufacturing of solar PV system, transporting the components from the country of producing the system's components (China) to the place of the operation and usage stage, Ireland (cradle-to-grave LCA). However, to create the technical cost breakdown structure of the system, it is assumed that some expenditure categories are already considered in other categories. For instance, the expenditure of transportation from China to Ireland is not considered as any separate category in this study. It is already included in the final cost of the solar equipment. These expenditure values were split across individual technical cost breakdowns for a specific solar system (cost for solar panels, inverter, cabels, battery and other components).

Table 8.4: Technical cost breakdown structure of PV solar system corresponding the SIC sectors
Source: Author based on (OECD.stat, 2021)

SIC sector code	**Technical cost center**	**OPEX and CAPEX share (2.96 kWp without battery)**	**OPEX and CAPEX share (4.4 kWp with battery)**

CAPEX	**Manufacturing of Solar PV system (Solar panels and BOS's components)**			**34.92%**	**45.31%**
	C26	26.51/2	Manufacture of electronic industrial process control equipment	0.28%	0.19%
	C27	27.00	Manufacture of electrical equipment	29.67%	28.49%
	C28	28.00	Manufacture of machinery and equipment	4.97%	16.63%
	Installation of the Solar PV system			**38.57%**	**36.12%**
	F43	43.21	Electrical installation	38.57%	36.12%
OPEX	**Operation and maintenance**			**26.52%**	**18.57%**
	M71	33.00	Repair and installation of machinery and equipment	26.52%	18.57%

Capital expenditure (CAPEX) and operational expenditure (OPEX) values are derived based on the technical cost breakdown structure. OPEX and CAPEX shares show the contribution of each technical cost breakdown in the GVA effect. Although Manufacturing of solar PV components has the high leakage rate (75 %), it accounted for the largest share in CAPEX, followed by installation of system and operation and maintanace sector.

Leakage

To describe the strength of the solar system as a final product and services on the Irish economy, variable leakage rates based on the proportianl of each activity within the economy of Ireland is defined in the model. During supply chain stages, since the factory which provides the equipment is located in Ireland, but manufacturing of PV components accures in China, it is assumed that most of the monetary values spending on production inputs is outside of the Irish borders, thus a leakage rate of 75 % is considered. Then, for the operation stage including all the installation activities, cabling and preparing mounting system, no leakage (0 %) is defined. All the mentioned activities such as engineering designs, installation works, testing, commissioning and consultancy entirely is conducted by domestic factories and labourers (leakage is 0%). Regarding repairs and maintenances of the equipment, it is assumed that machinery equipment such as inverter may need to be replaced every 10 years, and a leakage rate of 50% is defined.

Employment factor

The deployment of solar technology in Ireland will support commercial activities and jobs. According to the report published by the Irish Solar Energy Association in 2015 (KMPG Ireland, 2015), investment in solar technology can create up to 7,300 jobs per year between 2017 and

2030. Many of the jobs' opportunities will benefit from the construction sector. Therefore, another indicator to measure the socio-economic impact of the solar PV system is the employment factor. It gives the number of jobs per kWp for solar PV technology in construction, installation, operations and maintenance processes. The data was collected from previous studies and research and the Irish government to simulate and analyse the potential employment benefits in the area of Loop Head. These data are the input to the model to calculate the number and type of the job created as a result of installing solar PV systems with a specific installed capacity and the estimated number of households with installed solar panels. The calculation of the employment factor is described in chapter 8.2.4.

8.2.4. Result

By Fitri Wulandari

To analyse the socio-economic impacts of a solar PV installation on a residential level, both GVA and jobs were estimated using two different approaches.

<u>Welfare – GVA</u>

To estimate the economic productivity impact in Ireland from the solar PV industry, this study used an input-output (IO) model using the IO table of Ireland with some simplifications involved. Essentially this part of the study tried to analyse to which business sector in Ireland does the money go to everytime one household installs a solar PV system. This approach allows us to estimate how an increase in demand for solar PV can make an impact in the different sectors of an economy. Installing a solar PV on a household will generate GVA directly through preparation and installation phases and indirectly through the manufacturing phase. In this analysis, deadweight, displacement, and substitution were zero as the value would be too small that it was considered to be insignificant. The following discussion will present in detail the result of the IO model and the different impacts of installing solar PV on a residential level in the Irish economy.

Figure 8.23 shows that the economic impact of an investment made when installing solar PV would not be felt uniformly across the sectors involved. The repair and installation of machinery and equipment industry received the most output from the solar PV installation. This comes from the purchase of solar PV panels, the inverter, the battery, etc. Although almost all of the components are purchased abroad, there will still be some contributions to the Irish economy assuming that the household owner will buy the components through an Irish company (that serves as an intermediate). Hence, even when Ireland doesn’t manufacture any of the solar PV components at the time being, there will still be some GVA contributed to the Irish economy when purchasing the solar PV components. The next industry with the largest GVA benefit is the electrical installation industry, mainly because all of the money spent during the installation process will stay within the Irish economy, assuming that the solar PV installation process will be done by an Irish corporation, hence zero leakage.

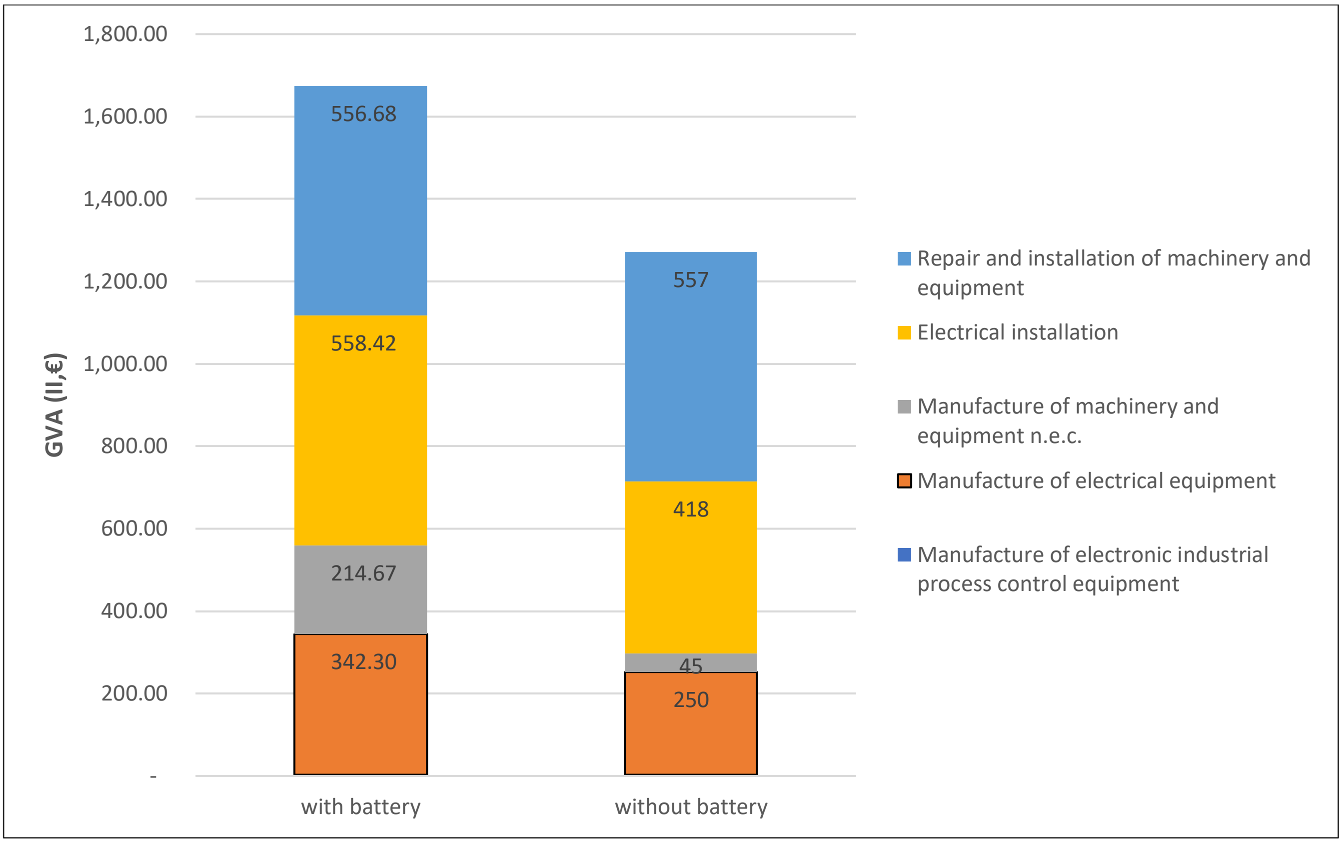


Figure 8.23: GVA comparison per industry, for case study III with and without battery
Source: Author based on own calculation

Figure 8.24 shows that most of the GVA into the Irish economy will come from the initial investment made when installing solar PV. The capital expenditures consist of the purchase of the components and the solar PV installation cost. The operational expenditure consists of the cost of inverter and its installation cost that will only happen once throughout the PV lifecyle.

Local environmental and socio-economic impacts

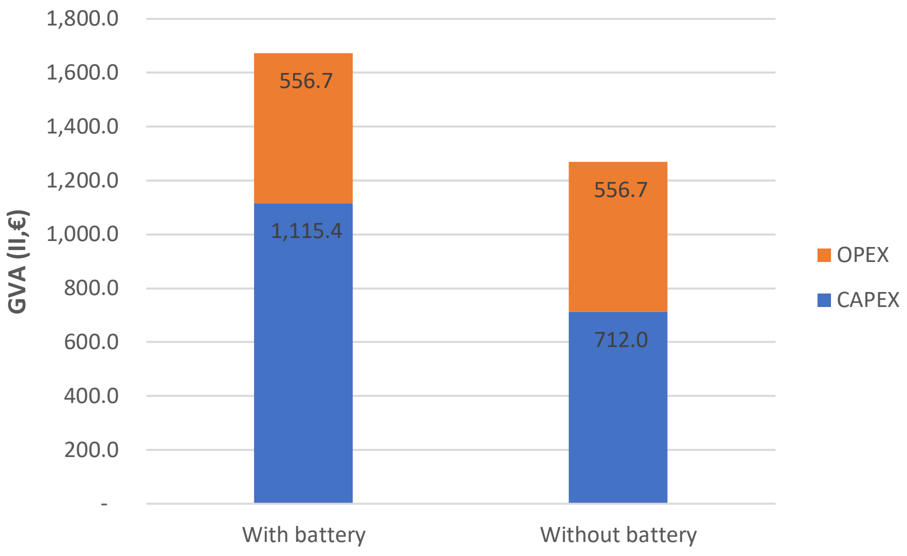


Figure 8.24: GVA comparison per type of expenditure, for case study III with and without battery
Source: Author based on own calculation

In total, the GVA from an installation of a 4.4 kWp solar PV system with battery would be 380 €/kW and the GVA from an installation of a 2.96 kWp solar PV system without battery would be 430 €/kW. Hence, referring to the investment cost mentioned in Chapter 7, it can be concluded that for every one euro invested to install a 4.4 kWp solar PV system with a battery, 30 cents will go to the Ireland economy, whereas for the installation of the 2.96 kWp solar PV system, for every one euro invested 34 cents will go to the Irish economy. Table 8.5 shows the summary of total investment and GVA to the Irish economy based on case study III.

Table 8.5: Summary of total investment and GVA of case study III
Source: author based on own calculation

	Total investment (€)	Investment (€/kW)	GVA (€/kW)
With battery (4.4 kWp)	6,449	1465.68	380.5
Without battery (2.96 kWp)	3,707	1252.36	429.3

Another important message here is that, although installing solar PV seems to bring value to the Irish economy, it is important to note that still, more than 60 % of the capital expenditure made within Ireland go outside of Ireland. In short: Ireland is losing money. (SEAI, 2017b) stated that although the country has the opportunities to be involved earlier in the value chain, Ireland is still considered as a technology-taker within the solar PV industry as most of the manufacturing of the solar PV system components happen in China and the know-how in deploying solar PV at scale is concentrated in other European, North American, and Australasian countries.

Job creation – Employment

As mentioned in sub-chapter 8.1.3, most of the main components in the solar PV value chain are currently still manufactured in China. In 2019, most of the key raw materials in the solar PV supply chain, such as polysilicon, glass, and aluminium frames were produced in China (IRENA & ILO, 2021). Hence, due to its strong domestic supply of the main components, more than 90 % of the world's wafer are manufactured in China, along with 78 % of the world's cell production and 72 % of module output (IRENA & ILO, 2021). Therefore, as there is only very little of the solar PV value chain that happens in Ireland, most of the job creation opportunities will exist in the construction and installation phase, as well as during operation and maintenance. In addition, as in 2018, it was recorded that Ireland's import dependence on fossil fuel was 67 % (Dineen et al., 2020), most of the jobs lost in the mining and refining sector as a result of lower demand will be incurred abroad hence was not considered further in this study. The following discussion will explore the employment opportunity in terms of job creation from solar PV installation on a residential level in Loop Head through qualitative assessment.

As mentioned in sub-chapter 8.2.3, the number of jobs supported by installing solar PV was estimated by using the employment ratios based on literature, but still regional and technology-specific. This number represents the total amount of full-time equivalent jobs created by the solar PV industry. Hence, to calculate the potentials of direct and long-term employment, the key inputs needed are the employment factor and the regional multiplier. Below are the formulas used in this study to calculate the job potential:

Equation 8.10: Calculation of energy supply jobs - construction
Source: (Rutovitz et al., 2015)

$$Number\ of\ jobs\ during\ contruction = MW\ installed\ per\ year \times construction\ employment\ factor \times regional\ job\ multiplier$$

Equation 8.11: Calculation of energy supply jobs – O&M
Source: (Rutovitz et al., 2015)

$$Number\ of\ jobs\ during\ O\&M = Cumulative\ capacity \times O\&M\ employment\ factor \times regional\ job\ multiplier$$

Local environmental and socio-economic impacts

The regional job multiplier used in this study is based on the regional job multiplier for the OECD countries which is 1 (Rutovitz et al., 2015). (KMPG Ireland, 2015) estimated the job employment factor for rooftop installation in Ireland is 13 job years/MW, 4.5 job years/MW for ground mount installation, and 0.3 jobs/MW for O&M for the year of 2017. These numbers were then compared with the employment factors from another literature (Rutovitz et al., 2015), where the global employment factor for solar PV construction is 13 job years/MW and 0.7 jobs/MW for O&M. Based on the employment factors for Ireland, the job creation potential for Loop Head was first estimated by assuming that in one year, 1,100 households will install solar PV with capacities as presented in sub-chapter 8.2.3. The resulting job creation opportunities are presented in Table 8.6.

Table 8.6: Potential of job creation in Loop Head for 1,100 households
Source: own calculation

	Case study III - 2.96 kWp capacity		Case study III - 4.4 kWp capacity	
	1 household	1,100 households	1 household	1,100 households
Roof top installation (job year)	0.04	42	0.1	63
Ground mount installation (job year)	0.013	15	0.02	22
Operations & maintenance (job year)	0.001	1	0.001	1

The result in this study was presented in one job year, which essentially means one job in one year. It is important to note that this doesn't simply mean one new employment in every year. However, the idea that 1,100 households will install solar PV within only one year period is difficult to imagine seems to be very optimistic. Hence, another way to present this was to assume that every year, 100 households would install solar PV for a period of 11 years. The resulting job creation opportunities for this approach are presented in Table 8.7.

Table 8.7: Potential of job creation in Loop Head for 100 households
Source: own calculation

	Case study III - 2.96 kWp capacity	Case study III - 4.4 kWp capacity
Roof top installation (job year)	4	6

Local environmental and socio-economic impacts

	Case study III - 2.96 kWp capacity	Case study III - 4.4 kWp capacity
Ground mount installation (job year)	1	2
Operations & maintenance (job year)	0.1	0.1

Based on this approach, if 100 households in Loop Head would install roof top Solar PV with 2.96 kWp capacity, four people in Loop Head would be employed for at least 11 years and 6 people would be employed if the households install roof top solar PV with 4.4 kWp capacity. For ground mounting installations, one person in Loop Head would be employed for at least 11 years and 2 people would be employed if the households install ground-mounted solar PV with 4.4 kWp capacity.

These numbers were then compared with the qualitative assessment done through an interview with Kenneth Thomas O'Connell, one of the engineers who work for a company that offers a solar PV installation service. During the interview, it was noted that to do a ground-mount installation for one household, two workers would be required for one work day. Roof top installation requires more labour, two workers would be required for almost three work days. However, for operational and maintenance, the labour required is so minimal if not zero as solar PV doesn't require any particular maintenance other than the replacement of inverter that would only happen once throughout the PV lifecycle. Another interview was done with one household that has already installed solar PV in Loop Head, in which the household owner stated that no additional service was required ever since he installed the solar PV.

However, it is important to note that the employment factor used in this study is the employment factor in 2017. This study did not further consider the learning adjustment rates or the declie factors for the solar PV technology that would take into account the reduction in employment per MW as the solar PV technology improves (Rutovitz et al., 2015). Furthermore, numerous changes can happen in the solar PV insutry over a period of 11 years. More people can be employed earlier in the value chain as Ireland has the capacity to capture the opportunity from the growing solar PV market. (SEAI, 2017b) identified that Ireland has the capability to play bigger role in the design and optimisation of solar PV and building integrated PV. Furthermore, (SEAI, 2017b) also stated that the country has potential to invent new solar PV technology or applications related to storage and monitoring, in which University of Limerick was mentioned as one of the institutions with know-how in electrochemistry.

Local environmental and socio-economic impacts

In terms of occupation, (IRENA & ILO, 2021) provides an estimation of the proportion of human resource requirements in a Solar PV installation project, as presented in Figure 8.25.

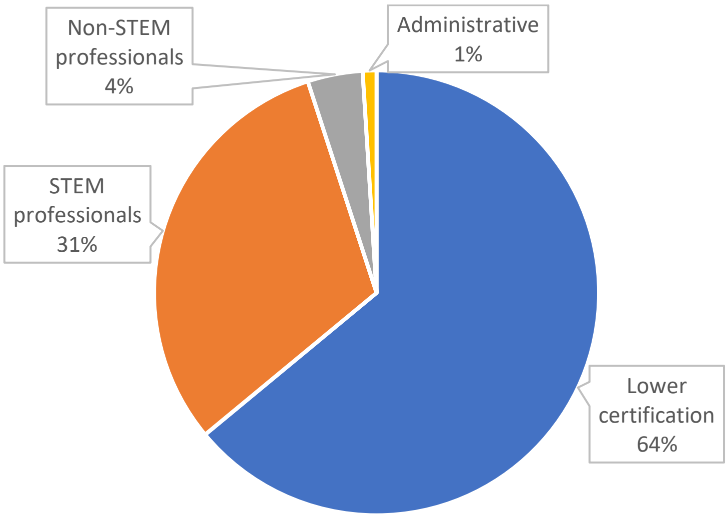


Figure 8.25: Human resource requirements for workers in solar PV
Source: author based on (IRENA & ILO, 2021)

According to (IRENA & ILO, 2021), 64 % of the human resources required during the installation of solar PV would be workers with lower certifications. The type of occupations could be electricians or roofers specializing in solar with skills that can be obtained through formal training and will work mostly during the construction phase. The second largest proportion, with 31 % of the human resource required, would be STEM (Science, Technology, Engineering, and Mathematics) professionals. These would be highly skilled workers in professional and managerial positions. The type of occupation would be system engineers who would be in charge of solar system design and site assessment for shadow and solar radiation.

In general, (IRENA & ILO, 2021) stated that solar PV is the largest driver of job growth in the renewable energy sector, mainly because compared with the other renewable energy technologies, solar PV draws the most investors and has greater labour intensity. Hence, there is no doubt that solar PV installation on the residential level in Loop Head will lead to more job creation and employment opportunities for the community.

(Stainforth, 2021) stated that one of the key factors that enable the community to fully harness the economic opportunities through renewable energy projects is the availability of local skilled labour. However, currently, there is a particular problem in Loop Head where many young people and potentially skilled workers move out. This needs to be addressed through education, skills, training, and retraining. An integrated approach between labour requirements in terms of education and skills needed in the solar PV sector and the gap in between needs to be addressed. This will also be further discussed in Chapter 9 for the opportunity within a social enterprise, focusing on different skill delivery pathways.

8.2.5. Critical discussion

By Saleheh Rahimi

The model was created based on some assumptions such as leakage which needs to be more precise to achieve more accurate results. Defining different scenarios based on high or low leakage also provides a supplement comparison to analyse the accuracy of the result. According to (SEAI, 2017b), the solar market has a total potential value of around €42-€216 million per year, thus solar technology is a fast-growing market in Ireland.The data for calculating the GVA multiplier for socioeconomic impacts derived from the references provided in the year 2018 (The Ireland Input-Output Table derived from OECD in 2018) so updated data was not available for 2022, however, the data for calculating the cost for CAPEX and OPEX was collected from market price resources in 2022. This disparity may have overlooked recent changes in the dynamics of both the solar PV industry and the Irish economy. In addition, to define the proper SIC class for each category, there was some uncertainties and doubts to selecting the correct and appropriate category associated with each component. For instance, for a smart meter, the recognition between "Manufacture of electronic industrial process control equipment" and "Manufacture of electrical equipment" and also other categories defined in the SIC list was not so specific and clear. Thus, it was attempted to select the most appropriate SIC category for the individual category. Ideally, more technical and economic analysis needs to be investigated.

Besides, the transportation expenditure has not been addressed as a separate cost in the technical breakdown structure. it is already included in the final cost of products which needs to be defined in more detail but due to uncertain data, a general estimation was identified.

Although employment creation could be calculated through the same approach as the GVA model from the Input-Output table, due to lack of sufficient data and limited time available, another approach was performed to estimate the job creation factor depending on qualitative data and based on literature review (for Ireland as a whole, not Loop Head). Alternatively, it would have been better to accurately calculate the job effects resulting from implementing solar PV systems in Loop Head using data only for Loop Head.

9. Next step to be taken for house owners

By Max Andriamanalina

After the analyses have been completed on the 3 Households case study and recommendations have been made, the next step is to find out how to implement the results of the study. Figure 9.1 below shows what could be the next step of the IC 2022 project.

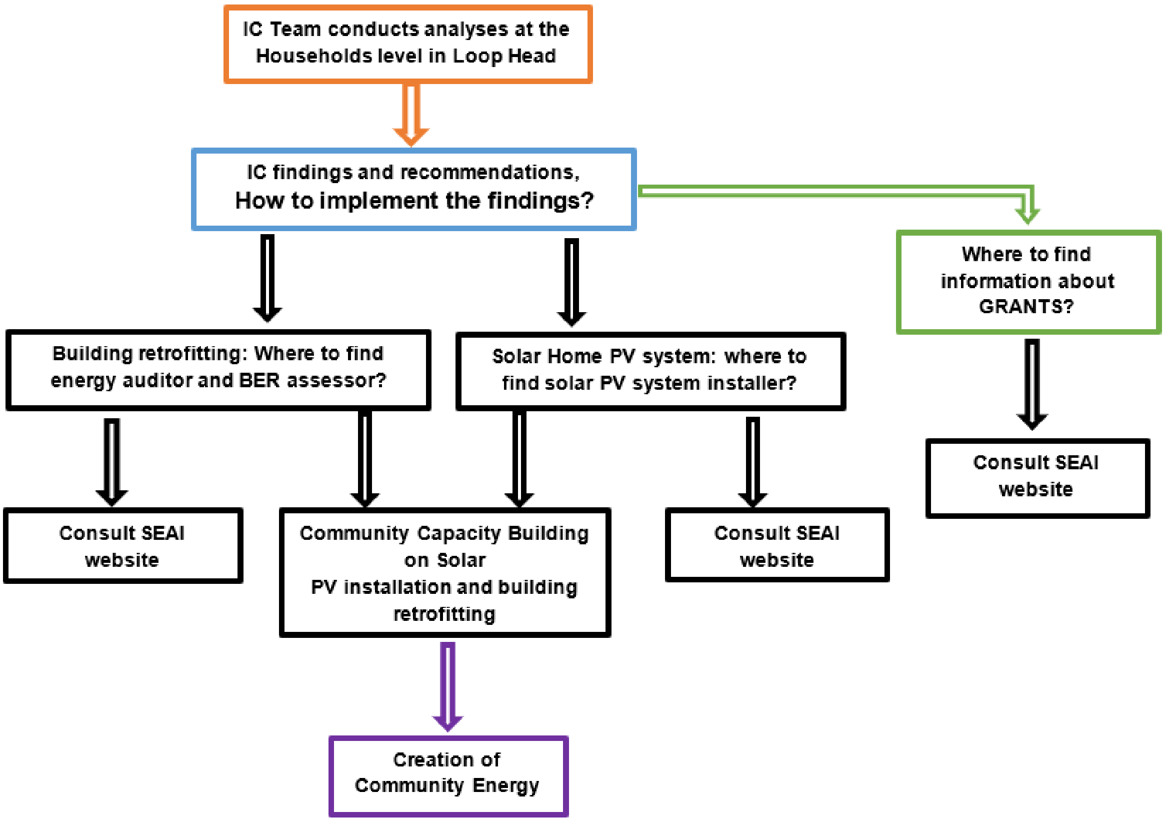


Figure 9.1: Way forward LEAP project
Source: Author

Information about grants for both solar electricity and building retrofitting are stated in Chapter 4. More in-depth information about grants is found on the SEAI website. Additionally, the SEAI website has information about where to find solar PV system installers, energy auditors as well as BER assessors. Another alternative for skilled labour as described in sub-chapter 9.1 is from capacity building of the community which could lead to the creation of social enterprise locally. There are numbers of social enterprise development funds in Ireland that the Loop Head community can also benefit from. Rethink Ireland, for example, provide € 9 million in cash grants and business support to 71 social enterprises in every county (Rethink Ireland, 2022). An initiative of creating a social enterprise in Loop Head could be proposed via the LT LEAP group.

Next step to be taken for house owners

9.1. Community energy capacity building

The Loop Head community is facing several challenges. One of the challenges is emigration. According to (Euromonitor International, 2016). Loop Head has experienced emigration during the recent economic growth period of Ireland which led to a significant decrease in the size of the population. According to (EEM IC, 2020) for instance, the population of Kilkee, the main village of Loop Head, decreased by 30% in a period of 10 years. Another challenge in Loop Head is the limited job opportunities within the peninsula, which is also a factor driving the migration of the residents to other locations. The community members also stated that there is not enough skilled labour in Loop Head who can assist them on matters such as installation of a solar PV system and building retrofitting for their homes. Thus, they are compelled to look for assistance from outside of Loop Head, which sometimes can be challenging.

To address these challenges, the community members should have access to training to gain technical skills that allow them to work on the installation by themselves. After the training, certificates should be delivered to the community to enable them to apply for job opportunities within the same field. In this regard, there should be a collaboration between trade associations and the Loop Head community. The association can offer training related to solar PV installation and building retrofitting to the community. This will address the issue related to the lack of skilled labour in the local area as described in sub-chapter 8.2.4. This will also create job opportunities for the community and subsequently attract residents to come back to Loop Head. Overall, socio-economic benefits could be induced to the community from capacity building.

9.2. Community ownership of renewable energy projects

According to (IRENA, 2020), “Community-ownership structures, in the context of the global energy transition and the decentralization of power systems, refer to the collective ownership and management of energy-related assets, usually distributed energy resources”. Energy community is a movement that brings the community together into the heart of the energy system. Energy community harnesses the power of renewable resources and provides the local community with clean and sustainable energy. It has recently experienced rapid growth given the opportunities it offers in producing energy from renewable sources and in reducing dependence on fossil fuels. Energy community is one of the tools used by the EU to drive the green transition regionally (Boulanger et al., 2021). Local energy communities involve citizens, public and private actors who both produce, sell and consume sustainable energy. Sustainable energy is then shared within the community and additional energy generated is sold to the grid. An example of community energy is the collective purchase of solar modules by the community members living in one area or a group of community members who collectively invest in a wind turbine and sell the output energy to the consumers living nearby or to the grid. (Gall J., 2018) reports that community-ownership projects vary in size but are often between 5 kW and 5 MW, depending on where they are being implemented. There are different energy community ownership models according to (IRENA, 2020) including community-owned electricity generation plants such as solar PV plants, wind power plants and biomass plants, community-owned district heating systems and community energy storage systems. Figure 9.2 depicts an energy system based on the community-ownership business model.

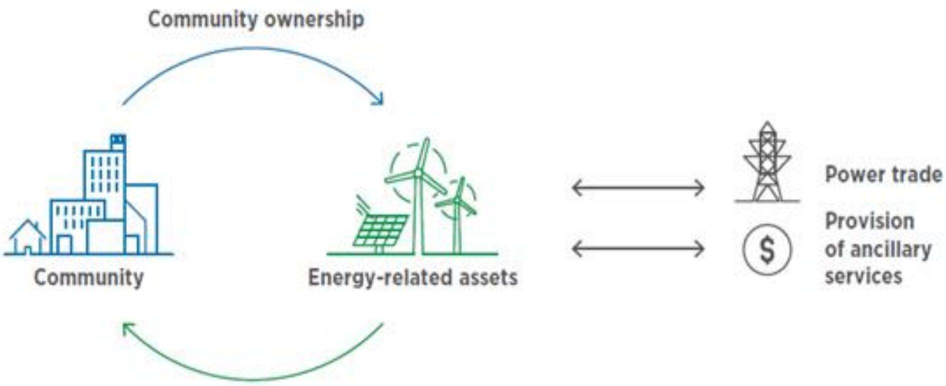


Figure 9.2: S Schematic of energy system based on the community-ownership business model
Source: (IRENA, 2020)

(Caramizaru, 2020) reports that 21 % of the solar installed in Europe could be owned by energy communities by 2030 and in the nine European countries that he investigated, there are 3,500 renewable community energy projects. Those projects, as shown in Figure 9.3 below, are mostly based in North-Western Europe. Community energy is not something new in Ireland, 500 communities are part of the Sustainable Energy Authority of Ireland's (SEAI's) community energy network and more than 25,000 citizens are engaged with it (SEAI, 2017d). An example of this is the Templederry Community Wind Farm in Co Tipperary which is now supplying electricity to homes and businesses all over Ireland and generating local jobs in rural communities. Community energy can be a potential opportunities for the community in Loop Head given the socio-economic benefit described in sub-chapter 9.5 it offers.

Next step to be taken for house owners

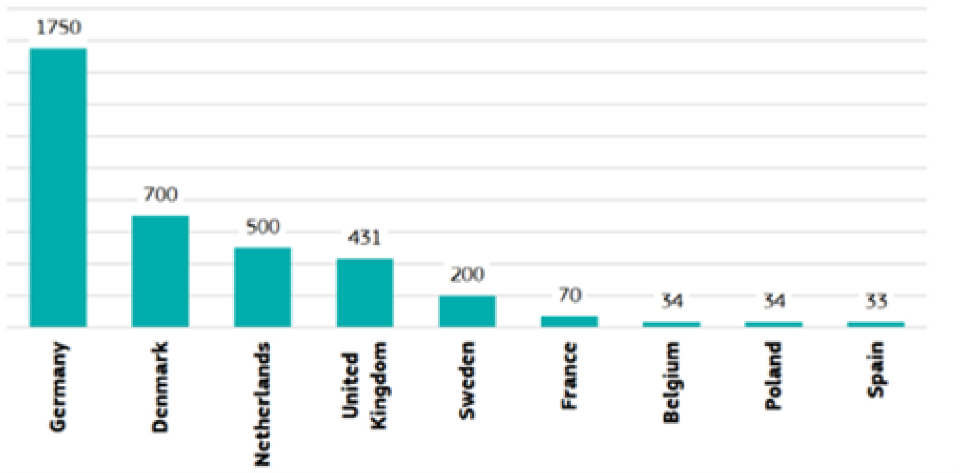


Figure 9.3: Number of community energy initiatives from the nine European countries
Source: (Caramizaru, 2020)

9.3. Solar community

Solar energy is one of the cheapest forms of clean energy. Its cost has steadily declined due to the fall in the cost of solar panels. This cost decline has turned solar into a booming industry in recent years. Community solar, which is a term used to describe solar farms owned by the members of the community, is a fast-growing part of the solar industry. According to (SEAI, 2021a), the US community solar market has grown from 66 MW to 1.8 GW since 2014, and currently, 25 states have at least one functional community solar project. Concerning Europe, (Caramizaru, 2020) reports that solar energy has the highest share of energy community projects in Europe. As shown is in Figure 9.4 below, solar represents 38 % of the total community energy projects in Europe.

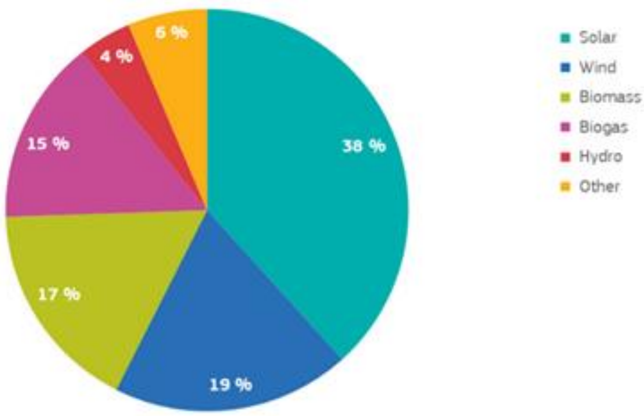


Figure 9.4: Energy community share per technology in Europe
Source: : (Caramizaru, 2020)

Next step to be taken for house owners

9.4. Community solar participation models

There are two community solar participation models: ownership-based and subscription-based community solar (Etelson E., 2022). In the ownership-based model, the participants own a share in the project (own some of the solar panels for instance), then receive credit for all the electricity their share generates. In subscription-based community solar, on the other hand, the community members do not own the solar farm, it is owned by a solar developer. However, each of the community members can buy part of the electricity generated from the solar farm at a lower price than the grid rate.

For both the subscription-based and the ownership-based models, the electricity produced at the farm is injected into the national grid. In the former, the members of the community solar (or subscribers) continue to receive their electricity bill from the utility. The share of electricity from the solar farm will then appear as a credit in the bill, which will lower the monthly electricity bill of the subscribers. Additionally, the subscriber will also receive a separate bill from the solar developer (Etelson E., 2022). During summer, when the solar panels generate more electricity, the subscribers will earn more credits. The surplus of the credit earned during the previous months will be added to the credit in the following months. In the latter, i.e., the case of the ownership-based model, the difference is that the community members do not pay any money for the electricity from the solar farm. However, if their electricity consumption is higher than the electricity produced from their share, they have to pay for the extra electricity to the utility. Figure 9.5 illustrates the electricity billing in community solar.

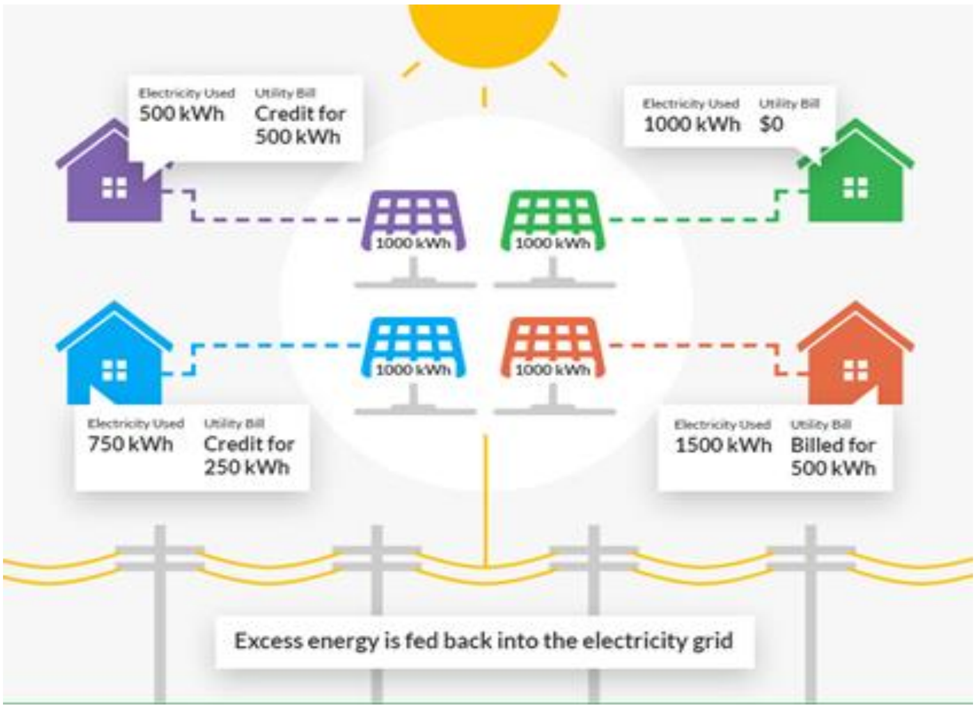


Figure 9.5: Community solar billing system
Source: (Etelson E., 2022)

Next step to be taken for house owners

9.5. Benefit of solar community

According to (Melius et al., 2013) only 22 % to 27 % of the residential rooftop area is suitable for hosting an on-site PV system. There are many reasons for which rooftop is not suitable for solar panels such as the roof size being too small to accommodate solar panels, the roof being too shaded, or restrictions from the landlords. Community solar is the solution for those who cannot have a traditional rooftop solar system in their own home. Another benefit of community solar is scalability, contrary to a solar rooftop system in which roof area is limited, community solar has the advantage of expanding the system, which makes it more flexible.

Additionally, community solar is an approach that allows everybody to participate in the benefits of solar (Maria G., 2019) It facilitates the process for low-income community members who do not have the necessary financial means to install a rooftop solar system, to benefit from solar energy and reduce their carbon footprint as described in sub-chapter 8.1.5 and 8.2.4. The goal of community solar is to bring solar to every household in the community. With community solar, a wide range of the community is engaged in planning, operating and maintaining the clean energy solution. To bring solar to all households in the Loop Head community is feasible through a solar community project.

From the economic point of view, community solar projects create local job opportunities such as during the construction and installation process of the PV system. After capacity building in collaboration with local institutions, as mentioned earlier, the community members can occupy these job opportunities themselves. Therefore, in response to the limited employment in Loop Head, community solar could be one of the solutions. But for the community solar to work, the community should be aware of the benefit it can bring so that the community is willing to get involved in it.

At a household level, Loop head community can also benefit from peer to peer (P2P) trading model as shown in Figure 9.6 below. Peer to peer electricity trading is a business model where households in a community that own rooftop solar home system can trade electricity among themselves at a desired price (IRENA, 2020). The benefit of P2P is that a household can sell the surplus energy from their solar PV system but also can buy surplus of energy at lower price compared to grid price from other households. With P2P, all households can benefit from the energy trade.

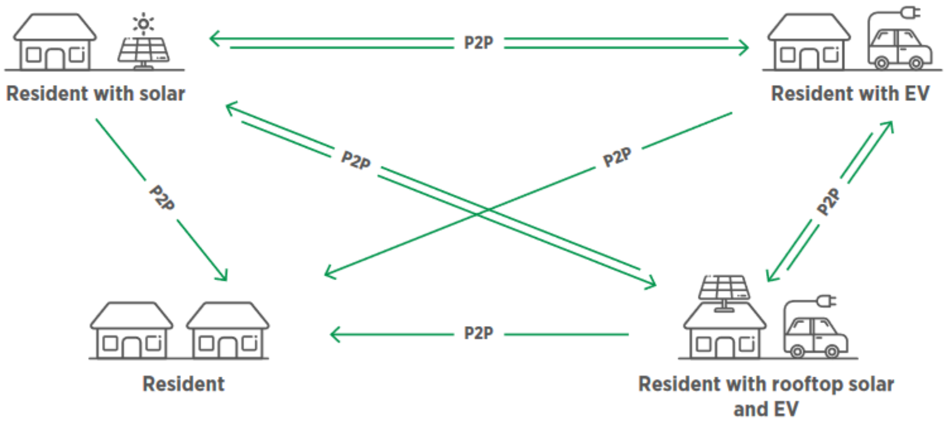


Figure 9.6: Structure of P2P electricity trading model
Source: (IRENA, 2020)

10. Conclusion and recommendation

Hiram Masese

IC 2022 team received a warm welcome back in Loop Head, especially after their predecessors had conducted IC 2021 virtually due to COVID-19 travelling restrictions at the time of their project execution. The community's interest in the project and the willingness to offer support was evident from when the Flensburg team arrived in Loop Head. On their part, the IC 2022 team planned a number of activities, such as solar lab demonstrations, to continuously engaging with the community members. This resulted in a highly hands-on project.

This study focused on the residential sector by building on previous years' work. At a community level, the findings indicated that a short-term strategy is needed for capacity building where a dedicated group of energy enthusiasts could be trained further and in turn, share the knowledge with the larger community. This approach will benefit the house owners with basic knowledge on efficient use of energy as well as appraise them on a roadmap towards the use of sustainable energy in their homes. The residents will enhance their knowledge on how energy matters and the energy-political framework that defines the space for action, and learn to differentiate facts from propaganda. The formulated group will be energy champions offering energy-related services and advice to the community. In the long-run, the group could also offer support on energy-related entrepreneurial ventures within the community. The community could aim to utilize the expertise in designing, procuring and installing Solar PV systems in the region. Provision of such services locally will ensure potential savings for residents who currently pay expensive costs to import labour and, in turn, economic growth for Loop Head when the savings are invested in other enterprises. Further, their training and facilitation services could extend to neighbouring communities hence earning Loop Head residents some additional income. Borrowing from community-level energy schemes from other regions, IC 2022 recommended that Loop Head members could consider trading energy among themselves in their quest to become energy sufficient, in a peer-to-peer energy network.

At a household level, the study revealed that most of the heat losses from households occurred through poorly insulated walls and roofs and that retrofitting of poorly insulated roofs should particularly be prioritized. Whereas the recommendations on retrofits are dependent on the results of a detailed energy audit of the building, the study indicated that the replacement of windows and doors, as part of the building’s envelope, generally have the least impact on energy savings. Additionally, the installation of efficient heat pumps and solar PV systems after envelope retrofits was noted to significantly improve the energy efficiency and, hence the comfort levels of homes as well as improved living standards, by creating warm and comfortable homes.

The interaction with the local residents revealed that a significant number operated their heat systems twice a day, in morning and evening cycles. However, this study indicated that such a practice leads to rapid cooling occurring in buildings which necessitates significantly higher energy for each heating cycle, as well as secondary heating from electricity and solid fuels. In contrast, IC 2022 estimated that lower energy would be needed in the case of a 24-hour thermostat-controlled system in households.

IC 2022 highlighted a roadmap towards sustainable energy in residential buildings at Loop Head to guide the residents in the projects. The residents were advised to:

i. Seek support from an energy expert in understanding their consumption pattern as a crucial first step when planning for energy efficiency measures in their household.

ii. Eliminate unnecessary electricity demand. This, together with knowledge of their consumption patterns, helps in preventing either over expenditure or under expenditure in investment decisions as the capacity of either solar PV or space heating units is dependent on the energy demand.

iii. Retrofit their building to eliminate heat losses in cases of poor insulation. However, IC 2022 advised that an individual that needs to carry out all home energy upgrades at once, an individual doesn't need to carry out all upgrades at once. On the contrary, building efficiency can be improved through a series of steps towards the desired state.

iv. Hold conversations with individuals who have already installed the desired energy technology to gain a basic understanding of how the system works. Residents were encouraged to learn from the 1.28 kWp solar PV system being installed at Keane's Beer Garden, at the time of writing this report.

v. Check on available grants they were eligible for which may reduce the capital expenditure of the intended projects. To be eligible for grants, one has to comply with the set standards which require that technology installations must be conducted by installers certified by SEAI.

vi. Seek professional support in the purchasing and installation of the energy system desired.

The 3 sampled households under the IC 2022 study were approximated to be representative of residential buildings in Loop Head. The project was estimated to give a general overview of the measures and costs which would be incurred by comparable household types in Loop Head.

On the environmental impact assessment, the study of the life cycle from raw materials and manufacturing, transport and use of solar PV components revealed that the use of solar energy is associated with CO_2 emissions, especially from the manufacturing phase of the solar modules. However, the findings indicated that this share is significantly lower as compared to the emissions resulting from the current Irish electricity mix. Consequently, the level of emissions resulting from the use of solar energy was considered to be manageable.

Additionally, the results from the land use analysis suggest that the use of solar energy has a lower negative impact on land areas than that caused by the current Irish electricity grid. Since the majority of residents in Loop Head are farmers while others are employed in the agricultural sector, the adoption of solar energy implies lesser constraints to the farming sector in Loop Head.

The socio-economic impact assessment of the cases studied in this research showed positive indicators. For instance, installing solar PV on a household level would benefit both the Irish economy (through the generation of gross value added) as well as support job creation within Ireland. The findings revealed, that if one household in Loop Head installed a solar PV system, for every one euro spent by the household owner the Irish economy would gain approximately 30 cents in gross value added.

Further, by considering the construction and installation phases and assuming that over a period of 11 years, 100 households per year in Loop Head install ground-mounted solar PV systems, one person in Loop Head would be employed for at least 11 years (for a 2.96 kWp system). The number would be higher for roof-top installation.

11. References

Acero, A. P., Rodríguez, C., & Changelog, A. C. (2015a). *LCIA methods Impact assessment methods in Life Cycle Assessment and their impact categories*. http://www.openlca.org/files/openlca/Update_info_open

Acero, A. P., Rodríguez, C., & Changelog, A. C. (2015b). *LCIA methods Impact assessment methods in Life Cycle Assessment and their impact categories*. http://www.openlca.org/files/openlca/Update_info_open

Agas. (2022). *R32 | Refrigerant Gases | Europe*. https://www.agas.com/eu/products-services/products-refrigerants/hfc/r32/

Ahern, C., Griffiths, P., & O'Flaherty, M. (2013). State of the Irish housing stock—Modelling the heat losses of Ireland's existing detached rural housing stock & estimating the benefit of thermal retrofit measures on this stock. *Energy Policy*, *55*, 139–151. https://doi.org/10.1016/J.ENPOL.2012.11.039

Aitor P. Acero, Cristina Rodríguez, & Andreas Ciroth. (2005). *LCIA methods Impact assessment methods in Life Cycle Assessment and their impact categories*. https://www.openlca.org/wp-content/uploads/2015/11/LCIA-METHODS-v.1.5.4.pdf

Alexey Dedulin. (2019). *Виды утеплителей для стен дома изнутри: разновидности теплоизоляционных материалов и их особенности*. https://sovet-ingenera.com/otoplenie/uteplenie/vidy-uteplitelej-dlya-sten-doma-iznutri.html

Anders Rosenkjær Andersen. (2021). *Technology Data Catalogue for Individual Heating Installations*.

Asset Heating & Solar. (2020). *HEAT PUMPS | Asset Heating & Solar*. https://assetheatingandsolar.ie/heat-pumps/

Astoneco Management. (n.d.). *Astoneco Management*.

Astoneco Management. (2020). *Astoneco Management*. https://www.astoneco.com/blog/leap-international-class-report-1-leap-towards-energy-sustainability-communities-loop-head

Aurora. (2021). *Comprehensive Guide to Solar Panel Types - Aurora Solar*. https://www.aurorasolar.com/blog/solar-panel-types-guide/

BOC Online. (2022). *R32 | BOConline Ireland*. https://www.boconline.ie/en/products-and-supply/refrigerant-gases/hfcs/r32/index.html

References

Bord Gais. (2021). *Your Guide to Heat Pumps in Ireland | Bord Gáis Energy*. https://www.bordgaisenergy.ie/home/heat-pump-guide

Borowicz, J. J., Psp, C., Brown, R. B., Donaldson, D. C., Dysert, L. R., Cep, C., Garcia Da Roza, R., Hollman, J. M., Hollmann, J. K., Cep, C., Kutilek, F., Mccuen, T. L., Parker, D. E., Todd, C., Pickett, W., Sinnathamby, K., Stephenson, C. H. L., Uppal, K. B., & Whiteside, J. D. (n.d.). *COST ESTIMATE CLASSIFICATION SYSTEM-AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE BUILDING AND GENERAL CONSTRUCTION INDUSTRIES*.

Borowicz, J. J., Psp, C., Brown, R. B., Donaldson, D. C., Dysert, L. R., Cep, C., Garcia Da Roza, R., Hollman, J. M., Hollmann, J. K., Cep, C., Kutilek, F., Mccuen, T. L., Parker, D. E., Todd, C., Pickett, W., Sinnathamby, K., Stephenson, C. H. L., Uppal, K. B., & Whiteside, J. D. (2020). *COST ESTIMATE CLASSIFICATION SYSTEM-AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE BUILDING AND GENERAL CONSTRUCTION INDUSTRIES*.

Boulanger, S. O. M., Massari, M., Longo, D., Turillazzi, B., & Nucci, C. A. (2021). Designing collaborative energy communities: A european overview. *Energies*, *14*(24). https://doi.org/10.3390/en14248226

Brockway, P. E., Owen, A., Brand-Correa, L. I., & Hardt, L. (2019a). Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources. *Nature Energy*, *4*(7), 612–621. https://doi.org/10.1038/s41560-019-0425-z

Brockway, P. E., Owen, A., Brand-Correa, L. I., & Hardt, L. (2019b). Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources. *Nature Energy*, *4*(7), 612–621. https://doi.org/10.1038/s41560-019-0425-z

Caramizaru, A. (2020). *Energy communities: an overview of energy and social innovation*. 3. https://doi.org/10.2760/180576

CARBON BRIEF STAFF. (2013). *Energy return on investment - which fuels win? - Carbon Brief*. https://www.carbonbrief.org/energy-return-on-investment-which-fuels-win

Carvalho, M. L., Temporelli, A., & Girardi, P. (2021). Life cycle assessment of stationary storage systems within the italian electric network. *Energies*, *14*(8). https://doi.org/10.3390/en14082047

CFI. (2022). *Discounted Payback Period - Definition, Formula, and Example*. https://corporatefinanceinstitute.com/resources/knowledge/finance/discounted-payback-period/

References

Charlotte Cochrane; Shona Pennock; Henry Jeffrey. (2021). *A study into the potential economic value offered to Europe from the development and deployment of wave and tidal energy to 2050*. www.ETIPOcean.eu

Chordia, M., Nordelöf, A., & Ellingsen, L. A.-W. (2021). Environmental life cycle implications of upscaling lithium-ion battery production. *The International Journal of Life Cycle Assessment*, *26*(10), 2024–2039. https://doi.org/10.1007/s11367-021-01976-0

Claudia Fruhmann, & Nina Knittel. (2016). Community Energy Projects: Europe's Pioneering Task. *Climate Policy Info Hub*. http://climatepolicyinfohub.eu/community-energy-projects-europes-pioneering-task

Clean Energy Council. (2022). *Community Engagement*. Clean Energy Council. https://www.cleanenergycouncil.org.au/advocacy-initiatives/community-engagement

Coyle, D. (2015). "A Life Cycle Cost Analysis of an Irish Dwelling Retrofitted to Passive House Standard: Can Passive House Become a Cost-Optimal Low-Energy Retrofit Standard? *Https://Arrow.Tudublin.Ie/Builtmas/22*.

CRU. (2021). *An Coimisiún um Rialáil Fóntais Commission for Regulation of Utilities An Coimisiún um Rialáil Fóntais Commission for Regulation of Utilities Remuneration of Renewables Self-consumers for exported electricity: Interim Clean Export Guarantee Decision Paper*.

CRU. (2022). *An Coimisiún um Rialáil Fóntais Commission for Regulation of Utilities An Coimisiún um Rialáil Fóntais Commission for Regulation of Utilities Non-binding Guidance to Electricity Suppliers on implementation aspects of Interim Clean Export Guarantee Guidance Notes*. www.cru.ie

Dave Judd. (2021). *Suspended Timber Floor Insulation - Best Practice Installation Guide | Ecological Building Systems*. https://www.ecologicalbuildingsystems.com/post/suspended-timber-floor-insulation-best-practice-installation-guide

DD - Stroi. (2020). *Projects of houses for construction*. https://dd-stroi.ru/shop/

DEFRA. (2008a). *Measurement of Domestic Hot Water Consumption in Dwellings*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

DEFRA. (2008b). *Measurement of Domestic Hot Water Consumption in Dwellings*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

References

Dineen, D., Howley, M., & Ó Cléirigh, B. (2020). *ENERGY SECURITY IN IRELAND 2020 Report*. https://www.seai.ie/publications/Energy-Security-in-Ireland-2020-.pdf

EEM IC. (2020). *A LEAP TOWARDS ENERGY SUSTAINABILITY FOR LOOP HEAD COMMUNITIES*.

EIRGRID. (2022). *CO2 Intensity - Ireland*. https://www.eirgridgroup.com/how-the-grid-works/system-information/

EirGrid. (2022). *EirGrid Group plc - Smart Grid Dashboard - CO2 Intensity*. https://www.smartgriddashboard.com/#roi/co2

Electric Vehicle Database. (2021). *Nissan Leaf 30kWh*.

Energlaze. (2022). *What is a BER and how do I get one? — Energlaze*. https://www.energlaze.ie/what-is-a-ber/

Energyd. (2022). *Solar Panel Power Diverters For Hot Water*.

Etelson E. (2022). *Promoting Community Solar How to Bring Clean Energy to Your Neighborhood*. https://www.letsgosolar.com/consumer-education/community-solar/

Euromonitor International. (2016). *Sustainability Series: Ireland's Loop Head Provides Best-Case Study in Destination Management*. https://www.euromonitor.com/article/sustainability-series-irelands-loop-head-provides-best-case-study-in-destination-management-part-1

European Commission. (n.d.). *European Platform on Life Cycle Assessment*. Retrieved February 11, 2022, from https://eplca.jrc.ec.europa.eu/?page_id=140.

European Heat Pump Association. (2021). *EHPA - EHPA*. https://www.ehpa.org/

Florida solar design group. (2020). *Whole Home Solar Backup vs Critical Load Backup*.

Fouad, M. M., Shihata, L. A., & Morgan, E. I. (2017). An integrated review of factors influencing the perfomance of photovoltaic panels. *Renewable and Sustainable Energy Reviews*, *80*, 1499–1511. https://doi.org/10.1016/j.rser.2017.05.141

Frank Brentrup, Jürgen Küsters, Joachim Lamme, & Hermann Kuhlmann. (2002). Life Cycle Impact assessment of land use based on the hemeroby concept. *The International Journal of Life Cycle Assessment Volume*, *7*. https://link.springer.com/article/10.1007/BF02978681

Frischknecht, R. (2015). *Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems Product Environmental Footprint Pilot: Electricity from Photovoltaic Panels View* *project Green Hospital-Environmental Impact Assessment, Resource Efficiency, and Hands-on Applications View project*. https://www.researchgate.net/publication/279180644

Frischknecht, R., Krebs, L., Scholten, M. de W., Sinha, P., & Stolz, P. (2020). *Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems 2020* .

Gall J. (2018, April 10). *The benefits of community-owned renewable energy projects*. https://renewableenergy.usask.ca/news-articles/the-benefits-of-community-owned-renewable-energy-projects.php

Global Solar Atlas. (2021). *Global Solar Atlas*. https://globalsolaratlas.info/map?c=52.63598,-9.63398,11&s=52.636,-9.6338&m=site

Government of Ireland. (2021). *gov.ie - Micro-generation*. https://www.gov.ie/en/publication/b1fbe-micro-generation/

Government of Ireland. (2022, February 8). *gov.ie - Government launches the National Retrofitting Scheme*. https://www.gov.ie/en/press-release/government-launches-the-national-retrofitting-scheme/

Grant Engineering. (n.d.). *Grant FAQ's*. Retrieved February 20, 2022, from https://grantengineering.ie/knowledge-hub/faqs/

Hall, C. A. S., Lambert, J. G., & Balogh, S. B. (2014). EROI of different fuels and the implications for society. *Energy Policy*, *64*, 141–152. https://doi.org/10.1016/j.enpol.2013.05.049

Hassellöv, I., Turner, D. R., Lauer, A., & Corbett, J. J. (2013). Shipping contributes to ocean acidification. *Geophysical Research Letters*, *40*(11), 2731–2736. https://doi.org/10.1002/grl.50521

Heat Pumps-Implementation Guide Heat Pumps Implementation Guide. (2020).

Heath, G., Fthenakis, V., Kim, H. C., Frischknecht, R., Raugei, M., Sinha, P., & Stucki, M. (2015). *Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems IEA PVPS Task 12, Subtask 2.0, LCA Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems*.

Herrando, M., Markides, C. N., & Hellgardt, K. (2014). A UK-based assessment of hybrid PV and solar-thermal systems for domestic heating and power: System performance. *Applied Energy*, *122*, 288–309. https://doi.org/10.1016/j.apenergy.2014.01.061

References

Homer. (2021). *Grid Costs*. https://www.homerenergy.com/products/pro/docs/latest/grid_costs.html

IAP2 Federation. (2014). *IAP2_Public_Participation_Spectrum*.

IC. (2020). *A LEAP TOWARDS ENERGY SUSTAINABILITY FOR LOOP HEAD COMMUNITIES*.

IEA. (2019). *China, Key energy statistics, 2019*. https://www.iea.org/countries/china

IEA. (2020). *Heat Pumps – Analysis - IEA*. https://www.iea.org/reports/heat-pumps

Insulation Superstore. (2020). *Insulating a floor - Insulation Superstore Help & Advice*. https://www.insulationsuperstore.co.uk/help-and-advice/project-guides/insulation/insulating-a-floor/

IRENA. (2018). *TRANSFORMING SMALL-ISLAND POWER SYSTEMS: TECHNICAL PLANNING STUDIES FOR THE INTEGRATION OF VARIABLE RENEWABLES*.

IRENA. (2020). *PEER-TO-PEER ELECTRICITY TRADING - INNOVATION LANDSCAPE BRIE*. https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Peer-to-peer_trading_2020.pd

IRENA, & ILO. (2021). *Renewable Energy and Jobs* . https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_RE_Jobs_2021.pdf

Irish Tax and Customs. (2022, January). *Reduced rate of VAT*. https://www.revenue.ie/en/vat/vat-rates/what-are-vat-rates/reduced-rate-of-value-added-tax-vat.aspx

Irwan, Y. M., Syafiqah, Z., Amelia, A. R., Irwanto, M., Leow, W. Z., & Ibrahim, S. (2016). Design the Balance of System of Photovoltaic for Low Load Application. *Indonesian Journal of Electrical Engineering and Computer Science*, *4*(2), 279. https://doi.org/10.11591/ijeecs.v4.i2.pp279-285

ISO. (2006). *ISO - ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework*. https://www.iso.org/standard/37456.html

Israel Urieli. (2014). *Chapter 5: The Second Law of Thermodynamics (updated 7/5/2014)*. https://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/Chapter5.html

James Frith. (2021, November 30). *Battery Price Declines Slow Down in Latest Pricing Survey*. Bloomberg Green.

References

Joseph Zacune. (2014, February). *Lithium*. Friends of the Earth Europe. https://www.foeeurope.org/sites/default/files/publications/13_factsheet-lithium-gb.pdf

Kansas State. (2020). *Leontif model*.

Kharseh, Mohamad., & Luleå tekniska universitet. Institutionen för samhällsbyggnad och naturresurser. (2011). *Reduction of prime energy consumption by ground source heat pumps in a warmer world*. Luleå tekniska universitet.

KMPG Ireland. (2015). *A Brighter Future A KPMG report for the Irish Solar Energy Association The Potential Benefits of Solar PV in Ireland*. https://irishsolarenergy.org/wp-content/uploads/2019/11/A-Brighter-Future.pdf

Koones, S. . (2020). Creating Energy Independence With Solar Panels And Storage Battery Systems In The Home. *Forbes*.

KORE. (2022). *Floor Insulation | KORE nZEB Floor Insulation | KORE Insulation*. https://www.kore-system.com/koreproduct/kore-floor-insulation/

Kumar, S. (2015). Modeling and Managing Stakeholder's Power and Influence for Quality Improvement in Construction Projects-A Case Study at-Jaipur Metroll. In *SSRG International Journal of Civil Engineering* (Vol. 2). www.internationaljournalssrg.org

Kun-Mo Lee, A. I. (2004a). *Life Cycle Assessment Best Practices of ISO 14040 Series Ministry of Commerce, Industry and Energy Republic of Korea Asia-Pacific Economic Cooperation Committee on Trade and Investment*. https://www.apec.org/-/media/APEC/Publications/2004/2/Life-Cycle-Assessment-Best-Practices-of-International-Organization-for-Standardization-ISO-14040-Ser/04_cti_scsc_lca_rev.pdf

Kun-Mo Lee, A. I. (2004b). *Life Cycle Assessment Best Practices of ISO 14040 Series Ministry of Commerce, Industry and Energy Republic of Korea Asia-Pacific Economic Cooperation Committee on Trade and Investment*. https://www.apec.org/-/media/APEC/Publications/2004/2/Life-Cycle-Assessment-Best-Practices-of-International-Organization-for-Standardization-ISO-14040-Ser/04_cti_scsc_lca_rev.pdf

lb-na-28266-en-n (1). (n.d.).

Leonard, B. (2022). *Solar Deep Dive*.

Lind, L. (2012). *The rise and rise of geothermal heat pumps in New Zealand*. https://www.researchgate.net/publication/316919670

LONGi. (2022, January 14). *About Us - Globalization*. https://www.longi.com/en/global-distribution/

References

Loop Head Together. (n.d.). *Let’s co-create our future!*

Ludin, N. A., Mustafa, N. I., Hanafiah, M. M., Ibrahim, M. A., Asri Mat Teridi, M., Sepeai, S., Zaharim, A., & Sopian, K. (2018). Prospects of life cycle assessment of renewable energy from solar photovoltaic technologies: A review. In *Renewable and Sustainable Energy Reviews* (Vol. 96, pp. 11–28). Elsevier Ltd. https://doi.org/10.1016/j.rser.2018.07.048

Maria G. (2019, April 4). *Energy Equity: Bringing Solar Power to Low-Income Communities*. https://e360.yale.edu/features/energy-equity-bringing-solar-power-to-low-income-communities

Marlec. (2016). *Install a Solar iBoost + and watch your heating bills fall! Gives you free hot water from your PV array! The UK’s favourite PV accessory!* www.solariboost.co.uk

MB services. (2019). *Air to Air Heat Pumps - MB Services*. https://www.mbservicesgroup.com/funding/heat-pumps/air-to-air-heat-pumps/

Melius, J., Margolis, R., & Ong, S. (2013). *Estimating Rooftop Suitability for PV: A Review of Methods, Patents, and Validation Techniques*. www.nrel.gov/publications.

Met Eireann. (2022). *Shannon Airport Hourly Data - Datasets - data.gov.ie*. https://data.gov.ie/dataset/shannon-airport-hourly-data?package_type=dataset

My Building Supplies. (2022). *Grant Vortex External Oil Boiler 90-120 (26-36kw) - MyBuildingSupplies.ie*. https://mybuildingsupplies.ie/shop/plumbing-heating/oil-boilers/grant-vortex-external-oil-boiler-90-120-26-36kw/?gclid=CjwKCAiA6seQBhAfEiwAvPqu1yOg8kd8o9EXIJb10RvctPRwd_cb-iZGQHFDIrKRMypcORR2Ajw91xoCsjkQAvD_BwE

NASA. (n.d.). *Second Law of Thermodynamics*. Retrieved February 20, 2022, from https://www.grc.nasa.gov/www/k-12/airplane/thermo2.html

NOAA. (2020, April 1). *Ocean acidification*. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

OECD.stat. (2021). *Input-Output Tables (IOTs) 2021 ed.* https://stats.oecd.org/Index.aspx?DataSetCode=IOTS_2021

OpenLCA. (2022). *OpenLCA 1.10.3* (1.10.3). https://www.openlca.org/.

Pérez-López, P., Gschwind, B., Blanc, P., Frischknecht, R., Stolz, P., Durand, Y., Heath, G., Ménard, L., & Blanc, I. (2017). ENVI-PV: an interactive Web Client for multi-criteria life cycle assessment of photovoltaic systems worldwide. *Progress in Photovoltaics: Research and Applications*, *25*(7), 484–498. https://doi.org/10.1002/pip.2841

References

PV production. (2022). *Refining Silicon | PVEducation*. https://www.pveducation.org/pvcdrom/manufacturing-si-cells/refining-silicon

PVGIS. (2019, October 15). *JRC Photovoltaic Geographical Information System (PVGIS) - European Commission*. https://re.jrc.ec.europa.eu/pvg_tools/en/#MR

R Nave. (2014). *Heat Pump*. http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatpump.html

Renewable Ninja. (2022). *Renewables.ninja*. https://www.renewables.ninja/

Renfrow, S. (2004). *What is the Energy Payback for Crystalline-Silicon PV Systems? What is the energy payback for PV? Energy Efficiency and Renewable Energy*. www.nrel.gov/ncpv.

Rethink Ireland. (2022). *Social Enterprise* . https://rethinkireland.ie/our-funds/social-enterprise/

Ricardo. (2020a). *Economic and policy advice to support the design and implementation of the new microgeneration support scheme in Ireland*.

Ricardo. (2020b). *Economic and policy advice to support the design and implementation of the new microgeneration support scheme in Ireland*.

Ronald E. Miller, & Peter D. Blair. (2009). *Input–Output Analysis Foundations and Extensions* (Vol. 2). Cambridge University Press. https://soc.razi.ac.ir/documents/443820/0/ستانده20%داده

Rutovitz, J., Dominish, E., & Downes, J. (2015). *Calculating global energy sector jobs: 2015 methodology*. https://opus.lib.uts.edu.au/bitstream/10453/43718/1/Rutovitzetal2015Calculatingglobalenergysectorjobsmethodology.pdf

SEA-DISTANCES. (2022, January 14). *Sea Distances*. https://sea-distances.org

SEAI. (n.d.-a). *DEAP-Heat-pump-methodology-2020-V1.0*.

SEAI. (n.d.-b). *HomeOwners Guide to Heat Pump Systems*. www.seai.ie

SEAI. (n.d.-c). *HomeOwners Guide to Heat Pump Systems*. www.seai.ie

SEAI. (2017a). *Best Practice Guide Photovoltaics (PV) CONTENTS Best Practice Guide-Photovoltaics (PV) 2 Best Practice Guide-Photovoltaics (PV)*. 17–18.

SEAI. (2017b). *Ireland's Solar Value Chain Opportunity*. https://www.seai.ie/publications/Solar-Chain-Opportunity-report.pdf

References

SEAI. (2017c). *Solar Electricity PV Grants | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/solar-electricity-grant/

SEAI. (2017d). *Start an Energy Community*. https://www.seai.ie/community-energy/sustainable-energy-communities/start-an-energy-community/

SEAI. (2020a). *HOW YOU CAN BENEFIT FROM INVESTING IN ATTIC OR RAFTER INSULATION*. www.seai.ie

SEAI. (2020b). *Solar PV Scheme Guide Solar PV Scheme Application Guide*. 3–4.

Seai. (2020). *Domestic Energy Assessment Procedure (DEAP)*. https://www.seai.ie/energy-in-business/ber-assessor-support/deap/.

SEAI. (2021a). *Community action in tackling climate change at an all time high, with more than 25,000 citizens engaged across the community energy network.* https://www.seai.ie/news-and-media/more-than-500-communities/

SEAI. (2021b). *Dwelling Energy Assessment Procedure (DEAP) Guidance Document DEAP Guidance Document Dwelling Energy Assessment Procedure (DEAP) Guidance Document*.

SEAI. (2022a). *Air Source Heat Pump System Grants | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/heat-pump-systems/

SEAI. (2022b). *Air Source Heat Pump System Grants | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/heat-pump-systems/

SEAI. (2022c). *Domestic Fuels*. www.revenue.ie

SEAI. (2022d). *DOMESTIC SOLAR PHOTOVOLTAIC CODE OF PRACTICE FOR INSTALLERS Domestic Solar Photovoltaic-Code of Practice for Installers Code of Practice for Installers*.

SEAI. (2022e). *Electricity | Energy Statistics In Ireland | SEAI*. https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/electricity/

SEAI. (2022f). *Electricity | Energy Statistics In Ireland | SEAI*. https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/electricity/

SEAI. (2022g, February). *Energy Efficient Homes - Home Energy Upgrades And Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/

SEAI. (2022h, February). *Free Home Energy Upgrade | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/free-upgrades-for-eligible-homes/

References

SEAI. (2022i, February). *Individual Energy Upgrade Grants | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/individual-grants/

SEAI. (2022j, February). *One Stop Shop Services | Home Energy Grants | SEAI*. https://www.seai.ie/grants/home-energy-grants/one-stop-shop/

SEAI Blog. (2019, January 16). *Why Warm Houses For The Elderly Are Important | SEAI Blog | SEAI*. https://www.seai.ie/blog/warm-house/

Sea-route. (2021). *Port.com*. http://ports.com/sea-route/dublin-port,ireland/port-of-shanghai,china/

SEETECH. (2022). *Where Does Heat Loss Occur in a House?* https://seetech.no/where-does-heat-loss-occur-in-a-house/

Solartricity. (2022). *Mounting_Solutions_-TreeSystem*.

SpringerNature. (2021). *SpringerNature*. https://media.springernature.com/m685/springer-static/image/art%3A10.1038%2Fs41560-019-0440-0/MediaObjects/41560_2019_440_Fig1_HTML.png

SSE. (2018a). *Calculating the economic contribution of 10 years of onshore wind at SSE-2008 to 2018*. www.sse.com/beingresponsible/reporting-and-policy.

SSE. (2018b). *Calculating the economic contribution of 10 years of onshore wind at SSE-2008 to 2018*. www.sse.com/beingresponsible/reporting-and-policy.

Stainforth, T. (2021). *The socio- economic impacts of renewable energy in EU regions: Strengthening local benefits of renewable energy deployment*. www.ieep.eu

Statista. (2022). *• Ireland - Inflation rate 2026 | Statista*. https://www.statista.com/statistics/375229/inflation-rate-in-ireland/

Tabula. (2014, August). *Building Typology Brochure Ireland*. https://episcope.eu/fileadmin/tabula/public/docs/brochure/IE_TABULA_TypologyBrochure_EnergyAction.pdf

Tariq, J. (2019a). *Incorporating LCA in Solar PV Design and Planning for Sustainability Optimization*.

Tariq, J. (2019b). *Incorporating LCA in Solar PV Design and Planning for Sustainability Optimization*.

The Economic Times. (2017). *What are the GDP nad GVA in growth calculation?*

References

UNITED NATIONS. (2018). *Handbook on Supply and Use Tables and Input Output-Tables with Extensions and Applications*.

UO SRML. (2007). *UO SRML: Sun chart program*. http://solardat.uoregon.edu/SunChartProgram.html

USAID. (n.d.). *GUIDE TO COMMUNITY ENGAGEMENT FOR POWER PROJECTS IN KENYA*. www.ltwp.co.ke

Versta Research. (2011). *How to Estimate the Length of a Survey*.

WeatherSpark. (2021). *Weather Spark*. https://weatherspark.com/y/32674/Average-Weather-in-Shannon-Ireland-Year-Round

Window Efficiency. (2020). *WindowEfficiency1-1-1-1024x858.jpg (1024×858)*. https://www.buildingenergyvt.com/wp-content/uploads/2021/02/WindowEfficiency1-1-1-1024x858.jpg

world nuclear association. (2020). *Energy Return on Investment - World Nuclear Association*. https://world-nuclear.org/information-library/energy-and-the-environment/energy-return-on-investment.aspx

Zendehdel, M., Yaghoobi Nia, N., & Yaghoubinia, M. (2020). Emerging Thin Film Solar Panels. In *Reliability and Ecological Aspects of Photovoltaic Modules*. IntechOpen. https://doi.org/10.5772/intechopen.88733

Zondag, H. A. V., van Helden, W. G. J., Bakker, M., Affolter, P., Eisenmann, W., Fechner, H., Rommerl, M., Schaap, A., Soerensen, H., & Tripanagnostopoulos, Y. (2015). *PVT roadmap. A European guide for the development and market introduction of PVT technology*.

12. Annex

Annex 1: Stakeholder identification

S/N	Stakeholder	Stake in the project
1	Community Members	Target audience most affected by the project
2	Flensburg Students Team	Involved in the research and the daily execution of the project
3	Astoneco Management	Facilitated the development project of the IC within Loop Head Community
4	Loop Head Together Programme	Community-based group spearheading the overall development projects in Loop Head
5	F4 Energy Limited	Supplied solar panels used in the demonstration workshops and later installed at Keane's Beer Garden. They also offered technical input for conducted solar workshops.
6	Building Energy Rating Specialist	Offered technical input for households' energy assessment
7	Local Community Member with installed solar PV system	Offered input on benefits realized and challenges experienced from using the system during organized workshop
8	Sustainable Energy Authority of Ireland (SEA)	Source of information on regulation and policies of the energy sector in Ireland
9	Department of Immigration	Clearance for travel into Ireland
10	Department of Health	Offered updates on local Corona pandemic protocols
11	Noel O'shea Coaches	Local transport services

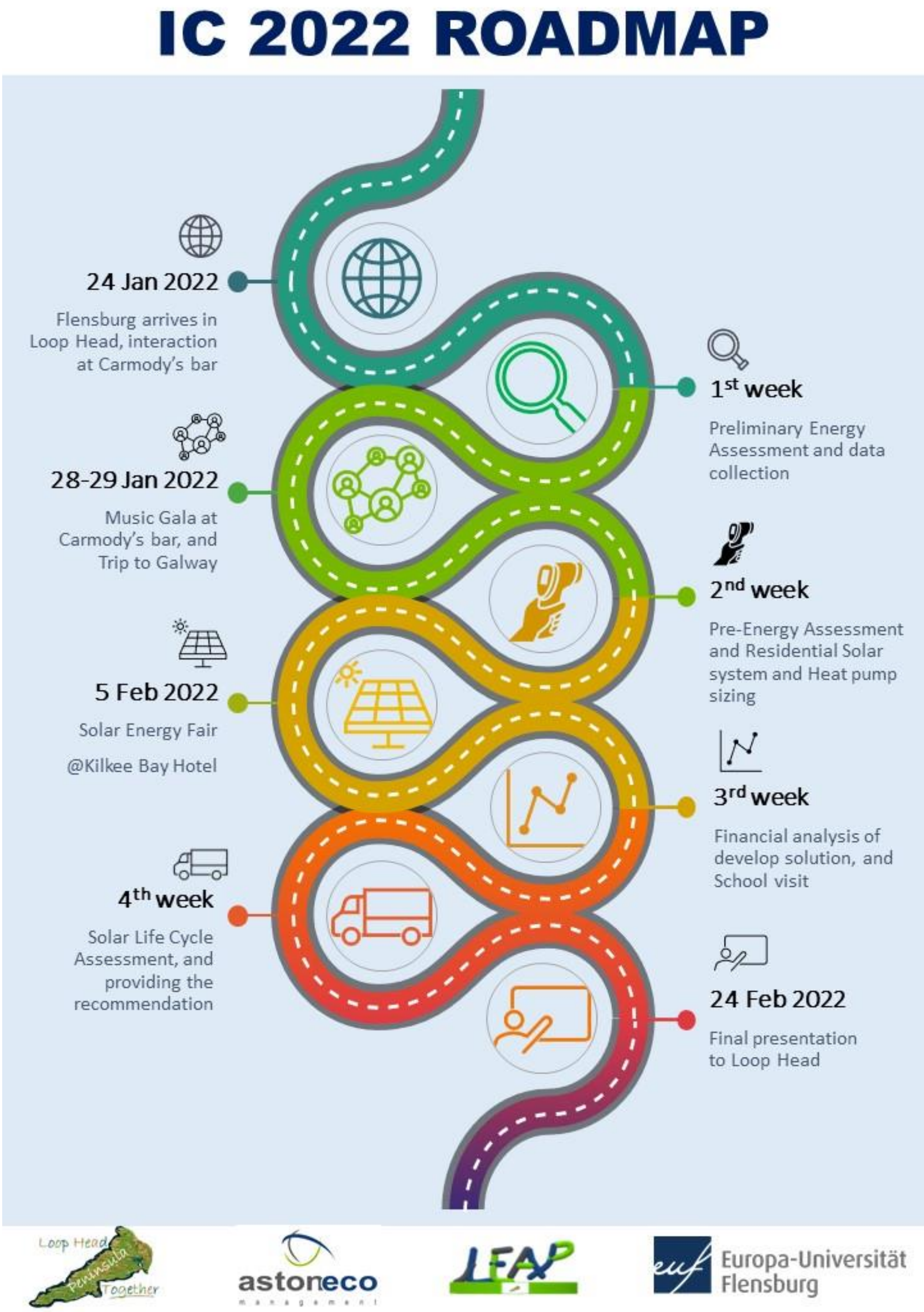
S/N	Stakeholder	Stake in the project
12	Owners of sampled households for the case study	Offered their houses for case study purposes
13	Kilkee Bay Hotel Owner	Conference facility used for the workshops
14	Carmody's Bar Owner	Social Meet up venue for community interaction
15	Keane's Bar Owner	Social Meet up venue for community interaction
16	Other Business owners	Assisted in the dissemination of information through display of project activities' posters
17	Community Social Media Management Team	Assisted in the dissemination of information through uploads in the available social media platforms
18	Carrigaholt National School Principal	Approval for school visit to conduct energy awareness workshop
19	Accommodation Premises Landlords	Provided renting pace for accommodation of the Flensburg team on the Loop
20	North Clare Municipal visiting representatives	Benchmarking with ongoing project and knowledge sharing on progress in the neighboring community.

Annex

Annex 2: Stakeholders mapping

Stakeholders	High Influence	Low Influence
	Manage	**Inform**
High Interest	-Community Members -Loop Head Together Programme -Flensburg University Team -Astoneco Management -Owners of sampled households for the case study	-F4 Energy Limited -Building Energy Rating Specialist -Local Community Member with installed solar PV system -Kilkee Bay Hotel Owner Bar Owner -Keane's Bar Owner -Other Business Owners -Community Social Media Management Team -Carrigaholt National School Principal
	Satisfy	**Monitor**
Low Interest	-Sustainable Energy Authority of Ireland (SEA) -Department of Immigration -Department of Health -Accommodation premises Landlords -Noel O'shea Coaches	-North Clare Municipal visiting representative

Annex 3: Community engagement activities roadmap



Annex 4: Pre-survey questionnaire

2/21/22, 5:13 AM Loop Head Pre-Survey Questionnaire

Loop Head Pre-Survey Questionnaire

Dear members of the Loop Head community,

We, the students from University of Flensburg, would like to partner with the Loop Head Peninsula's community's energy revolution by investigating and demonstrating the implementation/benefits of sustainable energy solutions, with a visit from 23.01.2022 to 26.02.2022. In order to make the best use of the time with you and to make all necessary preparations, we kindly ask you to answer the following short questions. This questionnaire will serve as an orientation and planning tool for the upcoming International Class. Responses captured here are completely anonymous. No personally identifiable information is captured, unless you voluntarily offer personal or contact information in any of the comment fields.
We look forward to a large number of participants and to spending time together in Loop Head.

Thank you in advance and best regards from Flensburg,

The International Class Team 2022

*Required

https://docs.google.com/forms/d/1oqJeXHzP0nqNSkhTCnGKvapfftQqqpZSbjBYVjiDDYg/edit 1/6

1. To help us evaluate and incorporate diverse views, a) Please indicate what your areas of energy interest are.

____
____
____
____
____

2. b) Please indicate what are your expectations (if any) for the International Class 2022.

____
____
____
____
____

3. To avoid repetition and build upon the learnings and outcomes of the previous international classes in 2020 and 2021, please indicate if you have participated in the workshops organised in previous years by the students from the University of Flensburg. *

Mark only one oval.

- ( ) Attended 2020 *Skip to question 4*
- ( ) Attended 2021 *Skip to question 4*
- ( ) Attended 2020 and 2021 *Skip to question 4*
- ( ) Did not attend any *Skip to question 8*

4. To gauge the impact of previous international classes and focus on the needs of the community, please select the statement(s) which you agree with. *

You may skip this question if it does not apply to you.

Tick all that apply.

- [ ] I am more aware of my energy consumption.
- [ ] I think the International Class has had a positive impact on the Community.
- [ ] I am interested in learning more about energy related problems.
- [ ] I did not feel any impact.

5. Have you implemented any recommendations given from the workshops in your household/daily life? *

Mark only one oval.

- ( ) Yes *Skip to question 6*
- ( ) No *Skip to question 8*

6. To learn from your experience, would you be willing to share aspects of what you have implemented, with us and other community members? *

Mark only one oval.

- ( ) Yes *Skip to question 7*
- ( ) No *Skip to question 8*

7. If you are interested in sharing your experience please let us or John know and/or enter your name and preferred contact information here.

____

8. The scope of IC 2022 includes a proposed high level house-hold energy audit. Would you be willing to welcome Flensburg students into your house for this purpose? *

Mark only one oval.

- Yes *Skip to question 9*
- No *Skip to question 11*
- Maybe *Skip to question 10*
- Energy audit has already been conducted *Skip to question 11*

9. If you are interested in an energy audit at your home by students please let John or us know and/or enter your name and preferred contact information here.

____

Skip to question 11

10. Many of us will learn a lot through analysing energy usage in sample houses. But it is also normal for people to be reluctant to share this information. Please indicate the conditions upon which you would grant permission for us to visit your home to analyse energy usage.

____
____
____
____
____

Information collected under this section will help obtain baseline information on energy awareness within the Loop Head community and so help in planning for a knowledge sharing workshop(s).

11. To identify opportunities to influence the community's energy consumption behavior, how aware are you about the things you can do to keep your electricity consumption in check? *

Mark only one oval.

	1	2	3	4	
Not aware	◯	◯	◯	◯	Very aware

12. Please select the device(s) or activity(-ies) that consume the biggest share of electricity in your house. *

Tick all that apply.

- [ ] Lighting
- [ ] Water heating
- [ ] Room heating
- [ ] Room cooling
- [ ] Refrigerator
- [ ] Washing machine
- [ ] Dish washer
- [ ] Microwave
- [ ] Electric cooking stove
- [ ] Other

13. Please elaborate if you chose "Other" above.

____

14. When you buy new appliances, what is the most important factor for you among those listed below? *

Mark only one oval.

- Brand
- Price
- Efficiency
- Durability

15. How does energy awareness affect your behavior? *

Please select all that apply to you.

Tick all that apply.

- [ ] I run full loads when using the washing machine
- [ ] I completely switch off electronic devices (TV, Computer, Laptop, Microwave, etc.) [no standby]
- [ ] I turn off water when applying soap/gel during showers
- [ ] I switch off lights when leaving the room
- [ ] I heat water in a kettle instead of using a pot
- [ ] I defrost the freezer/refrigerator regularly (at least once in 2 month)
- [ ] None of the above

Annex 5: Music gala

Annex

Annex 6: Solar deep dive

Annex 7: Solar deep dive arising questions

S/N	Question	Scope Check
1	Do I need to have certified installer of solar in order to receive grants?	Part of the IC2022 scope of work
2	How can I insulate cavity walls and what grants are available for this?	Part of the IC2022 scope of work
3	Should I go for solar or for a wind? Wind is strong in the region will it break the wind turbine?	Out of IC2022 scope
4	What are the social and economic benefit of installing solar PV?	Part of the IC2022 scope of work
5	How can change in behavior affect the household electricity consumption?	Part of the IC2022 scope of work
6	What are the changes that can be done daily behavior that can lower the electricity bill?	Part of the IC2022 scope of work
7	How can installing solar PV benefit our community in Loop Head?	Part of the IC2022 scope of work
8	How can I know the BER rating of my house now?	Part of the IC2022 scope of work
9	Are there grants I am eligible for to improve the BER rating of my house?	Part of the IC2022 scope of work
10	Who should be contracted for house retrofitting?	Part of the IC2022 scope of work
11	What capacity of solar PV should I go for?	Part of the IC2022 scope of work
12	How much will solar PV installation cost me?	Part of the IC2022 scope of work

Annex 8: Workshop 2

Annex

Annex 9: DEAP for New – Final and existing Home Survey Form

DEAP for NEW-FINAL and EXISTING HOMES SURVEY FORM

Property address:

Assessor name / BER reg. no.

Survey Date:

Eircode | MPRN

Number of storeys | Number of bedrooms | Number of extensions

Dwelling Type
- ☐ detached house
- ☐ semi detached house
- ☐ end of terrace
- ☐ mid terrace
- ☐ ground floor apartment
- ☐ mid floor apartment
- ☐ top-floor apartment
- ☐ basement apartment
- ☐ maisonette

Pick dwelling type that is closest to actual dwelling type

Age: Dwelling	Age: Extension 1	Age:Extension 2
☐ pre 1900	☐ pre 1900	☐ pre 1900
☐ 1900 - 1929	☐ 1900 - 1929	☐ 1900 - 1929
☐ 1930 - 1949	☐ 1930 - 1949	☐ 1930 - 1949
☐ 1950 - 1966	☐ 1950 - 1966	☐ 1950 - 1966
☐ 1967 - 1977	☐ 1967 - 1977	☐ 1967 - 1977
☐ 1978 - 1982	☐ 1978 - 1982	☐ 1978 - 1982
☐ 1983 - 1993	☐ 1983 - 1993	☐ 1983 - 1993
☐ 1994 - 1999	☐ 1994 - 1999	☐ 1994 - 1999
☐ 2000 - 2004	☐ 2000 - 2004	☐ 2000 - 2004
☐ 2005 - 2009	☐ 2005 - 2009	☐ 2005 - 2009
☐ 2010 onwards	☐ 2010 onwards	☐ 2010 onwards

Type of Rating
- ☐ new-final dwelling
- ☐ existing dwelling

Purpose of Rating
- ☐ new: owner occupation
- ☐ sale
- ☐ private letting
- ☐ social housing letting
- ☐ grant support
- ☐ major renovation
- ☐ other

Wall construction Main Wall*
- ☐ stone — ☐ wall thickness (mm)
- ☐ solid brick — ☐ is wall semi exposed?
- ☐ cavity
- ☐ solid concrete
- ☐ hollow block
- ☐ timber frame
- ☐ other/unknown

Wall Insulation
- ☐ as built — bead ☐
- ☐ cavity fill — EPS ☐
- ☐ external — min fibre ☐
- ☐ internal — dense ☐

Insulation thickness if observable(mm) ☐

Roof Construction: Main Dwelling*
- ☐ pitched - insulation btw joists
- ☐ pitched - insulation in rafters
- ☐ flat - insulation integral
- ☐ room in roof
- ☐ no heat loss roof
- ☐ other

Roof Insulation

thickness (mm) ☐ — fibre ☐ — warmcell ☐ — EPS ☐ — ☐ unknown — dense ☐

Ground Floor Construction: Main Dwelling*
- ☐ solid — ☐ no heat loss ground floor
- ☐ suspended: sealed ☐ unsealed ☐
- ☐ above unheated basement
- ☐ heated basement
- ☐ other

Floor Insulation — **Type of Insulation (if any)**

☐ thickness (mm) (only if any observed) — EPS ☐ — min fibre ☐

☐ none — unknown ☐ — dense ☐

Total Floor Areas, Heat Loss Floor Areas, Gross Heat Loss Wall Areas, Gross Heat Loss Roof Areas, Storey Heights* (internal dimensions only)

	Storey height (m)	Total floor area (m^2)	Heatloss Floor 1 Area (m^2)	Heatloss Floor 2 Area (m^2)	Heatloss Floor 3 Area (m^2)	Heatloss Floor 4 Area (m^2)	Heatloss Perimeter (m)	Heatloss Wall 1 Area (m^2)	Heatloss Wall 2 Area (m^2)	Heatloss Wall 3 Area (m^2)	Heatloss Wall 4 Area (m^2)	Heatloss Roof 1 Area (m^2)	Heatloss Roof 2 Area (m^2)	Heatloss Roof 3 Area (m^2)	Heatloss Roof 4 Area (m^2)
Ground / Lowest Floor															
First / Next Floor															
Second / Next Floor															
Third / Next Floor															
Basement															

living area (m^2) ☐

room in roof area (m^2) ☐

perimeter/total ground floor (P/A) ratio: F type#1 ☐ F type#2 ☐ F type#3 ☐

% draughtstripping ☐

Lighting design known (yes/no)? If yes, keep Wattage /Lumens proof on file. ☐

Thermal mass	light	med	heavy
external wall	☐	☐	☐
floor	☐	☐	☐
separating walls	☐	☐	☐
internal walls	☐	☐	☐
Overall thermal mass			

Room by Room record (use more than 1 row for a room if required)

OPENING DATA											ROOM DATA					
Room	Opening	opening dimensions (W x H or m^2)	Glazing details	Frame	Gap	over shading	direction	Wall / roof type	# of openable windows/ doors / attic hatches?	# windows/ doors/ hatches with draught stripping	Chimney or Flueless	Open Flues	Fans / vents	Rads with or w/o TRVs?	Number of fixed lights	What type of fixed lights? Use more than 1 row if needed.

Heating system (Domestic Hot Water)

Primary Hot Water System

- ☐ from primary heating system
- ☐ gas instant: single point
- ☐ backboiler / kitchen range
- ☐ electric immersion
- ☐ gas instant: multi point
- ☐ gas ☐ oil ☐ SF
- ☐ electric instantaneous
- ☐ gas circulator pre 1998
- ☐ gas circulator 1998 or later

If instantaneous combi boiler: ☐ keep hot facility controlled by ☐ timeclock ☐ no timeclock

If storage combi: store volume ☐ <55 litres ☐ >= 55 litres

Hot Water Cylinder, Insulation and Controls ☐ cylinder ☐ combi ☐ CPSU ☐ thermal store

☐ no access

Insulation: ☐ no insulation ☐ lagging jacket ☐ factory fitted

capacity (litres) or dimensions

primary pipework insulated ☐

insulation thickness (mm)

Controls: cylinder thermostat ☐ independent timer ☐ storage is outdoors ☐

Cylinder volume/dimensions does not include insulation thickness

Solar Water Heating System ☐ Yes ☐ No

☐ evacuated tube ☐ flat plate, glazed ☐ Flat plate unglazed

solar collector area (m^2) ☐ area is "gross" area ☐ area is "aperture area

overshading: ☐ very little (<20%) ☐ modest (20-60%) ☐ significant (61-80%) ☐ heavy (>80%)

dedicated solar storage volume (litres)

contained within combined cylinder ☐

contained within separate cylinder ☐

orientation ☐ tilt ° ☐

Solar panel make and model:

Supplementary Summer Hot Water

☐ not applicable

☐ electric heater present for supplementary hot water heating*

**only if space heating and water heating cannot be separated and main water heating isn't electric. See DEAP manual*

Comments on water heating system

Showers and baths

☐ Bath in dwelling (y/n)? ☐ Is water use target (hot and cold) 125 l/p/d (y/n)?

Shower #	Is flow rate known? (y/n)	Shower type: Electric/ Unvented/ Vented/ Vented+pump	Flow restrictor? (y/n)	Flow rate (if known)?	WWHR efficiency and utilisation factor	
1						
2						
3						
4						
5						

Heating system (Controls)

Heating Controls (tick all that apply)

- ☐ no controls
- ☐ programmer / timeclock
- ☐ room thermostat number ☐
- ☐ TRV's % rads with TRVs ☐
- ☐ bypass
- ☐ load compensator
- ☐ weather compensator
- ☐ full zone control
- ☐ boiler energy management system
- ☐ delay start thermostat
- ☐ boiler interlock
- ☐ appliance thermostat
- ☐ appliance timeclock

Underfloor heating (UFH)

- ☐ in insulated timber floor
- ☐ whole house UFH
- ☐ in screed
- ☐ Partial UFH including living area
- ☐ in concrete
- ☐ Partial UFH not including living area

Pumps

☐ How many central heating pumps for space heating?

Central heating pump(s) outdoors ☐

☐ How many oil boiler fuel pumps?

Oil fuel pump(s) outdoors ☐

☐ How many gas boiler flue fans?

Comments on Heating Controls

Group Heating

Distribution Loss Factor and charge method

- ☐ pre 1991 full flow mid-high temp: not pre-insulated
- ☐ pre 1991 full flow low temp: pre-insulated
- ☐ 1991 or later variable flow mid temp: pre-insulated
- ☐ 1991 or later variable flow low temp: pre-insulated

See DEAP C1.1 for dist. loss factor derivation method

consumption charged: flat rate ☐ linked to use ☐

Heating system #1

☐ efficiency %

☐ proportion of group heating %

Fuel type of heating system

Make and model of heating system

Heating system #2

☐ efficiency %

☐ proportion of group heating %

Fuel type of heating system

Make and model of heating system

CHP / Waste Heat

☐ % heat from CHP (or power station)

☐ power station

☐ CHP

CHP efficiencies

☐ Electrical %

☐ Thermal %

Fuel

Any other comments or details on assessment including items observed which affect the rating but not shown elsewhere on survey form/sketches.

Annex

Ventilation Factors

- draught lobby on main entrance
- pressure test results available
- If yes, enter adjusted result (ac/h)
- Is there uninsulated ducting on MVHR system outside dwelling envelope?
- number of sides sheltered
- Pressure test result reference number
- natural ventilation
- positive input ventilation from loft
- positive input ventilation from outside
- whole house extract ventilation
- balanced whole-house mech. ventilation without heat recovery
- balanced whole-house mechanical ventilation with heat recovery
- exhaust air heat pump (EAHP) — air flow rate for EAHP (m^3/h)

DEAP manual contains guidance on using non default SFP and efficiency for mechanical ventilation units as well as identifying the air flow rate in EAHPs.

Mech. ventilation system details if available (e.g. model&number, along with # of rooms from which air is extracted and use of flexible/rigid ducting)

Lighting summary (total number of each bulb type from room by room record)

#Linear flourescent	#CFL	#Halogen lamps
#LED	#Halogen LV	#Incandescent/ unknown

Space heating system (general information)

Primary Heating System	Secondary Heating System	Primary Heating Fuel		Secondary Heating Fuel	
radiator system	no secondary system	mains gas	housecoal	no secondary system	housecoal
storage heaters	radiator system	bulk LPG	anthracite	mains gas	anthracite
underfloor	storage heaters	bottled LPG	smokeless	bulk LPG	smokeless
warm air	underfloor	heating oil	peat briquettes	bottled LPG	peat briquettes
room heaters only	warm air	electricity	sod peat	heating oil	sod peat
community	room heaters only	heat from CHP	wood pellets	electricity	wood pellets
fan coil radiators	fan coil radiators	bioethanol	wood chips	heat from CHP	wood chips
other (describe briefly):	other (describe briefly):	other:	biodiesel	bioethanol	biodiesel
				other:	

Gas / Oil / LPG Boilers — primary / secondary

Boiler type	Flue type	Age
standard	open	1998 or later
combi	balanced	pre 1998
condensing	fan assisted	oil: pre 1985
back boiler	**Mounting**	gas/ LPG pre 1979
CPSU	wall	**Ignition**
range cooker	floor	auto
single burner		permanent pilot
twin burner		

Manufacturer / make / model number

Solid Fuel Boilers — primary / secondary

- open fire + back boiler
- closed room heater + back boiler
- range cooker boiler with: integral oven; independent oven
- grate: rectangular; trapezium
- manual feed boiler
- biomass boiler
- auto feed boiler
- wood chip / pellet boiler
- MF / AF boiler in heated space?

Manufacturer / make / model number

Comments on heating system

Electric Boilers — primary / secondary

- direct acting
- CPSU
- dry core
- water storage
- dry core / water storage in heated space

Electric Storage Heaters — primary / secondary

- modern / slimline
- fan assisted
- convector
- old (pre-1980) large volume
- integrated storage / direct acting (inc. room stat)

Control options

- manual charge control
- automatic / weather dependent
- Celect-type

Gas Room Heaters — primary / secondary

	Front
pre 1980	
coal effect - sealed flue	open-fronted
coal effect - open to chimney	glass-fronted
flueless	**Flue type**
condensing	open
back boiler (no rads)	balanced
other (none of above)	fan assisted

Warm Air Systems — primary / secondary

Ducted or Stub Ducted	Other Features (tick all that apply)
on - off	fan assisted
modulating	condensing
Age	with flue heat recovery
1998 or later	**Other types**
pre 1998	Room heater with in floor ducts
	Electric electricaire

Oil Room Heaters — primary / secondary

- room heater / range
- room heater/range with boiler (no rads)
- Age: pre 2000; 2000 or later

Solid Fuel Room Heaters — primary / secondary

- open fire in grate
- stove (pellet-fired)
- open fire with backboiler (no rads)
- flueless bioethanol
- closed room heater
- closed room heater with backboiler (no rads)

Individual CHP?

- % heat from CHP

CHP efficiencies

- Electrical %
- Thermal %

Fuel

Heat Pumps — primary / secondary

- air-to-air
- ground-to-air
- water-to-air
- air-to-water
- ground-to-water
- water-to-water
- gas-fired - ground / water
- gas-fired, air source
- heat pump includes auxiliary electric heater

Manufacturer / make / model number

Electric Room Heaters — primary / secondary

- panel, convector, or radiant heater
- fan heater

Secondary heating make / manufacturer/model number

Annex 10: Excel Data collection sheet

Window Schedule				Address:							
Ref	Room	Floor Level	Orient..	Dimensions		Total Area	Open-ings	Flue Chimn	Fans Vents	Over-Shadin	Notes
	Front/Rear			H	L						Lighting Constr. etc.
W1											
W2											
W3											

Source: Author based on Johnny Redmond

Annex

Thermocamara configurations

Data was An infrared camera FLIR b40 with the instrument's high accuracy of 2%, thermal sensitivity of 0.1ºC and boasting a temperature range of between -20ºC to +120ºC was used to survey the case study buildings.

Annex 11: FLIR B40 Technical Specifications
Source:

Imaging and optical data	
Field of view (FOV)	25° × 25°
Thermal sensitivity/NETD	< 0.1°C (0.25°C) / 100mK
Image frequency	9 Hz
Detector data	
Detector type	Uncooled microbolometer
Spectral range	7.5–13 µm
IR resolution	120 x 120
Measurement	
Object temperature range	-20°C to +120°C
Accuracy	±2% of reading
Area (Max/Min)	Isotherm (above/below selected temperature interval)
Emissivity Emissivity Table	0.1 to 1.0 adjustable or selected from list of materials

Annex 12: Link to thermographer inspection report – case study I, II, and III

https://eufbox.uni-flensburg.de/index.php/s/6CAxZsDKcSqbWzD/download

Annex 13: Cost estimation for building retrofiting in Ireland

Description	**(Euro/m2)**	**Unit price (Euro)**
Pitch Roof insulation – 300 mm Mineral Wool	22.63	
Flat Roof insulation - HARDROCK Underlay slab 150mm	41.65	
External wall insulation - 100 mm Gray EPS	167.67	
External wall insulation - 200 mm Gray EPS	181.37	
Floor Insulation – 125 mm White EPS	256	
Windows (Triple glaze, U-Value 1.4)		815
GRP Composite doors, U-Value 0.8		965

*All costs include the cost of material plus the installation cost.

*The costs are subjected to 13.5% VAT

Annex 14: AWHP

THERMA V. R32 MONOBLOC

PRODUCT SPECIFICATION

MONOBLOC

HM051M.U43
HM071M.U43
HM091M.U43

R32

65℃ A+++ Ocean Black Fin SmartThinQ

Seasonal Energy

Description			Unit	HM051M.U43	HM071M.U43	HM091M.U43
Space Heating (According to EN14825)	Average Climate water outlet 35℃	SCOP		4.45	4.45	4.45
		Rated heat output (Prated)		6	6	6
		Seasonal space heating efficiency (ηs)	%	175	175	175
		Seasonal space heating eff. Class		A+++[1]	A+++[1]	A+++[1]
		Annual energy consumption	kWh	2,551	2,668	2,784
	Average Climate water outlet 55℃	SCOP		3.12	3.12	3.12
		Rated heat output (Prated)		6	6	6
		Seasonal space heating efficiency (ηs)	%	122	122	122
		Seasonal space heating eff. Class		A+	A+	A+
		Annual energy consumption	kWh	3,638	3,638	3,638

Note

1. A+++ label is available from 26, Sep. 2019 and should be considered as A++ label until that time.

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Product Specification

Description			Unit	HM051M.U43	HM071M.U43	HM091M.U43
Nominal Capacity	Heating	LWT 35℃ at OAT 7℃	kW	5.50	7.00	9.00
		LWT 55℃at OAT 7℃	kW	5.50	5.50	5.50
		LWT 35℃ at OAT 2℃	kW	3.30	4.20	5.40
	Cooling	LWT 18℃ at OAT 35℃	kW	5.50	7.00	9.00
		LWT 7℃ at OAT 35℃	kW	5.50	7.00	9.00
Nominal Power Input	Heating	LWT 35℃ at OAT 7℃	kW	1.22	1.56	2.15
		LWT 55℃ at OAT 7℃	kW	2.04	2.04	2.04
		LWT 35℃ at OAT 2℃	kW	0.94	1.20	1.54
	Cooling	LWT 18℃ at OAT 35℃	kW	1.20	1.56	2.14
		LWT 7℃ at OAT 35℃	kW	1.96	2.59	3.46
COP	Heating	LWT 35℃ at OAT 7℃		4.50	4.50	4.18
		LWT 55℃ at OAT 7℃		2.70	2.70	2.70
		LWT 35℃ at OAT 2℃		3.52	3.51	3.50
EER	Cooling	LWT 18℃ at OAT 35℃		4.60	4.50	4.20
		LWT 7℃ at OAT 35℃		2.80	2.70	2.60
Operation range	Heating	Water Side (LWT)	℃	15 - 65		
		Air Side	℃	-25 - 35		
	Cooling	Water Side (LWT)	℃	5 - 27		
		Air Side	℃	5 - 48		
	Domestic Hot Water	Water Side (LWT)	℃	15 - 80		
Refrigerant	Type			R32		
	GWP (Global Warming Potential)			675		
	Charge		kg	1.4		
			TCO2eq	0.95		
Compressor	Quantity		EA	1		
	Type			Scroll		
Water Flow Rate	Rated		LPM	14.4	20.1	25.9
Piping Connections	Water Circuit	Inlet	mm (in)	Male PT 25(1)		
		Outlet	mm (in)	Male PT 25(1)		
Dimensions	Unit	W x H x D	mm	1,239 × 907 × 404		
Net Weight	Unit		kg	96		
Sound power level	Heating	Rated	dBA	60		
Power supply	Phase / Frequency / Voltage		Φ / Hz / V	1 / 50 / 220-240		
	Maximum Running Current		A	23		

Note

1. Due to our policy of innovation some specifications may be changed without notification.
2. Wiring cable size must comply with the applicable local and national codes. And "Electric characteristics" chapter should be considered for electrical work and design. Especially the power cable and circuit breaker should be selected in accordance with that.
3. Sound Level Values are measured at Noise Measuring chamber accordance with standard. Therefore, these values depend on the ambient conditions and values are normally higher in actual operation.
4. Performances are accordance with EN14511.
5. This product contains Fluorinated greenhouse gases.
6. LWT : Leaving Water Temperature, OAT : Outdoor Air Temperature

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Annex 15: AWHP Auxilary Equipment

THERMA V. R32 MONOBLOC

PRODUCT SPECIFICATION

Product Specification

Description			Unit	HM123M.U33	HM143M.U33	HM163M.U33
Nominal Capacity	Heating	LWT 35℃ at OAT 7℃	kW	12.00	14.00	16.00
		LWT 55℃at OAT 7℃	kW	12.00	12.00	12.00
		LWT 35℃ at OAT 2℃	kW	11.00	12.00	13.80
	Cooling	LWT 18℃ at OAT 35℃	kW	14.00	14.00	16.00
		LWT 7℃ at OAT 35℃	kW	14.00	14.00	16.00
Nominal Power Input	Heating	LWT 35℃ at OAT 7℃	kW	2.61	3.11	4.00
		LWT 55℃ at OAT 7℃	kW	4.29	4.29	4.29
		LWT 35℃ at OAT 2℃	kW	3.13	3.42	3.94
	Cooling	LWT 18℃ at OAT 35℃	kW	3.04	3.26	4.00
		LWT 7℃ at OAT 35℃	kW	5.19	5.38	6.40
COP	Heating	LWT 35℃ at OAT 7℃		4.60	4.50	4.00
		LWT 55℃ at OAT 7℃		2.80	2.80	2.80
		LWT 35℃ at OAT 2℃		3.52	3.51	3.50
EER	Cooling	LWT 18℃ at OAT 35℃		4.60	4.30	4.00
		LWT 7℃ at OAT 35℃		2.70	2.60	2.50
Operation range	Heating	Water Side (LWT)	℃	15 - 65		
		Air Side	℃	-25 - 35		
	Cooling	Water Side (LWT)	℃	5 - 27		
		Air Side	℃	5 - 48		
	Domestic Hot Water	Water Side (LWT)	℃	15 - 80		
Refrigerant	Type			R32		
	GWP (Global Warming Potential)			675		
	Charge		kg	2.4		
			TCO2eq	1.62		
Compressor	Quantity		EA	1		
	Type			Scroll		
Water Flow Rate	Rated		LPM	34.5	40.3	46.0
Piping Connections	Water Circuit	Inlet	mm (in)	Male PT 25(1)		
		Outlet	mm (in)	Male PT 25(1)		
Dimensions	Unit	W x H x D	mm	1,239 × 1,450 × 404		
Net Weight	Unit		kg	130		
Sound power level	Heating	Rated	dBA	63		
Power supply	Phase / Frequency / Voltage		Φ / Hz / V	3 / 50 / 380-415		
	Maximum Running Current		A	15		

Note

1. Due to our policy of innovation some specifications may be changed without notification.
2. Wiring cable size must comply with the applicable local and national codes. And "Electric characteristics" chapter should be considered for electrical work and design. Especially the power cable and circuit breaker should be selected in accordance with that.
3. Sound Level Values are measured at Noise Measuring chamber accordance with standard. Therefore, these values depend on the ambient conditions and values are normally higher in actual operation.
4. Performances are accordance with EN14511.
5. This product contains Fluorinated greenhouse gases.
6. LWT : Leaving Water Temperature, OAT : Outdoor Air Temperature

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ELECTRIC BACK UP HEATER

HA031M.E1
HA061M.E1

Product Specification

Electrical Specification			HM031M.E1	HA061M.E1
Backup Heater	Type		Sheath	Sheath
	Number of Heating Coil	EA	1	2
	Capacity Combination	kW	3.0	3.0 + 3.0
	Operation		Automatic	Automatic
	Heating Steps	Step	1	2
	Power Supply	V, Φ, Hz	220-240, 1, 50	220-240,1,50
	Maximum Current	A	12.0	24.0
Wiring Connections	Power Cable (included Earth, H07RN-F)	No. x mm2	3 x 1.5	3 x 4.0
	Communication Cable (H07RN-F)	No. x mm2	4 x 0.75	4 x 0.75

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THERMA V ACCESSORIES

LG Wi-Fi MODEM

PWFMDD200.ENCXLEU

Access LG THERMA V anytime and from anywhere with Wi-Fi equipped device
LG's exclusive Home Appliances control app (Smart ThinQ) is available
Simple operation for various functions

- On/Off
- Operation Mode Selection
- Current Temperature
- Set Temperature
- On/Off Reservation
- Energy Monitoring

Model Name	PWFMDD200
Size (mm)	46 x 68 x 14
Interfaceable Products	THERMA V Split & Monobloc
Connection Type	Indoor Unit 1:1
Communication Frequency	2.4GHz
Wireless Standards	IEEE 802.11b/g/n
Mobile Application	LG Smart ThinQ (Android v4.1(Jellybean) or higher, iPhone iOS 9.0 or higher)
Optional Extension Cable	PWYREW000 (10m extension)

*** Functionality may be different according to each Indoor model (Split and Monobloc available)**
*** User interface of application shall be revised for its design and contents improvement**
*** Application is optimized for smartphone use, so it may not be well functioning with tablet devices.**
1) Vane Control may not be possible according to the type of indoor unit
2) For the compatibility with indoor unit, please contact regional office

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DOMESTIC HOT WATER TANK

OSHW-200FAEU
OSHW-300FAEU
OSHW-500FAEU
OSHW-300FD.AEU

Double Coil　Single Coil

DOMESTIC HOT WATER TANK			OSHW-200F	OSHW-300F	OSHW-500F	OSHW-300FD
General Characteristics	Water Volume	L	200	300	500	300
	Diameter	mm	640	640	810	640
	Height	mm	1,350	,850	1,900	1,350
	Empty Weight	Kg	61	100	146	106
	Tank Materials		F18 STEEL	F18 STEEL	F18 STEEL	F18 STEEL
	Color		Grey	Grey	Grey	Grey
Characteristics of Electrical Back-up	Additional Electric Heater	W	2,400	2,400	2,400	2,400
	Power Supply	Φ/ V / Hz	1/ 230W / 50- 60Hz	1/ 230W / 50- 60Hz	1/ 230W / 50- 60Hz	1/ 230W / 50- 60Hz
	Adjustable Thermostat	℃	0-90	0-90	0-90	0-90
Characteristics of Exchanger	Exchanger Type		Single	Single	Single	Double
	Material Exchanger		F18 STEEL	F18 STEEL	F18 STEEL	F18 STEEL
	Maximum Water Temp	℃	90	90	90	90
	Coil Surface	mm	2.3	3.1	4.8	3.1/0.97
Hydraulic Connections - Heat Pump	Inlet	mm	1"	1"	11/4 "	1" (Sup ¾")
	Outlet	mm	1"	1"	11/4 "	1" (Sup ¾")
Hydraulic Connections - Domestic Hot Water Tank	Domestic hot water inlet	mm	¾"	¾"	1"	¾"
	Domestic hot water outlet	mm	¾"	1"	1"	1"
Energy Efficiency Class			B	B	B	B
Standing Heat Loss		W	61	70	83	70

Mandatory Optional Accessories				
Domestic Hot Water Tank Installation Kit	PHLTB	PHLTB	PHLTB	PHLTB
Optional Accessories				
Mixing Valve (3/4" dn20)	OSHA-MV	OSHA-MV	OSHA-MV	OSHA-MV
Mixing Valve (1" dn25)	OSHA-MV1	OSHA-MV1	OSHA-MV1	OSHA-MV1
3-Way Valve	OSHA-3V	OSHA-3V	OSHA-3V	OSHA-3V

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THERMA V ACCESSORIES

ACCESSORIES PROVIDED BY LG

Accessory	Feature
Domestic Hot Water Tank	
Domestic Hot Water Tank Kit	• **PHLTB (Monobloc)** **Features** Easy to install the domestic hot water for monobloc. There is a MCCB to protect the product. Dimension (mm) (H x W x D) : 250 x 170 x 110 Weight (kg) : 2.1 To extend THERMA V functionality in generating domestic hot water. * The sensor (PHRSTA0) can be purchased separately in case of using other brand's Domestic tank.  PHLTB
Remote Temperature Sensor	• **PQRSTA0** **Features** It can help to detect the exact room temperature. Applied to ceiling cassette, ceiling concealed duct, AWHP and Hydro Kit. **Parts Included** Remote temperature sensor / Extension cable (15m) / Manual 
Solar Thermal Kit	• **PHLLA** **Features** To interface solar-thermal system with THERMA V and double coil Domestic tank. Installed at the water pipe, between Domestic tank and solar-thermal system. Dimension (mm) (H x W x D) : 110 x 55 x 22 
Dry Contact	• **PDRYCB000 / PDRYCB300** **Features** For connection with boiler (Bivalent scene) 

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RECOMMENDED OPTIONAL ACCESSORIES

No.	Accessory	Picture	Purpose	Specification
1	Domestic Hot Water Tank		Store and provide hot water for sanitation	Volume : 200 ~ 400 l Enameld or stainless-steel tank / Insulating foam (e.g. PUR ~ polyurethane) heat-exchanger surface ≥ 3 m²
2	3-Way-Valve		Switch between heating and domestic hot water circuit	230V AC SPDT (Single Pole Double Throw) / opening time 30 ~ 90 sec / final position switch Internal leakage rate < 0,1%
3	Electrical Tank Heater		Supports heating of domestic hot water, when heat pump is blocked or capacity is limited	2 ~ 6 kW Connector dimension suitable for DHW tank
4	Buffer Tank		Prevents cycling, when water volume is low and /or heating demand is low, secures enough heat for defrosting cycle	Insulating foam (e.g. PUR ~ polyurethane) Volume : 100 ~ 200 l (Installation in series with heat pump) 500 ~ 1,000 l (Installation in parallel with heat pump)
5	Bypass Valve		Ensures minimum water flow rate, when flow through heating circuits is limited due to closed valves	Dimensioning according manufacturer adjustable opening pressure
6	2-Way-Valve		Blocks heating circuits, that are not suitable for cooling during cooling operation	230V AC NO or NC type final position switch
7	Expansion Vessel		Absorption of pressure differences in the heating circuits due to temperature increase / decrease of the water	Dimensioning on-site required
8	Strainer		Protects plate-heat-exchanger from blocking particles	1inch / 25.4mm, Mesh size ~ 1 x 1mm for HM03M1.U42 only (other models are included)
9	Heating Cable		Prevents the condensate pan and the drainage pipe from icing	Thermostatic control depending on outdoor temperature All models do have electric heating cable for prevent frost from condensing water at the condensing pan except 3kW capacity
10	Antifreeze		Prevents the heating water from freezing, when heat pump is out of order	Monoethyleneglycole Concentration according to lowest possible outdoor temperature
11	Noise Damper		Prevents that structure-born noise is transported via the water piping	EPDM; Operating temperature according climate region (at least -10 ~ + 90°C)
12	Anti-Noise Sockets		Prevents that structure-born noise is transported to the base or to the brackets	Dimensioning on-site required
13	Thermostat		When thermostatic room temperature control is preferred by costumer	230V AC When heat pumps operates in heating and cooling mode : thermostat with mode selection
14	Refrigerant Tubes		Pre-fabricated double-pipe to connect split indoor and outdoor unit	Diameter : Please refer to Specification
15	Water Tubes		Pre-fabricated double-pipe to connect monobloc outdoor unit with heating system	When heat pump is used for cooling : diffusion-resistant tubes
16	Bushing Sleeve		Protecting the building against pressing water coming through the duct of the heating tubes	Dimensioning on-site required
17	Insulation Material		Mandatory when heat pump is used for cooling; prevents condensate water on cold pipes and assemblies	Diffusion-resistant

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Annex

Annex 16: Space Heating and DHW Excel Model Interface

	A	B	C	D	E	F	G	H	I	J	K
1	Input			Ref Temp	17	Output					
2	Total heat Demanded of the house	5.917	KW	acc. To rad Sizes		Total Annual ΔT (Heat Delivere	55,929.20	KelvinHrs			
3	HP Capacity	6	KW	Occupants Per Dwelling	2.00	Total Annual Electrical Consumption	2979.24	kWhs			
4	Annual Total Space and DHW Heat Demand	10,818.94	kWhs			Yearly COP	3.6314		3.95		
5	Occupants Per Dwelling	2.00				Total Annual Heat Supplied to Dwelling(Space and DHW)	10,818.94	kWh s		Yearly average COP	
6	Total Heat Demanded per Year acc. to DEAP	9,622.09	kWhs			Annual Domestic Hot Water Heat Demand	1,196.85	kWhs			
7											
8											
9											
10											
11					Radiator (KW)						
12	Time	Ambient Temperature		ΔTat T_{indoor} =18	Q_h= ΔT/total yearly Δ T *annual heat demand	Rad Δ T= Δ $T_{max}/Q_{max}XQ_h$	FWD T= Rad Δ T+ $T_{return(25)}$	Heat load (kwhs)	COP	Electrical Load (kwhs)	
13	1/1/2021 0:00	3.7		13.3	2.57	12.86	37.86	2.57	3.38	0.76	
14	1/1/2021 1:00	3.5		13.5	2.61	13.06	38.06	2.61	3.36	0.78	
15	1/1/2021 2:00	3.2		13.8	2.67	13.35	38.35	2.67	3.34	0.80	
16	1/1/2021 3:00	2.8		14.2	2.75	13.73	38.73	2.75	3.31	0.83	
17	1/1/2021 4:00	2.6		14.4	2.79	13.93	38.93	2.79	3.29	0.85	
18	1/1/2021 5:00	1.9		15.1	2.92	14.60	39.60	2.92	3.24	0.90	
19	1/1/2021 6:00	1.9		15.1	2.92	14.60	39.60	2.92	3.24	0.90	

Space Heating&DHW | .COP Duration Curve | COP Duration Frequency | HP Monthly Energy Profil ...

Annex 17: Radiators

Stelrad Radical

30Δt (55/45/20°C)

K1 

K2 

Height	Length mm	K1 Straight 10mm UIN	K1 Angle 10mm UIN	K1 Straight 15mm UIN	K1 Angle 15mm UIN	K1 Heat output Watts	K1 Heat output Btu/hr	K2 Straight 10mm UIN	K2 Angle 10mm UIN	K2 Straight 15mm UIN	K2 Angle 15mm UIN	K2 Heat output Watts	K2 Heat output Btu/hr
300	1000	33111010S	33111010A	33111015S	33111015A	262	894	33221010S	33221010A	33221015S	33221015A	480	1639
500	400	35110410S	35110410A	35110415S	35110415A	171	585	35220410S	35220410A	35220415S	35220415A	288	984
	500	35110510S	35110510A	35110515S	35110515A	215	733	35220510S	35220510A	35220515S	35220515A	361	1232
	600	35110610S	35110610A	35110615S	35110615A	258	879	35220610S	35220610A	35220615S	35220615A	433	1478
	700	-	-	-	-	-	-	35220710S	35220710A	35220715S	35220715A	505	1724
	800	-	-	-	-	-	-	35220810S	35220810A	35220815S	35220815A	577	1970
	900	-	-	-	-	-	-	35220910S	35220910A	35220915S	35220915A	649	2216
	1000	-	-	-	-	-	-	35221010S	35221010A	35221015S	35221015A	722	2462
	1200	-	-	-	-	-	-	35221210S	35221210A	35221215S	35221215A	866	2954
	1400	-	-	-	-	-	-	35221410S	35221410A	35221415S	35221415A	1010	3446
	1600	-	-	-	-	-	-	35221610S	35221610A	35221615S	35221615A	1155	3940
	1800	-	-	-	-	-	-	35221810S	35221810A	35221815S	35221815A	1299	4432
	2000	-	-	-	-	-	-	35222010S	35222010A	35222015S	35222015A	1443	4924
600	400	36110410S	36110410A	36110415S	36110415A	202	689	36220410S	36220410A	36220415S	36220415A	333	1137
	500	36110510S	36110510A	36110515S	36110515A	252	861	36220510S	36220510A	36220515S	36220515A	417	1432
	600	36110610S	36110610A	36110615S	36110615A	303	1033	36220610S	36220610A	36220615S	36220615A	500	1704
	700	-	-	-	-	-	-	36220710S	36220710A	36220715S	36220715A	583	1989
	800	-	-	-	-	-	-	36220810S	36220810A	36220815S	36220815A	666	2274
	900	-	-	-	-	-	-	36220910S	36220910A	36220915S	36220915A	749	2557
	1000	-	-	-	-	-	-	36221010S	36221010A	36221015S	36221015A	833	2841
	1100	-	-	-	-	-	-	36221110S	36221110A	36221115S	36221115A	916	3126
	1200	-	-	-	-	-	-	36221210S	36221210A	36221215S	36221215A	999	3409
	1400	-	-	-	-	-	-	36221410S	36221410A	36221415S	36221415A	1166	3978
	1600	-	-	-	-	-	-	36221610S	36221610A	36221615S	36221615A	1332	4546
	1800	-	-	-	-	-	-	36221810S	36221810A	36221815S	36221815A	1499	5115
	2000	-	-	-	-	-	-	36222010S	36222010A	36222015S	36222015A	1666	5683

Annex 18: Existing Geothermal Heat Pump Commissioning Sheet

Greener Homes Scheme

Heat Source Details:

Type of refrigerant: 407C

Quantity 2.2 kg

Air source: Indoor evaporator ☐ Outdoor evaporator ☐

Closed loop (brine):

Type of anti-freeze Ethylene Glycol

Concentration 40 %

- *Vertical collector:*
  - *number of boreholes:* 2
  - *total length of boreholes:* 200m
- *Horizontal collector:*
  - *collector area::* ______ m^2
  - *collector total pipe length:* ______ m
- *Surface water:*
  - *Lake collector* ☐
  - *River collector* ☐

Open loop (water) heat pump:

- *Surface water (river, lake)* ☐
- *Groundwater* ☐
- *Extraction Flow (m3/h or litres/min.):* ______
- *Method of disposal of extracted water:* ______

Direct Expansion (DX)? Yes ☐ No ☑

Installation Details

Date of Completion 27/8/07

Pre-existing heating system? Yes ☐ No ☑

Home/Bungalow floor area ______ m^2

Is the system for:

- water heating only ☐
- space and water heating ☑
- cooling ☐

Size of hot water storage tank: 500 litres

Size of Buffer Tank, if fitted: 25 litres

Heat distribution system details:

Radiators ☐

Underfloor heating ☑

Warm air ☐

Other (describe): DHW

Pressurisation: Open vented ☑ Pressure vessel ☐

Measured operating temperatures:

Source:	Flow:	6°C	°C
	Return:	10°C	°C
Heating:	Flow:	46	°C
	Return:	41	°C
Refrigerant:	Evaporator:	-2	°C
	Condensor:	52	°C

Describe briefly heating control strategy:

Time & temperature control with DHW priority.

Service / Access code for controller: N/A

Heat Pump System Performance:

Rated capacity of the heat pump system at average expected operating temperatures: 12 kW

Expected average coefficient of performance (COP) of the heat pump system: 4:1

Electricity tariff in place:

standard day rate ☐

night rate ☑

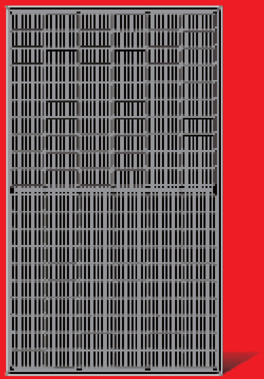
Estimate the proportion of electricity that will be charged at night rate: 70%

other: 30%

Estimate the average annual electricity consumption of the system: 6,930 kW

Comments:

Annex 19: Solar Panel



LR4-60HPB

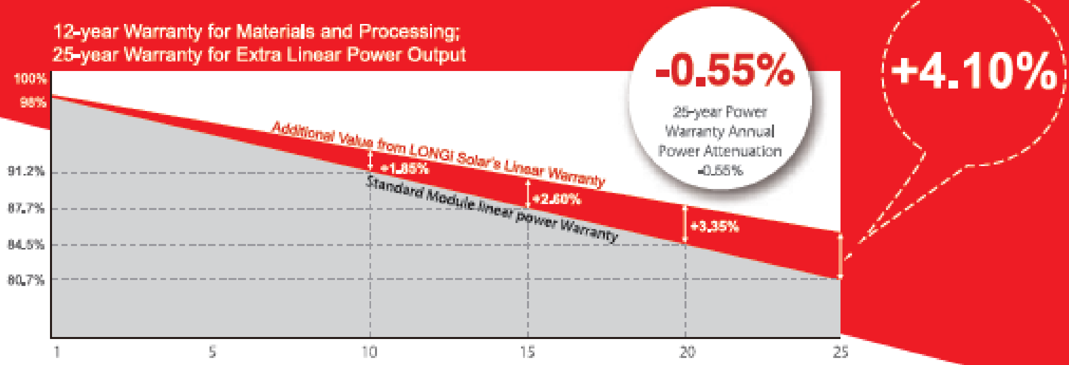
345~370M

Hi-MO 4m (Black)

NEW

High Efficiency
Low LID Mono PERC with
Half-cut Technology

12-year Warranty for Materials and Processing;
25-year Warranty for Extra Linear Power Output



Complete System and Product Certifications

IEC 61215, IEC 61730, UL 61730

ISO 9001:2008: ISO Quality Management System

ISO 14001: 2004: ISO Environment Management System

TS62941: Guideline for module design qualification and type approval

OHSAS 18001: 2007 Occupational Health and Safety

* Specifications subject to technical changes and tests. LONGi Solar reserves the right of interpretation.

Positive power tolerance (0 ~ +5W) guaranteed

High module conversion efficiency (up to 20.3%)

Slower power degradation enabled by Low LID Mono PERC technology: first year <2%, 0.55% year 2-25

Solid PID resistance ensured by solar cell process optimization and careful module BOM selection

Reduced resistive loss with lower operating current

Higher energy yield with lower operating temperature

Reduced hot spot risk with optimized electrical design and lower operating current

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Note: Due to continuous technical innovation, R&D and improvement, technical data above mentioned may be of modification accordingly. LONGi have the sole right to make such modification at anytime without further notice; Demanding party shall request for the latest datasheet for such as contract need, and make it a consisting and binding part of lawful documentation duly signed by both parties.

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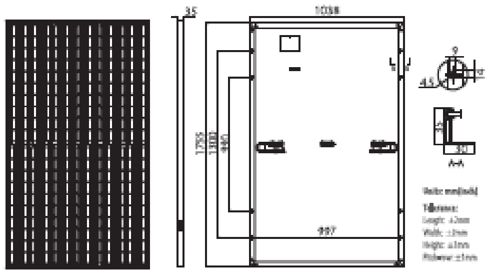
LR4-60HPB **345~370M**

Design (mm)



Mechanical Parameters

Cell Orientation: 120 (6×20)
Junction Box: IP68, three diodes
Output Cable: 4mm², 1200mm in length (for EU DG)
Glass: Single glass, 3.2mm coated tempered glass
Frame: Anodized aluminum alloy frame
Weight: 19.5kg
Dimension: 1755×1038×35mm
Packaging: 30pcs per pallet, 180pcs per 20'GP, 780pcs per 40'HC

Operating Parameters

Operational Temperature: -40℃ ~ +85℃
Power Output Tolerance: 0 ~ +5 W
Voc and Isc Tolerance: ±3%
Maximum System Voltage: DC1000V (IEC/UL)
Maximum Series Fuse Rating: 20A
Nominal Operating Cell Temperature: 45±2℃
Safety Class: Class Ⅱ
Fire Rating: UL type 1 or 2

Electrical Characteristics

Test uncertainty for Pmax: ±3%

Model Number	LR4-60HPB-345M		LR4-60HPB-350M		LR4-60HPB-355M		LR4-60HPB-360M		LR4-60HPB-365M		LR4-60HPB-370M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	345	257.6	350	261.4	355	265.1	360	268.8	365	272.6	370	276.3
Open Circuit Voltage (Voc/V)	40.2	37.7	40.4	37.9	40.6	38.1	40.8	38.2	41.0	38.4	41.2	38.6
Short Circuit Current (Isc/A)	11.06	8.95	11.16	9.02	11.25	9.09	11.33	9.16	11.41	9.23	11.50	9.30
Voltage at Maximum Power (Vmp/V)	34.2	31.8	34.4	32.0	34.6	32.2	34.8	32.4	35.0	32.6	35.2	32.8
Current at Maximum Power (Imp/A)	10.09	8.09	10.18	8.16	10.27	8.23	10.35	8.30	10.43	8.36	10.52	8.43
Module Efficiency(%)	18.9		19.2		19.5		19.8		20.0		20.3	

STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5

NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20℃, Spectra at AM1.5, Wind at 1m/S

Temperature Ratings (STC)

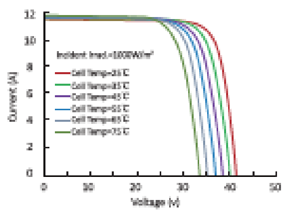
Temperature Coefficient of Isc	+0.048%/℃
Temperature Coefficient of Voc	-0.270%/℃
Temperature Coefficient of Pmax	-0.350%/℃

Mechanical Loading

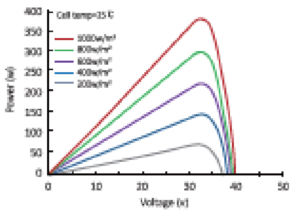
Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

I-V Curve

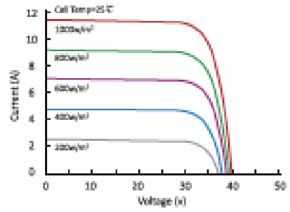
Current-Voltage Curve (LR4-60HPB-360M)



Power-Voltage Curve (LR4-60HPB-360M)



Current-Voltage Curve (LR4-60HPB-360M)



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Annex 20: Solis Mini Inverter

Datasheet

Model Name	Solis-mini-700-4G	Solis-mini-1000-4G	Solis-mini-1500-4G	Solis-mini-2000-4G	Solis-mini-2500-4G	Solis-mini-3000-4G	Solis-mini-3600-4G
Input DC							
Recommended max. PV power	0.9kW	1.2kW	1.8kW	2.3kW	3kW	3.5kW	4kW
Max. input voltage	600V						
Rated voltage	200V			330V			
Start-up voltage	60V			90V			
MPPT voltage range	50-500V			80-500V			
Max. input current	11A						19A
Max. short circuit current	17.2A						30A
MPPT number/Max. input strings number	1/1						1/2
Output AC							
Rated output power	0.7kW	1kW	1.5kW	2kW	2.5kW	3kW	3.6kW
Max. apparent output power	0.8kVA	1.1kVA	1.7kVA	2.2kVA	2.8kVA	3.3kVA	3.6kVA
Max. output power	0.8kW	1.1kW	1.7kW	2.2kW	2.8kW	3.3kW	3.6kW
Rated grid voltage	1/N/PE, 220/230V						
Rated grid frequency	50/60Hz						
Rated grid output current	3.2A/3.0A	4.5A/4.3A	6.8A/6.5A	9.1A/8.7A	11.4A/10.9A	13.6A/13A	16A
Max. output current	4.4A	5.2A	8.1A	10.5A	13.3A	15.7A	16A
Power Factor	>0.99 (0.8 leading - 0.8 lagging)						
THDi	<3%						
Efficiency							
Max. efficiency	97.2%				97.5%		
EU efficiency	96.5%				96.8%		
Protection							
DC reverse-polarity protection	Yes						
Short circuit protection	Yes						
Output over current protection	Yes						
Surge protection	Yes						
Grid monitoring	Yes						
Anti-islanding protection	Yes						
Temperature protection	Yes						
Integrated DC switch	Optional						
General Data							
Dimensions (W*H*D)	310*373*160 mm						
Weight	7.4kg				7.7kg		
Topology	Transformerless						
Self consumption	<1W (night)						
Operating ambient temperature range	-25 ~ +60°C						
Relative humidity	0-100%						
Ingress protection	IP65						
Cooling concept	Natural convection						
Max. operation altitude	4000m						
Grid connection standard	VDE-AR-N 4105, VDE V 0124, VDE V 0126-1-1, UTE C15-712-1, NRS 097-1-2, G98, G99, EN 50549-1/-2, RD 1699, UNE 206006, UNE 206007-1, IEC 61727						
Safety/EMC standard	IEC 62109-1/-2, IEC 62116, EN 61000-6-1/-2/-3/-4						
Features							
DC connection	MC4 connector						
AC connection	Quick connection plug						
Display	LCD						
Communication	RS485, Optional: Wi-Fi, GPRS						

Annex 21: Solis Single Phase Dual MPPT

solis

Datasheet

Model Name	RHI-3K-48ES-5G	RHI-3.6K-48ES-5G	RHI-4.6K-48ES-5G	RHI-5K-48ES-5G	RHI-6K-48ES-5G
Input DC (PV side)					
Recommended max. PV power	7kW	7kW	8kW	8kW	8kW
Max. input voltage	600V				
Rated voltage	330V				
Start-up voltage	120V				
MPPT voltage range	90-520V				
Max. input current	11A/11A				
Max. short circuit current	17.2A/17.2A				
MPPT number/Max. input strings number	2/2				
Battery					
Battery type	Li-ion/Lead-acid				
Battery voltage range	42 - 58V				
Battery capacity	50 - 2000Ah				
Max. charging power	3kW		5kW		
Max. charge/discharge current	62.5A/62.5A		100A/100A		
Communication	CAN/RS485				
Output AC (Back-up)					
Rated output power	3kW		5kW		
Max. apparent output power	4kVA		6kVA		
Back-up switch time	<20ms				
Rated output voltage	1/N/PE, 220/230V				
Rated frequency	50/60Hz				
Rated output current	13A		22A		
THDI	2% (linear load)				
Input AC (Grid side)					
Input voltage range	180-270V				
Max. input current	26.1A				
Frequency range	45-55 Hz/ 55-65 Hz				
Output AC (Grid side)					
Rated output power	3kW	3.6kW	4.6kW	5kW	6kW
Max. apparent output power	3.3kVA	4kVA	4.6kVA	5.5kVA	6kVA
Operation phase	1/N/PE				
Rated grid voltage	220/230V				
Rated grid frequency	50/60Hz				
Rated grid output current	13A	15.7A	20.9A	21.7A	26.1A
Max. output current	15.7A	17.3A	23A	23.9A	26.1A
Power Factor	>0.99 (0.8 leading - 0.8 lagging)				
THDI	<2%				
Efficiency					
Max. efficiency	>97.5%				
EU efficiency	>96.8%				
Protection					
Ground fault monitoring	Yes				
Integrated AFCI (DC arc-fault circuit protection)	Optional				
DC reverse-polarity protection	Yes				
Protection class/Over voltage category	I/II				
General Data					
Dimensions (W*H*D)	333*505*249 mm				
Weight	17kg				
Topology	High frequency isolation (for battery)				
Operating ambient temperature range	-25 ~ +60°C				
Ingress protecton/ Pollution degree	IP65/PD3				
Cooling concept	Natural convection				
Max. operation altitude	2000m				
Grid connection standard	EN50438, G98, G99, AS4777.2:2015, VDE0126-1-1, IEC 61727, VDE N4105, CEI 0-21,CE				
Safety/EMC standard	IEC62040-1, IEC62109-1/-2, AS3100, NB/T 32004, EN61000-6-2, EN61000-6-3				
Features					
DC connection	MC4 connector				
AC connection	Quick connection plug				
Display	7.0"LCD color screen display				
Communication	RS485, Optional: Wi-Fi, GPRS				

Annex 22: US2000B PYLONTECH

US2000B FROM PYLONTECH
PRODUCT DATA

SOLAX POWER

5 YEAR WARRANTY

10 YEAR LIFESPAN

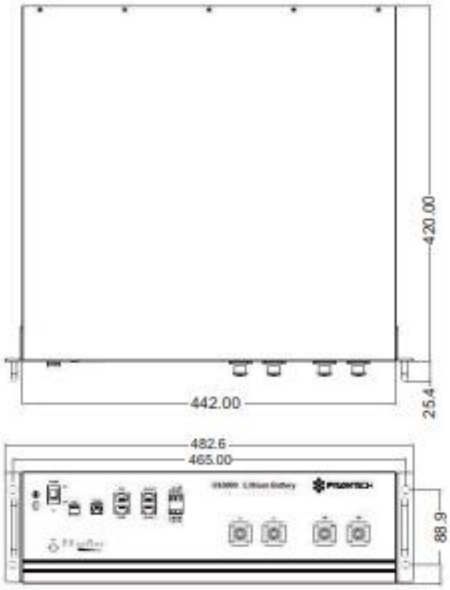
SCALABLE STORAGE

CUTTING EDGE DESIGN

Dimension (mm)	440 x 410 x 89
Weight (Kg)	24
Nominal Capacity (Ah)	50 (2.4kWh)
Nominal Voltage (V)	48
Discharge Voltage (V)	45 ~ 54
Charge Voltage (V)	52.5 ~ 54
Maximum Discharge Current (A)	100 (2C)@1Min
Maximum Charge Current (A)	100 (2C)@1Min
Life cycle	>6000 (80% DoD)
Depth of Discharge	80%
Working Temperature	0°C~50°C
Communication Interface	RS232, RS485, CAN
Certification	TüV / CE / UN38.3 / TLC
Warranty	5 years

Annex 23: US3000 Pylontech

2.2 Specifications



Basic Parameters	US3000
Nominal Voltage (V)	48
Nominal Capacity (Wh)	3552
Usable Capacity (Wh)	3200
Dimension (mm)	442*420*132
Weight (Kg)	32
Discharge Voltage (V)	45 ~ 53.5
Charge Voltage (V)	52.5 ~ 53.5
Recommend Charge/Discharge Current (A)	37
Max. Charge/Discharge Current (A)	74
Peak Charge/Discharge Current (A)	100A@15sec
Communication	RS485, CAN
Configuration (max. in 1 battery group)	8pcs
Working Temperature	0℃~50℃ Charge
	-10℃~50℃ Discharge
Shelf Temperature	-20℃~60℃
Protective class	IP20
Cooling type	Natural Cooling
IP rating of enclosure	IP20
Humidity	5% ~ 85%
Certification	IEC62619/ CE / UN38.3
Design life	10+ Years (25℃/77℉)
Cycle Life	>6,000 25℃
Reference to standards	IEC62619, IEC62040, IEC62477-, IEC61000-6-2,IEC61000-3, UN38.3

4 / 23 19BQSV0102

Annex 24: Triple Power

3.2 Basic Features

3.2.1 Features

The T-BAT SYS-HV is one of the advanced energy storage systems on the market today, incorporating state-of-the-art technology, high reliability, and convenient control features shown as below:

- 90% DOD
- 99% Faradic charge efficiency
- 95% Battery roundtrip efficiency
- Cycle life > 6000 times
- Secondary Protection by hardware
- IP55 protection level
- Safety & Reliability
- Small footprint
- Floor or wall mounting

3.2.2 Certifications

T-BAT system safety	CE, FCC, RCM, TUV (IEC 62619), UL 1973
Battery cell safety	UL 1642
UN number	UN 3480
Hazardous materials classification	Class 9
UN transportation testing requirements	UN 38.3
International protection marking	IP 55

3.3 Specifications

3.3.1 T-BAT SYS-HV Configuration List

No.	Model	BMS	Battery Module	Energy(kWh)	Voltage (V)
1	T-BAT H4.5	MC0500x1	HV10045X1	4.5	85-118
2	T-BAT H9.0	MC0500x1	HV10045X2	9	170-236
3	T-BAT H13.5	MC0500x1	HV10045X3	13.5	255-354
4	T-BAT H18.0	MC0500x1	HV10045X4	18	340-472
5	T-BAT H6.3	MC0500x1	HV10063X1	6.3	85-118
6	T-BAT H12.6	MC0500x1	HV10063X2	12.6	170-236
7	T-BAT H18.9	MC0500x1	HV10063X3	18.9	255-354
8	T-BAT H25.2	MC0500x1	HV10063X4	25.2	340-472

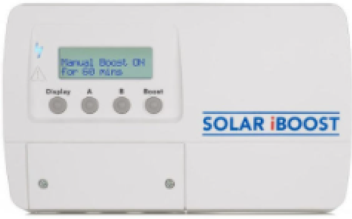
3.3.2 Performance

	MC0500	HV10045	HV10063
Nominal Voltage(Vdc)	/	100.8	100.8
Operating Voltage(Vdc):	70-500	85-118	85-118
Nominal Capacity(Ah):	/	45	63
Max. charge/discharge Current(A) :	30	30	30
Recommend Charge/Discharge Current (A):	25	25	25
Standard Power(kW)	/	2.5	2.5
Maximum Power(kW)	/	3	3
Faradic Charge Efficiency(25℃/77℉)	99%		
Battery Roundtrip Efficiency(C/3,25℃/77℉)	95%		
Expected Lifetime(25℃/77℉)	5 years		
Cycle life(100% DOD,25℃/77℉)	6000 cycles		
Available Operating Temperature	0~45 ℃		
Optimal Operating Temperature	15℃--30℃		
Storage Temperature	-20℃~45℃ (3 months)		
	-20℃~20℃ (1 year)		
Ingress Protection	IP55		

Annex

Annex 25: Hot water power diverters

Solar iBoost+



A common power diverter on the Irish market. Features include:

- Boost Button (Programmable)
- Programmable on a weekly cycle to kill Legionella
- Dual-immersion function
- Battery-Compatible

SOLiC 200

A simple and popular zero-export power diverter. Features include:

- Boost button (90-minutes)
- Zero-export
- Wired energy usage sensor

myEnergi Eddi

An advanced power diverter known for reliability. Features include:

- Boost function
- Programmable
- Remote access via mobile app
- Zero-export and battery-compatible modes
- Recommended by EnergyD

Annex 26: Solar PV system with 2.2 kWp capacity (bill of quantity)

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	6	174.00	1044.00
Inverter – Solis Dual MPPT, 2.5 kW	Nos.	1	511.00	511.00
Battery- Pylontech 3.6 kwh, Lithium Ion	Nos.	1	1052.00	1052.00
BOS Cost	Nos.	1	681.00	681.00
The total cost of Material (Including 23% VAT)				

Annex

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	4	1	1	340.00
Electrical wiring	4	-	2	200.00
Transport				125.00
The total cost of installation				**665.00**
The total cost of the PV system				**3953**

Annex 27: Solar PV system with 1.48 kWp capacity

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	4	174.00	696.00
Inverter – Solis Mini 2000 4G, 1.5kW	Nos.	1	375	375
Battery- Pylontech 2.4 kwh, Lithium Ion	Nos.	1	1064	1064
Firefighter safety switch – 2pole	Nos.	1	200.00	200.00
AC isolator – 20/25 A per pole	Nos.	1	40.00	40.00
DC isolator 2 Pole, 1 string	Nos.	3	100.00	300.00
Wiring cable – 4 sq. mm solar cable	Meter	100	1.10	110.00
Cable connector (MC4 solar connector)	Pair	2	6.50	13.00

Annex

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Energy meter – single phase	Nos.	1	23.00	23.00
Mounting system – ground mount	Set.	1	223.00	223.00
System labeling sticker	Nos.	1	10.00	10.00
The total cost of Material (Including 23% VAT)				**3054**
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	4	1	1	340.00
Electrical wiring	4	-	2	200.00
Transport				125.00
The total cost of installation				**665.00**
The total cost of the PV system				**3719**

Annex 28: Solar PV system with 2.96 kWp capacity

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	8	174.00	1392.00
Inverter – Solis Mini 2000 4G, 3kW	Nos.	1	507.00	507.00
Firefighter safety switch – 2pole	Nos.	1	200.00	200.00
AC isolator – 20/25 A per pole	Nos.	1	40.00	40.00

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
DC isolator 2 Pole, 1 string	Nos.	2	100.00	200.00
Wiring cable – 4 sq. mm solar cable	Meter	100	1.10	110.00
Cable connector (MC4 solar connector)	Pair	2	6.50	13.00
Energy meter – single phase	Nos.	1	23.00	23.00
Mounting system – ground mount	Set.	1	412.00	412.00
System labeling sticker	Nos.	1	10.00	10.00
The total cost of Material (Including 23% VAT)				**2907.00**
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	5	1	1	425.00
Electrical wiring	5	-	2	250.00
Transport				125.00
The total cost of installation				**800.00**
The total cost of the PV system				**3707.00**

Annex 29: Solar PV system with 4.4 kWp capacity

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	12	174.00	2088.00

Annex

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Inverter –Solis Dual MPPT 3.6 kW	Nos.	1	612.00	612.00
Battery- Pylontech 3.6 kwh, Lithium Ion	Nos.	1	1422.00	1422.00
Firefighter safety switch – 2pole	Nos.	1	200.00	200.00
AC isolator – 20/25 A per pole	Nos.	1	40.00	40.00
DC isolator 2 Pole, 1 string	Nos.	3	100.00	300.00
Wiring cable – 4 sq. mm solar cable	Meter	100	1.10	110.00
Cable connector (MC4 solar connector)	Pair	4	6.50	26.00
Energy meter – single phase	Nos.	1	23.00	23.00
Mounting system – ground mount	Set.	1	548.00	548.00
System labeling sticker	Nos.	1	10.00	10.00
The total cost of Material (Including 23% VAT)				**5379.00**
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	7	1	1	595.00
Electrical wiring	7	-	2	350.00
Transport				125.00
The total cost of installation				**1070.00**

Annex

Annex 30: Solar PV system with 5.18 kWp capacity without battery storage

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	14	174.00	2436.00
Inverter – Solis Dual PPT, 6kW	Nos.	1	798.00	798.00
Firefighter safety switch – 2pole	Nos.	1	200.00	200.00
AC isolator – 20/25 A per pole	Nos.	1	40.00	40.00
DC isolator 2 Pole, 1 string	Nos.	3	100.00	200.00
Wiring cable – 4 sq. mm solar cable	Meter	100	1.10	110.00
Cable connector (MC4 solar connector)	Pair	2	6.50	13.00
Energy meter – single phase	Nos.	1	23.00	23.00
Mounting system – ground mount	Set.	1	868.00	868.00
System labelling sticker	Nos.	1	10.00	10.00
The total cost of Material (Including 23% VAT)				**7700.00**
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	15	1	1	1275.00
Electrical wiring	13	-	2	650.00
Transport				125.00
The total cost of installation				**2050.00**
The total cost of the PV system				**6470.00**

Annex

Annex 31: Solar PV system with 5.92 kWp capacity with 3.6kWh battery storage

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
Solar PV panel – Longi 370W	Nos.	16	174.00	2784.00
Inverter – Solis Dual MPPT ,6kW	Nos.	1	798.00	798.00
Battery- Pylontech 2.4 kwh, Lithium Ion	Nos.	1	1052.00	1052.00
Firefighter safety switch – 2pole	Nos.	1	200.00	200.00
AC isolator – 20/25 A per pole	Nos.	1	40.00	40.00
DC isolator 2 Pole, 1 string	Nos.	3	100.00	300.00
Wiring cable – 4 sq. mm solar cable	Meter	100	1.10	110.00
Cable connector (MC4 solar connector)	Pair	2	6.50	13.00
Energy meter – single phase	Nos.	1	23.00	23.00
Mounting system – ground mount	Set.	1	1295.00	1295.00
System labeling sticker	Nos.	1	10.00	10.00
The total cost of Material (Including 23% VAT)				**6625.00**
Cost of installation (Labour & transport)				
Work description	Nos. of hours	Nos. of Electrician: 60.00€/hour	Nos. of Normal labour: 25€/hour	Total cost €
Installation of solar PV system	15	1	1	1275.00
Electrical wiring	13	-	2	650.00
Transport				125.00
The total cost of installation				**2050.00**

Annex

Cost of material				
Item description with specifications	UOM	Quantity	Unit Price	Total price
The total cost of the PV system				**8675.00**