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Microgeneration of Electricity Using a Solar Photovoltaic System in Ireland

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Received: 30 October 2019; Accepted: 2 December 2019; Published: 3 December 2019

Abstract: Microgeneration of electricity using solar photovoltaic (PV) systems is a sustainable form of renewable energy, however uptake in Ireland remains very low. The aim of this study is to assess the potential of the community-based roof top solar PV microgeneration system to supply electricity to the grid, and to explore a crowd funding mechanism for community ownership of microgeneration projects. A modelled microgeneration project was developed: the electricity load profiles of 68 residential units were estimated; a community-based roof top solar PV system was designed; an electricity network model, based on a real network supplying a town and its surrounding areas, was created; and power flow analysis on the electrical network for system peak and minimum loads was carried out. The embodied energy, energy payback time, GHG payback time, carbon credits and financial cost relating to the proposed solar PV system were calculated. Different crowdfunding models were assessed. Results show the deployment of community solar PV system projects have significant potential to reduce the peak demand, smooth the load profile, assist in the voltage regulation and reduce electrical losses and deliver cost savings to distribution system operator and the consumer.

Keywords: microgeneration; solar energy; photovoltaic; renewable energy; crowd funding

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1. Introduction

The fifth assessment report of the Intergovernmental Panel on Climate Change [1] has concluded that human influence on the climate system is clear, and anthropogenic emissions of greenhouse gases (GHG) are the highest in history. GHG emissions are driving the increase in global average temperatures by over 1 °C above preindustrial times with this trend projected to continue. In Ireland, the burning of fossil fuels for energy generation is the dominant contributor to total national GHG emissions (60% in 2017) [2]. With limited indigenous fossil energy resources, Ireland is significantly dependent on fossil fuel imports which accounted for over 90% of the primary electricity demand in 2017 [2]. The Irish Government is committed to decrease GHG emissions and advance alternative energy sources to reduce the national dependence on fossil fuels (2009/28/EC Renewable Energy Directive (RED)) [3] and has committed to a target of 40% electricity use from renewables by the year 2020 [4]. In Ireland in 2017 only 10.6% energy supply came from renewable sources and the country was ranked 26th out of the European Union (EU)-28 for progress toward meeting 2020 renewable energy target [5]. Overall renewable energy has displaced 1.8 million tonnes of oil equivalent (Mtoe) of fossil fuel and reduced GHG emissions by 4.2 million tonnes (Mt) CO_2 in 2017 (80% from generation of electricity). The renewable electricity sources include wind, hydro, biomass, renewable wastes, landfill gas, biogas and solar PV, however, the level of electricity generation from solar PV remains very low [5].

Ireland is not on track to meet 2020 renewable energy targets which has cost implications of €100 to €150 million for each percentage point shortfall [4]. The Irish Government has agreed to the binding renewable energy target for 2030 of 32% in line with EU recast RED 2 [6]. Microgeneration of electricity using solar PV system is expected to contribute to meeting these targets mitigating some of the adverse effects of environmental pollution and climate change. The renewable energy sector technologies are evolving rapidly and ensuring higher levels of renewable energy generation will require substantial investments in new infrastructure which includes wind farms, solar PV systems, grid reinforcement, storage development and interconnection. However, high risks and the high up-front costs associated with developing technologies is a major barrier to securing finance. As a result of rapid growth in the use of social media, crowdfunding is increasingly replacing conventional funding models used as an alternative means of funding renewable energy projects [7].

1.1. Microgeneration

Microgeneration is a form of decentralized or distributed energy supply [8] where: energy generation serves in-situ demand (high degree of self-consumption); installations are deployed at lower-voltage distribution network level; and small-scale technologies are deployed including rooftop solar PV, small wind turbines, small hydro and domestic combined heat and power (CHP) [9]. Benefits include lower electricity bills, hedging against future electricity price rises, lower GHG emissions, reduced reliance on fossil fuels, reduced electrical losses on the electricity network and improved building energy rating (BER) [10].

Photovoltaics is the direct conversion of light into electricity at the atomic level by materials displaying a photoelectric effect causing them to absorb photons of light and release electrons. When these free electrons are captured, it results an electric current [11]. Semi-conductors are treated/doped to form a p-n junction such as in crystalline silicon cells by diffusing phosphorous into the silicon and introducing a small quantity of boron, forming an electric field. When photons are absorbed by a PV cell, electrons under the influence of the field move out towards the surface. This flow or current is 'harnessed' by an external circuit with a load [12]. The electricity generated is direct current (DC), converted to alternating current (AC) using an inverter to synchronise with mains electricity [10]. Solar PV panels do not generate CO_2 emissions during their operation; however, emissions are generated during the production of the solar panels and during their disposal. Solar PV systems can be connected to home for supplemental power, full power and backup supply (off-grid) or as a revenue generating power system [13].

Solar PV panels are installed in residential, commercial and industrial settings or as a stand-alone system for generation of electricity for feeding to the national grid. In 2017 very little renewable electricity in Ireland was produced from solar PV, with installed capacity of around 15.7 MW and around 11 gigawatt hours (GWh) of electricity generated equating to 0.1% of renewable electricity or 0.04% of electricity gross final consumption (GFC) [5]. Households currently account for approximately 1.0 megawatt (MW) of installed residential solar PV systems connected to the grid [5]. The Irish Government, in its climate action plan 2019, has indicated the solar PV system is expected to grow to 1.5 gigawatt (GW) of installed capacity by 2030 [14].

1.2. Solar Energy Potential in Ireland

At the Earth's surface radiation can exist in three forms: direct radiation which comes directly from the sun; diffuse radiation which has undergone scattering during its passage through the atmosphere; or reflected radiation from the ground [15]. Solar radiation distribution and intensity are the key factors in determining the efficiency of solar PV systems and results are highly variable [16]. Ireland typically receives an annual solar radiation of 900 kWh m^{-2} [12] compared to Greece with 1890 kWh m^{-2} and Italy with 1680 kWh m^{-2} [17], where unsurprisingly, solar PV accounted for largest total electricity generation in 2017 (8.7% in Italy and 7.6% in Greece) [18]. As well as solar radiation, module efficiency depends on the type of module and the module temperature [19]. The annual energy output (kWh) of the solar PV systems also depends on the peak rating of the solar PV installation (kWp) [12]. The measured performance of a 1.72 kWp rooftop grid connected PV system in Ireland is 885.1 kWh kWp^{-1} $year^{-1}$ [20]. The location of site and the tilt and orientation of solar PV panels are important for the energy output (kWh) of the solar PV systems [12]. For example, the site should be south facing of have a slight south-east or south-west orientation and should not be overshadowed by obstacles which could prevent sunlight getting to the system [21].

1.3. Barriers to Implementation

Despite the potential of microgeneration technologies to help Ireland meet its energy and emission targets and induce positive shifts in energy consumption, the rate of adoption among homeowners remains low. The reasons include low awareness of microgeneration among homeowners, with intention to install at just over 7% [9] and homeowners' willingness to pay (WTP) falling significantly below market prices. In addition, homeowners purchase, or investment decisions are influenced by factors other than cost–benefit evaluations including the benefits of microgeneration and positive social pressure which can translate into higher uptake [22]. Existing installed microgeneration capacity is very low and a very large increase in installation by 2025 would be required to meet the proposed 5% renewable target. In addition, the network potential to accommodate such an increase in capacity in microgeneration on low voltage network by 2025 not well understood.

Microgeneration policies in other jurisdictions have also encountered issues with growing costs and inadequate incentives i.e., export payment as the only incentive, may not sufficiently stimulate large scale deployment (for example export tariff would need to be 27 cents to have same economic impact as SEAI grant for typical 2 kW system with 20% export) [9]. In 2007, the number of microgeneration installations in the UK was estimated at less than 100,000, but between 2009 to 2014 over 730,000 systems were installed, 88% of which are solar PV [8]. The renewable microgeneration technologies adoption has resulted in significant annual savings in energy running cost [23]. The introduction of feed-in tariff (FiT) support has encouraged greater numbers of installations [24] and the global solar PV market has grown significantly, leading to a reduction in capital costs in the UK between December 2010 and September 2012 of around 50%. Consumer cost reductions are mostly likely to occur through market development with increased number of installations or policies to reduce capital costs such as capital grants and low interest loans which are repaid through FiT payments, potential adopters are also driven by the desire to show others their environmental commitment to reduce GHG emissions and earning or saving money through incentives and reduced fuel bills [24].

The most important barriers to adoption in the UK were the higher capital costs compared to annual energy savings and payback period, the absence of subsidies and the regulatory requirements. Other factors include home ownership, the level of available capital for investment and size of house or the suitability of microgeneration technologies [24]. There is also the loss of utility to households caused by space requirements (e.g., roof top space to install solar PV and/or solar thermal, fuel storage-hot water tanks and gardens dug up to install ground heat pumps etc.). These costs would be reduced by concentrating policy on new houses, where microgeneration technologies could be designed into the house at construction at a lower cost [23].

1.4. Financial Support Mechanism

Many support mechanisms have been employed in France, Germany, Greece, Italy and the UK to help increase the uptake of solar PV systems such as capital subsidies, VAT reduction, tax credits, renewable portfolio standards, net-metering, FiT etc. In 2012 the most popular support mechanism in terms of market share were FiTs (60%), capital subsidies and tax rebates (20%), self-consumption (12%), renewable portfolio standards (4%) and net-metering (2%). The electricity compensation schemes (self-consumption and net-metering) have increased their uptake in the last decade, rising from a 4% historical value to 14% in 2012. The reduction in PV costs has resulted in the reduction or elimination of the FiT mechanism instead introducing self-consumption rules [25].

In Ireland several initiatives have been taken to improve uptake of solar PV systems with limited success. The primary support mechanisms for installation of renewable electricity infrastructure are the Renewable Energy Feed-in Tariff (REFIT) schemes which provides a minimum price for each unit of electricity exported to the grid over a 15-year period giving certainty to renewable electricity generators. Currently solar PV systems are not supported under the REFIT scheme [26] however, the new Renewable Electricity Support Scheme (RESS) will provide opportunities for incorporating solar PV, bioenergy and wind within a cost competitive framework.

To deliver Ireland's renewable electricity ambitions to 2030 including reducing the gap to reach 2020 renewable energy targets and accommodating microgeneration by 2021, the Government of Ireland has indicated the key outcomes in energy sector between the years 2019–2021 will include the increased renewable energy usage in the electricity sector via increased levels of microgeneration. Solar energy has the potential to provide a community dividend while maintaining basic payment schemes, subject to EU commission approval [27].

1.5. Crowdfunding

The European Commission defines crowdfunding as an alternative form of financing that connects those who can give, lend or invest money directly with those who need financing for a specific project and usually refers to public online calls to contribute finance to specific projects [28]. Compared to other major world economies, crowdfunding for the EU market is not well developed as the lack of common rules across member states results in compliance issues and increased operational costs. The European Commission has proposed new regulations to address the barriers to crowdfunding use by small investors and businesses. In Ireland, crowdfunding is not currently a regulated activity constituting only 0.33% to 0.4% of the small to medium sized enterprise (SME) finance market whereas in UK it constitutes 12% [29]. It is planned to regulate crowdfunding in Ireland and enact a domestic regulatory regime which is in parallel with the European Commission regulation, to create an environment for the growth of crowdfunding as one of the alternative source of finance for the Irish SMEs and also to ensure sufficient consumer protection [30].

2. Materials and Methods

2.1. Solar PV System Description

The proposed solar PV microgeneration community-based project consists of 68 residential units located at Belfield, Dublin (herein referred to as "the project"). The solar irradiance data collected from the nearest weather station at Dublin airport is 963 kWh m^{-2}.

The solar PV panels are mounted on the rooftop of each unit with the collector facing south and a tilt angle of 30°. The PV solar panel for use in this system are the Hanwha Q cells (Seoul, South Korea) Q peak G4.1 300 Rev4 monocrystalline modules with dimensions of 1670 × 1000 × 32 mm, with a surface area of 1.67 m^2 and an efficiency of 18%. Annual average solar irradiation received by these modules was 1074 kWh m^{-2}. The roof area available on each unit for mounting of solar PV panels is 10.042 m^2. Solar PV system details are listed in Table 1 [4].

Table 1. Solar PV system details for each unit.

Data for Each Residential Unit	Unit	Quantity
Area of the roof area (A)	m^2	10.042
Panel efficiency (r)	%	18
Installed effect (Wpi)	kWp	1.8
Nominal power of panel (Wp)	kW	0.3
Number of panels (Np)	Piece	6
Annual average irradiation (H)	kWh m^{-2}	1074
Coefficient for losses (C)	Factor	0.8
Annual peak power output (Ep)	kWh $year^{-1}$	1553
Performance ratio (PR)	%	80
Lifetime expectancy	years	30

The total solar PV installed effect of each unit W_{pi} [31] is calculated using Equation (1):

$$\boldsymbol{W_{pi} = A \cdot r} \tag{1}$$

where,

W_{pi} = Total solar PV installed effect of each building in kW
$\boldsymbol{A}$ = Total roof area in m^2;
$\boldsymbol{r}$ = Solar panel efficiency in %.

The number of panels installed in each unit N_p [31] is calculated using Equation (2):

$$N_p = W_{pi}/W_p \tag{2}$$

where,

N_p = Number of panels installed;
W_{pi} = Total solar PV installed effect of each unit in kW;
W_p = Nominal power rating of the panel in kW.

The annual peak output of the solar PV system of each unit E_p [31] is calculated using Equation (3):

$$E_p = A \cdot r \cdot H \cdot C \tag{3}$$

where,

E_p = Annual peak output of the solar PV system in kWh $year^{-1}$
H = Annual average irradiation on tilted panels in kWh $m^{-2.}$
C = Coefficient for losses (range between 0.9 to 0.5).

Coefficient for losses will depend on the site, technology and sizing of the system including inverter losses (6 to 15%), temperature losses (5 to 15%), DC cable losses (1 to 3%), AC cable losses (1 to 3%), shading (0 to 40%), weak irradiation (3 to 7%), losses due to dust, snow (0 to 2%), degradation of modules (0.5 to 1%) and other (1 to 2%). Default value is set to 0.75 [31].

The performance ratio of the solar PV system, PR [31] is calculated using Equation (4):

$$PR = \left(\frac{\frac{E_p}{W_{pi}}}{H} \right) \cdot 100 \tag{4}$$

where,

PR = Performance ratio of the solar PV system in %.

2.2. Solar PV Electricity Generation

There are two options when modelling solar PV electricity for calculating yield [32], either using forecast or measured yields or using a weather profile with irradiance values (Wm^{-2}). The monthly values of solar PV electricity were produced from simulations in PV*SOL software [33] using the weather data from the integrated meteo weather database (meteonorm.com). This system uses World Meteorological Organization (WMO) data including global and regional databases in combination with spatial interpolation methods to generate data for locations between the weather stations [34].

2.3. Electricity Network Model

The electricity network model is based on a typical network supply to a town and its surrounding areas. The model consists of a primary substation, MV feeders, MV to LV distribution substation and other associated equipment. The primary substation is outdoor and air insulated which steps down the voltage from 38 kV to 10.47 kV and is equipped with two units of 5 Mega Volt Amp (MVA) transformers, the on-load tap changers of the 5 MVA transformers automatically regulates and controls the target voltage of 10.7 kV. The stepped down voltage (10.47 kV) is distributed from substation to the 10.47 kV to 0.400 kV substation via feeder circuits [32] Figure 1.

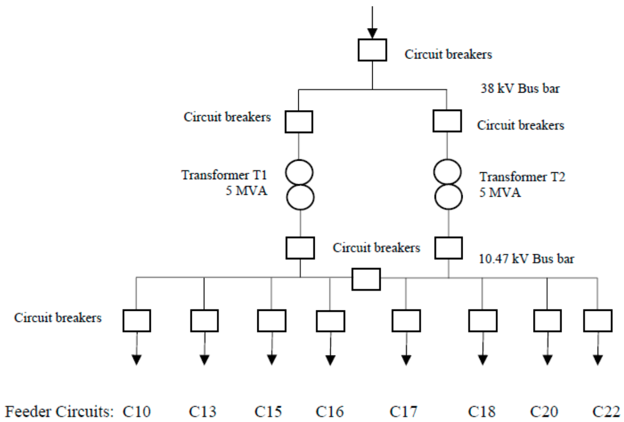

Figure 1. Primary substation single line diagram [32].

The feeder circuit C15 from the primary substation has a total circuit length of 40 km with a mix of overhead lines and underground cables. The project is assumed to be located to the south of the primary substation and main town centre [32] Figure 2.

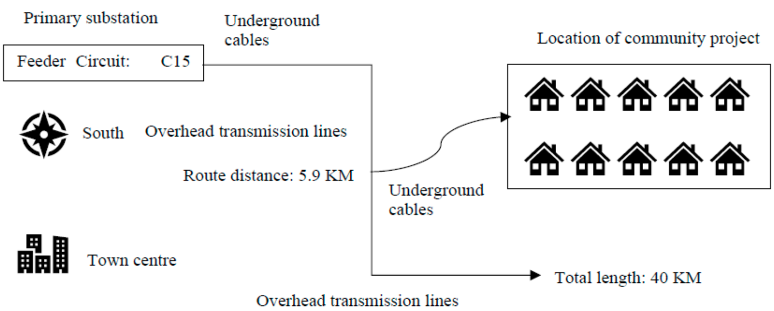

Figure 2. Feeder circuit C15 and location of the project [32].

The transition of the feeder circuit C15 from overhead line to underground cable takes place 5.9 km from the primary substation via spur connection and the underground cable is connected to distribution substation which is located at the edge of the existing project housing estate, where voltage is further stepped down from 10.47 kV to 0.400 kV using a 630 kVA transformer. The LV (0.400 kV) is further distributed using six LV underground cables to 11 street pillars. Over the entire network model, the number of units connected to each phase were balanced with 22 units connected to phase-1, 23 units connected to phase-2 and 23 units connected to phase-3 [32]. At all the 11 load points the solar PV system were connected by each unit.

2.4. Electricity Demand

The electricity demand examines the project demand profile and the demand components including existing demand on the MV circuits without the project; the additional demand on the existing MV including the project and the solar PV electricity output.

2.4.1. Community Project Electricity Demand Profile

To model the demand of the project, the electricity demand data was obtained from the distribution system operator's (Electricity Supply Board (ESB)) standard load profiles which is consolidated samples from residence meters which consists of high, middle and low annual usage from national average values Table 2 [35].

Table 2. Annual household electricity demand [35].

Low Usage	Medium Usage	High Usage
3100 kWh	5300 kWh	8100 kWh

The low usage electricity load profile (3100 kWh) was selected and the load profile of each unit was customized to reflect the monthly electricity consumption based on the approximate number of occupants. Simulations were also performed to determine the annual electricity yields available for self-consumption and for grid feed-in. The total electricity demand profile of the project is composed of variable hourly loads, the timing of usage varies for each unit due to preferences and behaviours of occupants [35].

2.4.2. Demand Components

The electrical network operation downstream of the primary substation was modelled to determine demand at each of the load points on the MV feeder circuit. The demand profile is composed of three components [32]:

(1) The existing demand on the MV circuits excluding the project.
(2) Additional demand on the existing MV circuits including the project based on average peak demand from each unit, (5 kW at 93% power factor in winter and 0.9 kW at 95% power factor in summer).
(3) Solar PV electricity output from community microgenerators.

To model the electrical network system peak and minimum load, the ESB electrical power flow analysis [32] for the following system load conditions are used:

- Peak electricity demand on winter maximum load reading day December 2015, 17:00 pm.
- Midday electricity on summer minimum load reading day in August 2016, 12:00 pm.

Existing Demand on the MV Circuit Excluding the Project

Existing demand on the MV circuits includes the load points (distribution transformer substations) which provide electricity supply to the LV networks consisting of connections to customers. Ideally the actual values of the demands at each of these load points would be metered. In this study known load information was used to calculate the existing demand on the distribution transformers substation and at the large consumer substations which are connected to the existing MV network [32]. The project model includes the LV sections up to the street pillars, (the load points), in this study units were evenly spread across the 3 phases of 11 street pillars, 2 to 4 units per phase [32].

Additional Demand on the MV Circuit Including the Project

The hourly loads of each unit are spikey in nature. In this study along with general loads, a heat pump is assumed to be used in each unit, the heat pump is assumed to consume a power input 2.14 kW to provide a power output 9 kW for an under-floor heating system and a hot water storage system. The timing of the usage or cycling of the heat pumps varies for each residential unit due to personal preferences and behaviours of occupants [32].

Solar PV Electricity Output from Community Microgenerators

The solar PV electricity output from community microgenerators are estimated from weather profiles based on simulations [33] using weather data (with irradiance values) from the integrated weather database.

2.5. Energy Assessment of the Solar PV System

The calculations for embodied energy and the energy payback time of the solar PV system, GHG emissions payback time and carbon credits are outlined.

2.5.1. Embodied Energy of the Solar PV System

Embodied energy of the solar PV system is defined as the energy consumed by the system for materials; manufacturing; transportation and installation [36]. The embodied energy of the solar PV system has been completed by evaluating the total energy required for each process [37].

The embodied energy of each component per m^2 of solar PV module E_{in} [37] for this study was calculated using Equation (5):

$$E_{in} = E_{mfg} + E_{use} + E_{del} \tag{5}$$

where,

E_{in} = Embodied energy of solar PV system (kWh m^{-2});
E_{mfg} = Total manufacturing energy (kWh m^{-2});
E_{use} =Total used energy in installation and operation and maintenance (kWh m^{-2});
E_{del} = Energy requirement to deliver from production to field site (kWh m^{-2}).

The total manufacturing energy E_{mfg} [37] is calculated using Equation (6):

$$E_{mfg} = E_{mpe} + E_{eqp} \tag{6}$$

where,

E_{mpe} = Total material production energy in kWh m^{-2};
E_{eqp} = Total operation and maintenance energy of equipment in kWh m^{-2};

Total material production energy E_{mpe} [37] is calculated using Equation (7):

$$E_{mpe} = \sum_i \left(e_{mpe,i} \cdot m_i\right) \tag{7}$$

where,

$E_{mpe,i}$ = Specific energy to produce ith material;
m_i = Total mass of ith product material.

The total used energy in installation and operation and maintenance E_{use} [37] is calculated using Equation (8):

$$E_{use} = E_{inst} + E_{am} \cdot T_{LS} \quad (8)$$

where,

E_{inst} = Installation energy requirement for the experiment;
E_{am} = Average energy operation and maintenance rate over the life of the PV system;
T_{LS} = Life of the system in years.

The energy requirement to deliver the product materials from production to field site E_{del} is calculated using Equation (9):

$$E_{del} = \sum \left(E_{trans_{i \to i+1}} + E_{pkg\ i \to i+1} \right) \quad (9)$$

where, E_{pkg} and E_{trans} are the packaging and energy requirement for the transfer of the product materials respectively from production to field site.

The balance of system (BOS) components e.g., battery, inverter, electronic components, cables and miscellaneous items should also be included in the calculations [38]. The breakdown of embodied energy of each component per m^2 of solar PV module for this study is in Table A1. (Appendix A).

2.5.2. Energy Payback Time of the Solar PV System (EPBT)

Energy payback time of the solar PV system is defined as the time needed for the system to generate the energy used in its life cycle from the extraction of raw materials to the construction and decommissioning phase. The EPBT [39] is calculated using Equation (10):

$$EPBT = \frac{E_{mat} + E_{manuf} + E_{trans} + E_{inst} + E_{eol}}{\frac{E_{aegen}}{\eta G} - E_{O\&M}} \quad (10)$$

where,

E_{mat} = Primary energy demand to produce materials comprising solar PV system;
E_{manuf} = Primary energy demand to manufacture solar PV system;
E_{trans} = Primary energy demand to transport materials used during the life cycle;
E_{inst} = Primary energy demand to install solar PV system;
E_{eol} = Primary energy demand for end of life management;
E_{aegen} = Annual electricity generation by solar PV system;
$E_{O\&M}$ = Annual primary energy demand for operation and maintenance of solar PV system;
ηG = Grid efficiency, the average primary energy to electricity to electricity conversion efficiency at the demand side.

2.6. GHG Emissions and Carbon Credits

The solar PV power generation is one of the cleanest sources of renewable energy [4]. In 2017, natural gas accounted for 51% of the fuel used for electricity generation in Ireland and the CO_2 intensity of electricity is 437 g CO_2 kWh^{-1} or 0.000437 t CO_2 kWh^{-1} [40].

2.6.1. GHG Payback Time

GHG payback time (GPBT) is defined as the number of years it takes solar PV system to pay back its embodied emissions through solar PV generation. The GPBT [41] is described by Equation (11):

$$GPBT = \frac{CO_2\ equivalents\ (eq) embodied}{CO_2\ eq\ avoided\ (year)} \quad (11)$$

where,

$$CO_2\ eq\ embodied = CO_2\ eq\ modules + CO_2\ eq\ mounting\ structures + CO_2\ eq\ electric\ (BOS) + CO_2\ eq\ transport\ etc;$$

$CO_2\ eq\ avoided\ (year)$ = Emissions avoided per year due to the production of electricity from the solar PV system installation.

2.6.2. Carbon Credits

Carbon credits are awarded for the reduction in GHG emissions which can be traded in international market at their current market price. CO_2 has been traded at € 21 per tonne CO_2 eq [42] and each ton reduction in CO_2 is a carbon credit earned [43]. The total carbon credits earned is described by Equation (12):

$$Total\ carbon\ credits\ earned = Net\ CO_2\ mitigation \cdot price \tag{12}$$

where,

price = Current market trading price

The yearly carbon credits earned is described by Equation (13):

$$Yearly\ carbon\ credit\ earned = Total\ carbon\ credits\ earned / T_{LS} \tag{13}$$

2.7. Financial Assessment of the Solar PV System

While use of solar PV systems has increased, it is suggested that they need to become more price competitive to sustain further growth [36]. A grid connected solar PV system can reduce capital and maintenance cost by eliminating the need for battery with the grid acting as a storage bank [44]. The financial assessment of the solar PV system is based on current market prices of the project components.

A review of residential solar installers currently active in the Irish market, determined the approximate cost per kWp for a fully installed rooftop solar PV system was €1744 [35]. The Sustainable Energy Authority of Ireland (SEAI) in their payback calculator for domestic solar PV have considered the approximate cost per kWp to be €1900 [45]. Solar PV system cost can vary depending on the quality of solar PV panels and installation and after sales support. The project cost includes [36] the cost of modules; cost of inverters; miscellaneous costs {electrical items such as cables etc., installation cost, packing and freight etc.}; and cost of operation and maintenance.

Net Present Value

The Net present value of the investment per residential unit in the solar PV project can be calculated [35] using Equation (14):

$$NPV = \sum_{n=1}^{30} \cdot \frac{S_n - C_n + NE_n \cdot t}{(1+d)^n} \tag{14}$$

where,

S_n = Savings calculated in year n

C_n = System cost in year n, including capital costs in year 1, operating expenditures and inverter replacement where applicable Table A1 (Appendix A)

NE_n = Net export or amount of excess generation for which the residential building owner is compensated;

t = Rate at which net export is remunerated;

t can be equal to retail rate (r) €0.133 per kWh in case of net metering or

t can be equal to € FiT per kWh amount in case of FiT or
t can be equal to €0 per kWh in case of where no subsidy applies

d = Discount rate (considered 0.55% reflecting mid-range of publicly advertised annual equivalent interest rates on savings account in Ireland).

2.8. Crowdfunding Model for Ireland

A review of crowdfunding alternatives associated with renewable energy projects was conducted, demonstrating the use of different types of crowdfunding model [7].

To forecast the potential of System Dynamics of Solar Crowdfunding (SCF) in Ireland this study incorporates a simulation model which is developed based on system dynamics which uses causal loop diagrams and stock-loop diagrams to express the causal links and relationships between various factors that affect the SCF that represents the SCF market [46] Figure 3.

The SCF potentials refers to the total number of solar projects requiring finance. The SCF adopters are parties looking for private ownership in the project, SCF market saturation can occurs when the SCF adopters decrease as a result of more projects adopting SCF. The SCF adoption is primarily dependent on awareness of the SCF with greater numbers of adopters increasing awareness.

Three risk categories for investors are identified:

- Low risk involving non-material returns (charitable undertakings);
- Low to medium risk involving material returns (rewarding investors);
- High risk involving financial returns (mainly venture capitalists) [7].

The motivation for funders involved in the case studies included: helping people in need of money for energy efficient technology and household appliances; the desire to reap a financial return from their contributions equating to non-trivial investment; desire to reap a financial return for their investment and to be involved as shareholders of the companies [7].

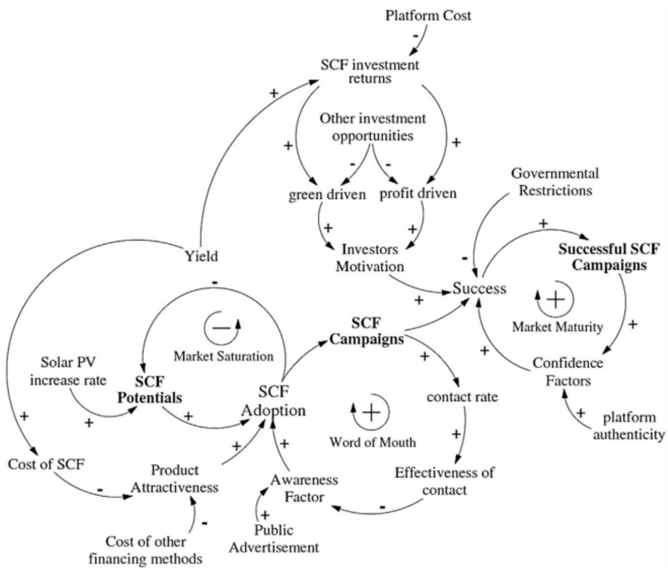

Figure 3. Causal loop diagrams [46].

3. Results

The impacts on electricity demand of the project; on the primary substation, MV feeder circuit, distribution transformer & LV network, network losses and voltage profile; energy pay-back time; GHG pay-back time, carbon credits and the crowdfunding model in Ireland are presented.

3.1. Impact on Electricity Demand of the Project

Using PV*SOL online software [33], (V0.7, Valentin Software GMBH, Berlin, Germany) the annual electricity demand (kWh) for the individual unit (3100 kWh approx.) Figure 4 was scaled to represent the annual electricity load of the project, approximately 210,800 kWh.

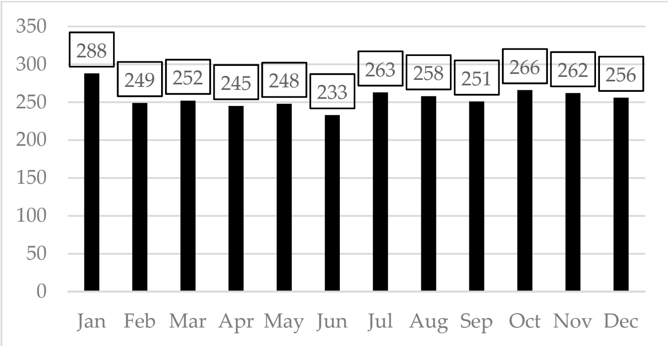

Figure 4. Annual electricity demand (kWh)of a residential unit.

Simulations were performed for a single PV system (the parameters used are listed in Table A2, Appendix C) and the solar PV electricity generation (1553 kWh) (Figure was then scaled to represent the annual solar PV electricity of the project = 105,604 kWh Figure 5.

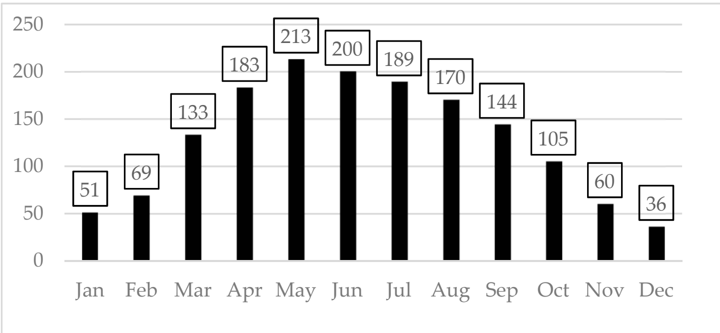

Figure 5. Annual solar PV electricity generation (kWh) of a single residential unit.

There was a low annual match between the annual electricity demand profile of the project and the annual solar electricity generated from the solar PV system. The annual electricity demand of the project without the solar PV system was 210,800 kWh, with the installation of the solar PV system the annual electricity demand of the project was reduced to approximately 166,514 kWh Figure 6.

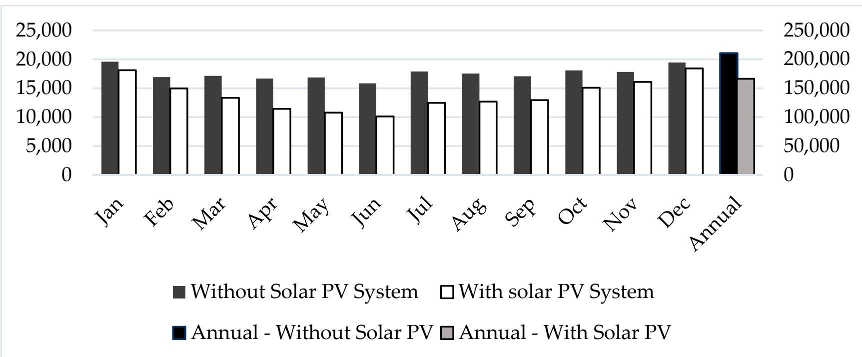

Figure 6. Annual electricity demand on grid of the project without and with solar PV system.

Out of 105,604 kWh annual solar PV electricity, the model shows approximately 44,354 kWh was self-consumed and 61,250 kWh of excess electricity was available to be fed directly into the electricity grid.

3.2. Impact of Project on Electricity Infrastructure

To assess the impact of the project electricity demand on the electricity infrastructure, an electricity network model was constructed incorporating, existing demand excluding the project; additional demand including the project; and with solar PV electricity output. Using the peak and minimum load conditions already outlined.

3.2.1. Impact on the Primary Substation

The primary substation (equipped with 2 × 5 MVA, 38/10.47 kV transformers giving a total continuous supply capacity of 10 MVA). Power flow analysis results using feeder circuit demand for winter peak load reading indicated total demand excluding the project was 7.19 MVA, including the project was 7.58 MVA and including the project with solar PV systems was 7.58 MVA. Summer minimum load reading indicated the total demand excluding the project was 4.93 MVA, including the project was 5 MVA and including the project with solar PV systems was 4.93 MVA [32].

3.2.2. Impact on the MV Feeder Circuit

The 10.47 kV feeder circuits consisted of a mixture of underground cables and overhead lines. Each feeder circuit was controlled by a circuit breaker which was installed in a primary substation rated at a capacity at 630 Amps (11.4 MVA). Each feeder circuit left the substation as an underground cable with a rated winter current of 532 Amps (9.65 MVA), the MV feeder circuits (underground cable and overhead lines) conductor size drastically reduced as demand decreased. Results of the power flow analysis demand for the winter peak load reading indicated total demand from all the feeders connected to the primary substation excluding the project was 2.34 MVA, including the project was 2.71 MVA and including the solar PV was 2.71 MVA [32]. Summer minimum load reading indicates total demand excluding the project was 1.91 MVA including the project was 1.98 MVA and including the project with solar PV systems was 1.91 MVA [32].

3.2.3. Impact on the Distribution Transformer and LV Network

The distribution transformer supplied the LV network and had a continuous rating of 630 kVA. Power flow analysis using electricity demand profiles for the winter peak load reading indicated [32]: the total demand on the distribution transformer including the project was 374 kVA; including the project with solar PV systems was 374 kVA. Summer minimum load demand including the project was 68 kVA and including the project with solar PV systems was 121 kVA.

The LV network was equipped 185 mm^2 cross sectional area conductor underground cable which consisted of six feeders to supply the project. The power flow analysis [32] using electricity demand profiles for the winter peak load reading giving total demand on LV feeders with and without solar PV system is shown in Table 3. The summer minimum load reading demand on LV feeders with solar PV is assumed, in this study, to be same as Table 3 above which is the worst-case scenario summer loading of LV feeders.

Table 3. Total demand on LV feeders with and without solar PV system [32].

LV Feeder	Rating (KVA)	Demand (kVA)	Net Demand with Solar PV (kVA)	% Contribution from Solar PV
01	246.64	52.81	29.41	44.3
02	246.64	87.60	64.20	26.7
03	246.64	60.08	37.00	38.4
04	246.64	59.14	46.49	21.4
05	246.64	47.43	24.35	48.7
06	246.64	63.25	51.55	18.5

3.2.4. Impact on the Network Losses

The technical losses occur because of the energy dissipated in feeder circuit conductors and core and windings losses in transformers [32]. Winter peak load reading indicated total technical losses in the existing electrical network excluding the project was 85 kW, including the project was 106 kW and including the project with solar PV systems was 106 kW. For summer minimum load reading the total technical losses excluding the project was 61 kW, including the project was 64 kW and including the project with solar PV systems was 62 kW [32].

3.2.5. Impact on the Voltage Profile

Voltage is the electric potential difference between two points. The voltage drop is the reduction in voltage in an electrical circuit between the source and load [47]. The voltage drop on feeders occurs because of: resistance increase from poor joints and terminations, hot spots, under-sized conductors and non-uniform conductor material or load increases [48]. Results of the power flow analysis carried out by [32] at MV feeder and LV feeder circuits indicated voltage at the MV feeder circuits including the project ranged from a maximum of 100% at primary substation to a minimum of 98.1% 16 km away. The voltage at the distribution substation including the project ranged from a maximum of 97.8% to a minimum of 96.2% at distribution substation. The voltage at the LV network entry point to a point 170 m closer to the project declined by another 2% [32].

3.3. Energy Payback Time

To assess the Energy Payback Time (EPBT) of the project with solar PV system, the embodied energy of each component and process of the proposed solar PV system was calculated using experiments conducted by [36] on monocrystalline PV modules as these experiments did not take into account the critical component of BOS i.e., inverter and the embodied energy associated with inverter, these data were extracted from the findings of [38]. This embodied energy value is often used to evaluate the energy balance of the solar PV system [48] i.e., energy metrics e.g., EPBT [36].

$E_{in} = E_{mat} + E_{manuf} + E_{trans} + E_{inst} + E_{eol}$	=	1471.34 kWh m^{-2}
Total area of modules	=	Number of panels (N_p)·(Length of panels)·(Width of panels)
	=	(6)·(1.67 m).(1.0 m)
	=	10.02 m^2 (i.e., A = Total roof area of one unit)
	=	(10.02 m^2)·(68)
	=	681.36 m^2 ((i.e., Total roof area of all units)
Total embodied energy for each unit E_{in}	=	(1471.34 kWh m^{-2})·(10.02 m^2) = 14,743 kWh
Total embodied energy for all units E_{in}	=	(1471.34 kWh m^{-2})·(681.36 m^2) = 1,002,513 kWh
E_{aegen}	=	1553 kWh year^{-1} for one unit or 105,604 kWh year^{-1} for all units.
ηG	=	0.483 Using grid conversion efficiency [4].
$E_{O\&M}$	=	0 (Assumed)

The annual electricity generated by solar PV system (Eagen) was estimated to be 105,604 kWh Figure 5.

The *EPBT* was calculated using Equation (10):

$$EPBT = \frac{E_{mat} + E_{manuf} + E_{trans} + E_{inst} + E_{eol}}{\frac{E_{aegen}}{\eta G} - E_{O\&M}} \quad (15)$$

EPBT =1,000,513

((105,604/0.483) − 0)

EPBT of the proposed project was 4.59 years.

3.4. GHG Payback Time (GBPT) and Carbon Credits

To assess the GBPT of the project, the emissions associated with the embodied energy of the proposed solar PV system were determined [41]. Calculated solar PV system emissions ranged between 50 g to 120 g CO_2 eq. kWh $^{-1}$ which agreed with the findings of [4] (69 g CO_2 eq kWh^{-1}, or 0.000069 tonne CO_2 eq. kWh^{-1}. The CO2 intensity of electricity in Ireland was 0.000437 tonne CO_2 eq. kWh^{-1} [5]. The annual electricity generated by solar PV system was estimated to be 105,604 kWh.

For the project the total embodied emissions, using results calculated from Equation (5):

$$\begin{aligned} CO_2\ eq{\cdot}embodied &= \text{(Total embodied energy for all units } E_{in} \text{ in kWh)}\cdot\text{(solar PV system emissions)} \\ &= 1{,}002{,}513 \text{ kWh * } 0.000069 \text{ tonne } CO_2 \text{ eq. kWh}^{-1} \\ &= = 69.2 \text{ t of } CO_2 \text{ eq.} \end{aligned}$$

GHG payback time is defined as the number of years it takes solar PV system to pay back its embodied emissions through solar PV generation. The *GPBT* [41] is described by Equation (11).

For the project, the total GHG emissions avoided in a year:

$$\begin{aligned} CO_2\ eq\ avoided\ (year) &= (E_{aegen})\cdot(CO_2 \text{ intensity of electricity}) \\ &= (105{,}604 \text{ kWh) } 0.000437 \text{ tonne } CO_2 \text{ kWh}^{-1} \\ &= 46.15 \text{ t of } CO_2 \text{ eq} \end{aligned}$$

Using Equation (11) for GHG payback time:

$$\begin{aligned} GPBT &= 69.2 \text{ t of } CO_2 \text{ eq./}46.15 \text{ t of } CO_2 \text{ eq} \\ &= 1.5 \text{ years.} \end{aligned}$$

The total carbon credits earned from the project was calculated [36] based on the amount of CO_2 mitigated by the project with solar PV systems at its current market trading price (€21 per tonne CO_2 eq.) [43].

$$\begin{aligned} Net\ CO_2\ mitigation &= (CO_2\ eq\ avoided\ (year)\ \cdot T_{LS}) - CO_2\ eq\ embodied \\ &= (46.15 \text{ t } CO_2 \text{ eq.})\cdot(30 \text{ years}) - 69.2 \text{ t } CO_2 \text{ eq.} \\ &= 1315 \text{ t of } CO_2 \text{ eq.} \end{aligned}$$

Carbon credits are awarded for the reduction in GHG emissions which can be traded in international market at their current market price and each ton reduction in CO_2 is a carbon credit earned [43].

The total carbon credits earned is described by Equation (12):

$$Total\ carbon\ credits\ earned = Net\ CO_2\ mitigation{\cdot}price \quad (16)$$

where,

price = Current market trading price (€21 per tonne CO_2 eq.) [41]

= (1315 t of CO_2 eq.)·(€21per t CO_2 eq.)

= €27,615

The yearly carbon credits earned is described by Equation (13):

$$\textit{Yearly carbon credit earned} = \frac{\textit{Total carbon credits earned}}{T_{LS}} \quad (17)$$

= €27,615/30 years

= €920

3.5. Financial Assessment of the Solar PV System

3.5.1. Cost of Modules

The cost of a Hanwha Q cells Q peak G4.1 300 Rev4 monocrystalline module (with an efficiency of 18% and lifespan of 30 years), is € 0.34 Wp^{-1} in Ireland [49].

Total module cost for each unit = (1800 Wp)·(€ 0.34 Wp^{-1}) = € 612

Total module cost for all units = (1800 Wp)·(68)·(€0.34 Wp^{-1}) = €41,616 (excl Value Added Tax (VAT) @13.5%) [50].

3.5.2. Cost of Inverters

The ABB UNO-2.0-I-OUTD (2 kWp) string inverter can be grid connected and eliminates the need to fit an isolator onto the DC cabling from the solar PV modules to the inverter, has a lifespan of 15 years, the inverter cost is € 920 in Ireland [51].

Total inverter cost for each unit = €920

Total inverter cost for all units = (68)·(€920) = €62,560 (excl VAT @13.5%)

3.5.3. Miscellaneous Cost

The miscellaneous cost includes electrical items (cables etc), installation cost, packing and freight with estimated the installation cost per kWp = €1362 [44]. Assumption of miscellaneous cost per kWp = SEAI approximate cost per kWp—approximate modules cost per kWp—approximate inverters cost per kWp = (€1900)−(€340+€460) = €1100.

Total miscellaneous cost for each unit = (1800 Wp)·(€1.1 Wp^{-1}) = €1980

Total module cost for 68 units = (1800 Wp)·(68)·(€1.1 Wp^{-1}) = €134,640 (excl VAT @13.5%)

3.5.4. Cost of Operation and Maintenance (O&M)

The O&M cost include the inverters replacement cost = €920 (excl VAT @13.5%) [51]. Annual operation, maintenance and insurance costs = €50 [44]. Both costs are subject to annual inflation 0.73% [35].

3.5.5. Other Costs

Annual Standing charge = €132.16 which covers range of electricity supplier and network costs [35]. Annual PSO levy = €41.76 [52]. The standing charge and PSO levy on electricity consumers is used to fund existing support schemes and are subject to changes [35].

3.5.6. Net Present Value (NPV)

The Net present value of the solar project can be calculated [35] using Equation (14):

$$NPV = \sum_{n=1}^{30} \cdot \frac{113.38 - 2302 + (900)\cdot(0.133)}{(1+0.0055)^n} \quad (18)$$

where,

S_n = reduction in annual energy costs due to solar energy self-consumption = 652 kWh × unit rate assuming (24-h rate of 17.39 cent per kWh); 652 × 0.174 = €113.38

C_n = year 1 (Table 4 includes cost of PV Modules, Inverters, Miscellaneous Costs, Annual operation, maintenance and insurance = €2302, for subsequent years costs are only annual operation, maintenance and insurance = €50; cost of replacement inverter in year 12 = €920).

NE_n = 900

t = €0.133 (assuming t equal to retail rate (r) €0.133 per kWh in case of net metering)

d = 0.55%

Approximately 44,354 kWh (42%) annual solar PV electricity generated by the project was self-consumed and the remainder (58%) 61,250 kWh available for the grid. This represents 652 kWh usage and 900 kWh for export for each residential unit.

NPV of the investment = −€1918.52 and no of years for financial payback = 12 years.

Table 4. Key cost assumptions of the solar PV system for the project.

Key Assumptions	Each Unit	All 68 Units
Cost of PV Modules (+)	€612	€41,616
Cost of Inverters (+)	€920	€62,560
Miscellaneous Costs (+)	€1980	€134,640
Cost of O&M		
Inverters Replacement Cost (+)	€920	€62,560
Annual operation, maintenance and insurance costs (+)	(€50)·(30 years) = €1500	€102,000
SEAI Grant Level (-)	€1260	€85,680
Total	€4672	€317,696

The SEAI grant level are subject to change and the above total amount excludes the annual rate of inflation (0.73%) and VAT (13.5%) [40].

3.6. Crowdfunding Model in Ireland

A review into renewable energy project case studies [7] determined that for financing solar projects, lending, debenture and equity-based crowdfunding models are the most common while donation and reward-based crowdfunding have seldom been used [46]. The validity of the system dynamic model was tested [46] to confirm: the causal loop diagram contained all important factors; model was dimensionally consistent (unit check function of Vensim PLE software used to confirm measurement units of the variables) and was tested under extreme conditions (sensitivity check of important variables which provided logical behavior of the system) [46]. The testing confirmed the validity of the developed model for simulating solar crowd funding in Ireland.

The review conclusions showed that to be successful project creators and/or campaigners should convey credibility and as well as create project demand [53] by: setting the lowest possible funding amount (as investors/participants were attracted to campaigns with higher percentage funded rather than higher amount funded); decreasing profit margin associated with rewards to encourage more backers; providing tangible reward options rather than gimmicky products e.g., t-shirts stickers etc; and including a short video outlining project, the development timelines, business plans, usage of funds and the motivation and inspiration for the project [53]. It was found that Kickstarter, IndieGoGo, The Funding Circle, Seedrs, Crowdcube etc. which are focused on Lending/Equity based crowdfunding are more suitable for solar crowdfunding of the community-based projects.

4. Discussion

The effect of the project on electricity demand, on primary substation, the MV feeder circuit, the distribution transformer & low voltage (LV) network, the network losses and voltage profile is discussed; the modelled energy and GHG pay-back time and potential carbon credits from the project are reviewed along with the crowdfunding model as a means of funding in Ireland.

4.1. Impact on Electricity Demand of the Project

The annual electricity demand of the project on electricity grid was approximately 210,800 kWh prior to the installation of 1.8 kWp solar PV, following installation, the demand reduced by 21% to 166,514 kWh. The model estimated the solar PV system generated 105,604 kWh electricity annually with 61,250 kWh of excess electricity fed into the electricity grid. These results would allow the unit owner to be compensated by net export rate where this applies and/or become more self-sufficient and less dependent on utility companies, protecting against higher electricity costs and contribute to increasing the security of electricity supply.

4.2. Impact on Primary Substation, MV Feeder Circuit, Distribution Transformer & LV Network, Network Losses and Voltage Profile

The impact of the contribution of the community project and solar PV system the distribution transformer & LV network, the network losses and voltage profile are discussed.

4.2.1. Impact on the Primary Substation

Total demand on the primary substation during a winter peak was 7.19 MVA and the addition of the project increased the demand to 7.58 MVA (a 5.4% increase in substation capacity). The solar PV system contribution at the time of the winter peak was zero as the peak occurred at night [32]. During a summer minimum load demand was 4.93 MVA and the addition of the project increased the demand on the primary substation to 5 MVA (1.4% increase), while the addition of the solar PV covered the increase in demand from the project by reducing the demand on the primary substation back to 4.93 MVA [32]. The impact at the primary substation level is very small. The small contribution of the solar PV system would maintain the demand marginally within the continuous rating of single primary transformer by 0.07 MVA which is around 1.4% [32].

The primary substation is equipped with two 5 MVA, 38/10.47 kV transformers giving a total continuous supply capacity of 10 MVA, one unit is used to meet the electricity demand of customers and another kept in standby mode and brought into operation in the event of failure. By incorporating microgeneration, the demand on the primary substation transformers can be reduced which reduces the temperature hot spot within the winding of the transformer avoiding the most severe electric power outages and increasing the electrical power system security standards [32].

4.2.2. Impact on the MV Feeder Circuit

The total demand from all the 10.47 kV feeders, was 2.34 MVA and 1.91 MVA for the winter and summer peak load reading respectively. The additional electricity demand for the project increased the demand on the all the 10.47 kV feeders to 2.71 MVA and 1.98 MVA for the winter and summer peak load reading respectively (representing a 16.2% and 3.5% increase in feeder capacity respectively). The contribution of the solar PV system at the time of the winter peak is zero (peak occurred at night-time) while in summer it decreased feeder capacity to 1.91 MVA i.e., 3.5% [32]. Overall there is no significant relief to the MV overhead lines and underground cables in the feeder [32].

4.2.3. Impact on the Distribution Transformer and LV Network

The electricity demand on the distribution transformer for the project during a winter peak load reading was 374 kVA. The contribution from the solar PV system at the time of the peak is zero because the peak occurred at night-time [32]. The demand on the distribution transformer during a summer minimum load reading was 68 kVA. The addition of the solar PV increased the demand on the distribution transformer by 56% to 121 kVA. This contribution will increase the demand within the continuous rating of single primary transformer by 53 kVA which is around 8.4% [32]. To allow expansion room for additional loads, the distribution substation should be equipped with one distribution transformer of 630 kVA, 10.47/0.400 kV designed for an emergency rating of 110% of the continuous rating i.e., 693 kVA for certain time period [32].

Incorporating microgeneration of solar PV system in the low voltage network, would increase the demand on the continuous rating of the distribution transformer, which in turn would increase the temperature hot spot within the winding of the transformer, however, the loading of the distribution transformer is significantly below the specified design limits contributing to increasing the electrical power system security [32].

The LV network is equipped 185 mm^2 cross sectional area conductor underground cable which consists of six feeders to supply the project. Each feeder is designed for a rated value of 246.64 kVA (total of 1480 kVA). ESB Network advise LV feeders should be loaded around 30% (74 kVA on each LV feeder or in total 444 kVA). In this study, the loading of the LV feeders is significantly below the specified design limits and further contributes to increasing the electrical power system security standards: avoiding short bursts of higher network losses in the LV and MV network; and voltage fluctuations [32].

4.2.4. Impact on the Network Losses

Total losses in the existing electrical network covering the primary substation and the MV network supplied from the substation during a winter peak load reading was 85 kW (1.18% of the total demand on the substation). The technical losses relate mainly to the primary transformers (40%) and the MV feeder circuit C15, which connected the residential units (44.7%) [32]. The addition of the project increased the technical losses to 106 kW (52.8%). There is no contribution to the time of peak losses from the solar PV system as the peak occurred outside the sunlight hours [32]. During a summer minimum load reading the total losses in the existing electrical network was 61 kW (1.23% of the total demand on the substation). The addition of the project increased technical losses to 64 kW (46.9%) [32]. The addition of the solar PV system reduced total losses to 62 kW which equates to 1.24% of the total demand on the substation. This contribution will maintain the demand marginally by decreasing the proportion of the losses occurring in MV feeder circuit C15 from 46.9% to 45.4% [32]. This suggests that wider deployment of solar PV system can have a significant impact on loss performance at distribution level, with potentially significant cost savings [32].

4.2.5. Impact on the Voltage Profile

The voltage profile at primary substation ranges from maximum 100% to minimum 98.1% at 16 km from the primary substation and at the distribution substation range from maximum 97.8% to minimum 96.2%. The voltage at the LV network entry point to further 170 m towards the project declined by another 2% [32]. The solar PV systems are typically located closer to the consumer load, which provides an opportunity for the electrical network to offset some of the reactive power requirements at the distribution system and provides benefits to the distribution system namely capital expenditure on the reinforcement due to power factor improvements, savings on voltage control equipment and reduced consumption of reactive power and is subject to the microgenerator connection point which is further depended upon the nature and topology of the connection method into the existing electrical distribution network [32].

4.3. Energy Payback Time

The EPBT for the solar installation for the project was 4.59 years i.e., it will take 4.59 years of operation of solar plant to generate the energy used to produce the system itself [4]. The EPBT of the solar PV system decreases as module efficiency increases, with an example of a rooftop mono-crystalline silicon PV system in Southern Europe (solar irradiation of 1700 kWh m^{-2} $year^{-1}$) which has and EPBT of 2.5 to 3 years [39].

4.4. GHG Payback Time and Carbon Credits

The GPBT for the solar installation for the project is 1.5 years. The life cycle GHG emissions from solar electricity production in Ireland are significantly lower than from electricity production on national grid. The net CO_2 mitigated due to incorporation of solar PV electricity of the project over the lifespan of 30 years is 1315 t of CO_2 eq. Carbon credits earned from the proposed project amounts to €27,615 which is approximately €920 per year.

The GHG emissions generally for wind and hydro power amounts to 6.2 to 46 g CO_2 eq kWh^{-1} and 2.2 to 74.8 g CO_2 eq kWh^{-1} respectively, wind power has the lower energy consumption and GHG emissions compared to solar PV system even though solar PV power has larger impact values due to module manufacturing process which has an general emission range of 2.89 to 671 g CO_2 eq kWh^{-1} (quantum dot to mono-si solar cells), but compares favourably to hard coal plant which has a general emission range of 750 to 1050 g CO2 eq kWh^{-1} [39].

4.5. Financial Assessment of the Solar PV System

The total cost of installing the solar PV system in an individual property was €4672 and for the project totaled €317,696. The NPV of the investment per property was calculated at −€1918.52, the negative NPV value means that the present value of the costs exceeds the present value of the returns at the current discount rate. In this scenario the investment cost would be repaid using the savings in electricity costs and payments for the excess electricity sent to the grid after 12 years.

4.6. Crowdfunding Model in Ireland

A review of eight renewable projects illustrates the use of different types of crowdfunding rewards and returns [7]. The choice of platform depends on the business model, lending, equity, reward and donation and the funding/investment amount and needs to be appropriate for the level of crowdfunding risk [46]. Not all the crowdfunding business models are applicable for solar projects. Lending, debenture and equity- based crowdfunding are the most common approaches for financing solar projects in the crowdfunding platforms [46].

This study provides a reference for policymakers in the country and industry practitioners to understand the approaches and processes involved in solar crowdfunding [46]. The system dynamics model outlines the combination of three stage solar crowdfunding process including the identification of potential SCF adopters, factors affecting the adoption and success of SCF, each stage involves numerous factors that shapes the feedback loops impacting the SCF market and provides a perspective to understand the mechanisms and complexity involved in solar crowdfunding which complements the qualitative methods [46].

The successful funding of the community is dependent on investor’s motivation, confidence factors as well as restrictions of the government [46]. Feedback from experienced crowdfunding participants suggested the campaign needs to convey credibility and create demand by setting the lowest possible funding amounts, decreasing the profit margin with rewards which are tangible to backers and create a short video outlining project [53]. A summary of findings is presented in Table 5.

Table 5. Summary of findings.

Key Findings	Brief Conclusion
Electricity demand and supply match	There is a low annual match between the project electricity demand profile and the solar electricity generated. As system is configured without battery storage the excess electricity is sent back to the grid.
Solar contribution to reduction of electricity demand	The annual electricity demand of the project without solar PV system was 210,800 kWh, installation of solar PV system reduced the project annual electricity demand to 166,514 kWh
Solar Electricity usage	Results show of 105,604 kWh solar electricity generated, 44,354 kWh was self-consumed, and 61,250 kWh was available for the grid
Impact of project on electricity infrastructure: Primary substation, MV Feeder circuits, Technical Losses, and Distribution Transformer	Power flow analysis showed the addition of the community project to the network increased demand on the primary substation and on the MV feeder circuits, by over 5% and 16% at winter peak and by 1% and 3% at summer minimum respectively. In both cases the addition of the solar PV system had no effect on winter peak demand but the reduction in summer minimum load covered the increase in electricity demand from the project installation. Technical losses increased in both winter (85 kW to 106 kW) and summer (61 to 64 kW) when project was added, solar PV did not reduce losses at winter peak, while in summer losses reduced to 62 kW following addition of solar PV. Total demand on distribution transformer was not reduced by solar PV system at winter peak, while at summer minimum, demand on distribution transformer increased by 8.4% following addition of solar PV.
Energy payback time	4.59 years (of operation to generate same energy used to produce the system).
GHG payback time	1.5 years (of operation to pay back embodied emissions through solar PV generation).
Yearly carbon credit earned	€920 per year, €27,615 over the 30-year lifetime of the project. Carbon credits are awarded for the reduction in GHG emissions, one per ton of CO_2 produced equals one carbon credit.
Total costs (assumed)	€4672 per unit, €317,696 for 68 units.
NPV of project	The financial payback based on NPV of the investment (for a single unit will take 12 years based on energy savings and payments for energy sent to the grid. This payback period may be well above what homeowners might require.
Crowdfunding	Lending, debenture and equity-based crowdfunding are the most common approaches for financing solar projects in the crowdfunding platforms.

5. Conclusions

This study demonstrates the impact of the based solar PV microgeneration project on the electricity grid in Ireland and outlines the most suitable crowdfunding mechanisms for the development of based solar PV microgeneration projects and details the financial costs associated with the project.

The solar PV system (122.4 kWp) designed for the project comprised an array containing 6 modules (300 watts each) on each unit (roof area 10.042 m^2 and 408 modules). The electricity network model was modelled on a typical network supply. The addition of the project to the electrical network resulted in peak demand increase on the MV feeders and increased voltage on MV and LV feeders. Coordination of the contribution from solar PV systems is required to avoid formation of new peak demand on distribution transformer and LV feeders. Controlled operation of larger scale solar PV projects could reduce the peak demand and smooth the load profile and assist in the voltage regulation on the electrical distribution system network. Technical losses on the MV and LV feeders were reduced which shows the potential to reduce the electrical network losses and lower operation costs and savings could be passed on to the consumer. The modelled energy payback time, of the project was 4.59 years and GHG payback time was 1.5 years. The model showed the project mitigated 1315 t of CO_2 and at current market price of €21 per tonne of CO_2 eq. and carbon credits earned was €27,615. The financial payback (NPV) of the investment will take 12 years based on energy savings and payments for energy sent to the grid. This payback period may be well above what homeowners might require.

Crowdfunding categories are based on project risk e.g., Low-risk crowdfunding models involved non-material returns, Low to medium risk crowdfunding models involved material returns and high-risk crowdfunding models involve financial returns. The project creators and/or crowdfunding campaigners need to convey credibility and as well as create demand for the project. Developing a short video was suggested to outline project as well as the motivation & inspiration to help secure crowd funding. The most suitable crowdfunding platform for community solar PV microgeneration projects include Kickstarter, IndieGoGo, The Funding Circle, Seedrs, Crowdcube or similar platforms which are focused on Lending and/or equity-based crowdfunding.

The modelled solar PV microgeneration system in the project would require total investment of €317,696 plus some variable amounts for campaign cost and profit of the project. The model calculated a displacement of 272 t of oil eq. (Appendix B), significant GHG emissions savings and further greening of the national grids. To encourage the accelerated uptake of the solar PV microgeneration projects in Ireland it is essential to extend REFIT to include solar PV systems which will improve sustainability of electricity supply by self-generation, consumption and feeding the excess electricity to the grid.

Author Contributions: V.V.—Conducted the original research work, drafted and corrected manuscript draft based on feedback and provided contributions to journal formatted manuscript. M.H.—Review and correction of original manuscript and preparation and finalizing manuscript for journal. K.M.—Review and correction of original manuscript and project supervisor.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Break-down of embodied energy for a solar PV system [36,37].

Process/Items	Embodied Energy kWh m^{-2}
Material Production Energy (E_{mpe})	
(A) Silicon purification and processing	670
(i) Metallurgical grade silicon production	
(ii) Electronic grade silicon production	
(iii) Silicon crystal growth	
(B) Solar Cell Production	120
(C) PV Module lamination and assembly	190
(i) Steel infrastructure	
(ii) Ethyl vinyl acetate	
(iii) Tedlar production	

Table A1. *Cont.*

Process/Items	Embodied Energy kWh m^{-2}
(iv) Glass Sheet production	
(v) Aluminium frame production	
(vi) Other material	
PV System Installation (E_{inst})	
(A) Support Structure	277.50
(B) Balance of System	
(i) Inverters	33
(ii) Electronic components, cables and miscellaneous items	45
Operation and Maintenance of Equipment $(E_{O\&M})$	
(A) Instruments	59.5
(i) Tong Meter	
(ii) Solarimeter	
(iii) Temperature sensor	
(iv) Anemometer	
(B) Paints	10
(C) Miscellaneous human labour, wires	12.84
Salvage operation	0
Transportation	53.5
Land Energy Required for Disposal	0

Appendix B

Total fossil resource displaced is calculated by

Annual electricity generated by residential units of the community project * Life span of the solar PV system.

= (105,604 kWh)·(30 years)

= 3168,120 kWh

Factor 1 ktoe = 11,630,000 kWh

Therefore, total fossil resource displaced = 272.40 t of oil equivalent.

Appendix C

To generate simulations using PV*SOL software, run software using the following link http://pvsol-online.valentin-software.com/#/.

Table A2. Parameters and values used for the PV*SOL simulation.

No.	Parameter	Value
1.	Address Search	Belfield, Dublin
2.	Load profile	2 Person Household with 2 children
3.	Annual consumption	3100
4.	PV Modules	Hanwha Q cells; Q peak G4.4 300 Rev1
5.	No of modules	6
6.	Inclination	30°
7.	Orientation	180°
8.	Installation Type	Roof parallel
9.	Albedo	20%
10.	Soil	0%
11.	Shadow	0%
12.	Inverter manufacturer	ABB

To run simulation, supply above parameters, Select "Get best configuration" button. Confirm "not a robot" by checking tick box. Select "Simulate PV System" button. Note: For simulation, software automatically picks up 951.3 kWh m^{-2} and performance ratio as 86.6% based on input parameters. However, in theoretical calculation it is considered 1074 kWh m^{-2} and performance ratio as 80%. To match the theoretical calculations the solar energy value simulated was reduced by approx. 4% in each month.

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