

## Article

# Using System Dynamics to Examine Effects of Satisfaction with PV Systems, Advertising, and Competition on Energy Security and CO<sub>2</sub> Emissions in Jordan

Abbas Al-Refaie <sup>1</sup> , Natalija Lepkova <sup>2,\*</sup>  and Constantinos Hadjistassou <sup>3</sup> 

<sup>1</sup> Department of Industrial Engineering, University of Jordan, Amman 11942, Jordan; abbas.alrefai@ju.edu.jo

<sup>2</sup> Department of Construction Management and Real Estate, Vilnius Gediminas Technical University (VILNIUSTECH), LT-10223 Vilnius, Lithuania

<sup>3</sup> Marine & Carbon Lab, Department of Engineering, University of Nicosia, Nicosia 1700, Cyprus; hadjistassou.c@unic.ac.cy

\* Correspondence: natalija.lepkova@vilniustech.lt

**Abstract:** With rapid technology advancements in renewable energy systems, rooftop photovoltaic (PV) products and systems can be considered a crucial element in the transition toward energy sustainability in residential buildings. Still, residents' initiatives are required to expand the adoption of clean energy-efficient technology to replace conventional energy systems and thereby achieve a sustainable environment. The aim of this study was, therefore, to develop system dynamics models to relate adopters' satisfaction with PV systems through word-of-mouth (WoM), advertising, and competition and then evaluate their impacts on the number of PV installations, generated electric power, and the reduction in CO<sub>2</sub> emissions for rooftop buildings in Jordan for the years from 2020 to 2040. Results revealed that the predicted cumulative PV installations will increase to 262 and 558 MW in 2030 and 2040, respectively. Due to this, the cumulative generated power (kWh) (=42.5 GWh) will reach 452 and 964 GWh in 2030 and 2040, respectively. Moreover, the cumulative CO<sub>2</sub> emission reductions may reach 262 and 558 million kg CO<sub>2</sub> in 2030 and 2040, respectively. In conclusion, continual assessment of the adopters' feedback on installed PV systems, adopting effective advertising, and advancement of PV designs and technology can significantly support achieving energy sustainability in residential buildings and reduce the dependency on traditional, scarce energy resources.

**Keywords:** CO<sub>2</sub> emission; system dynamics; word-of-mouth; satisfaction; PV systems



**Citation:** Al-Refaie, A.; Lepkova, N.; Hadjistassou, C. Using System Dynamics to Examine Effects of Satisfaction with PV Systems, Advertising, and Competition on Energy Security and CO<sub>2</sub> Emissions in Jordan. *Sustainability* **2023**, *15*, 14907. <https://doi.org/10.3390/su152014907>

Academic Editors: Antonio Caggiano, Gianluca Scaccianoce, Giorgia Peri and Laura Cirrincione

Received: 24 August 2023

Revised: 16 September 2023

Accepted: 12 October 2023

Published: 16 October 2023



**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Renewable energy has great potential to establish stability and is an ideal and economic alternative in developing countries. Renewable energy creates a balance between economic systems and the environment. Renewable energy can greatly reduce pollution and the dependency on fossil fuels, deliver high-quality energy, conserve natural resources, and create new jobs [1]. Specifically, solar photovoltaic (PV) systems enable countries worldwide to achieve economic growth, boost environmental sustainability, and reduce unemployment rates [2,3]. Consequently, wide-scale installations of rooftop PV systems have been observed [4–6]. Further, rapid reductions in the cost of PV modules and rises in their efficiency have made rooftop PV systems a crucial component in the transition toward energy sustainability by providing household owners with a range from approximately 50% to over 100% of the electricity needed to operate units of residential buildings [7,8]. Still, resident initiatives are required to expand the adoption of clean energy-efficient technology to replace conventional energy systems and thereby achieve a sustainable environment. The adopter experience with PV systems in the operation, maintenance, post-installation services, complaints handling, and quality assurance of PV systems may provide valuable

feedback to suppliers and manufacturers on how to gain competitive advantages in the PV market. Therefore, examining the effects of adopters' satisfaction with PV systems, installations, and post-installation services on renewable energy goals becomes a necessity.

Generally, satisfaction is a key determinant for the adoption of solar PV systems [9]. Satisfaction with PV systems can be defined as the overall affective response to a perceived discrepancy between prior expectations and perceived changes in energy consumption and environmental impacts after the installation of solar PV systems [10]. To enhance the quality perception of household energy usage and costs, manufacturers should explain all relevant technical aspects of PV systems. Poor quality of PV systems and high energy costs could negatively influence adopters' satisfaction with the PV systems [11,12]. Thus, a high service level should be maintained, and ongoing support and advice should be provided to adopters on how to maximize the economic and environmental benefits gained from the adoption of solar PV systems. The efficiency of PV systems can also be increased by the installation of certain high-tech components that can absorb the minimum sunlight to generate energy. In return, adopting new designs of solar PV products can improve adoption behavior and installers' satisfaction with PV systems.

Further, the exposure to positive word-of-mouth (WoM) and/or electronic WoM (eWoM) prior to purchasing PV systems has a positive impact on the non-adopters' expectations. WoM/eWoM is a form of communication that aims to pass information from one person to another through various ways, such as face-to-face, telephone, and email [13–15]. WoM significantly influences non-adopter intentions to install PV systems and impacts their expectations and perceptions during information search during the buying process as well as influences attitudes during the pre-choice evaluation of alternative service providers [16,17]. Consequently, it can be hypothesized that positive WoM (eWoM) on PV systems results in increasing the number of PV installations and thereby generating more PV solar energy.

Furthermore, the success of companies operating in the renewable energy market depends on a public understanding of renewable energy resources and related technologies. Qu et al. [18] argued that public adoption is an important factor for both the development and application of renewable energy technologies. They stated that the disuse of renewable energy resources was negatively affected by public unawareness about new technologies, the lack of impartiality, mistrust, and suspicion towards investors. Therefore, the success of advertising can be assessed by consumers' interest and attention, motivated by efforts in advertising on the functional advantages of renewable energy [19,20]. As an important marketing channel, advertising must be conducted in an interactive way to stimulate customers. Advertising campaigns are established to achieve certain objectives, which may hierarchically include goals ranging from awareness enhancement to behavioral change [21]. Consequently, advertising and competition are considered key drivers to promote and develop high-quality PV products and systems [22,23]. Attitudes toward solar PV energy contribute to the growth in rooftop PV installation and have a significant impact on households' intention to adopt renewable electricity [24,25]. PV non-adopters who actively search for new information on renewable energy products are more likely to have a positive attitude toward rooftop PV installation. Therefore, suppliers and manufacturers of PV solar systems should work closely with "early adopters" to develop the operational economic aspects of PV products [26]. In this context, it is hypothesized that advertising and competition are positively related to the number of PV installations.

In Jordan, residential buildings are considered the largest electricity consumers, accounting for 43% of the total electrical energy consumption [27]. Specifically, a large proportion of fossil fuels in Jordan is imported to meet its domestic energy needs, which account for a share of about 20% of total GDP [28–31]. Moreover, the demand for energy increases at an annual rate of 3%, urging the government to set a target of obtaining 10% of its energy needs from renewable energy resources by increasing electricity generation from its present share of 1.13 GW to 1.8 GW by 2020 [32–34]. Furthermore, the imported fossil fuel resources have contributed to a very high level of greenhouse gas emissions

(GHG) per capita [35]. The total GHG represents 0.06% of the world's total CO<sub>2</sub> emissions, and it is expected to reach 2.7% between the years 2016 and 2040. Hence, the Jordanian government set a target of achieving a 14% CO<sub>2</sub> emission reduction by 2030 [36]. To meet the expected electricity demand and reduce CO<sub>2</sub> emissions, renewable energy policies were applied to achieve a target of 50% of energy demand to be obtained from renewable sources by 2030 [33]. Fortunately, renewable energy resources play a critical role in satisfying the growing need for energy in developed countries [34]. In Jordan, the building and construction industry has grown rapidly, with the residential market accounting for 72% of that expansion [35]. In response, the domestic solar PV market has grown rapidly, resulting in cutting down expensive energy consumption in households [3,34]. Rooftop PV installations are essential to achieve a significant increase in the use of renewable solar energy sources for achieving sustainable development goals. Within the residential category, roughly 50% of the total rooftop surface can be utilized for PV generation [36]. In these regards, this research aims to:

- Develop causal relationships using system dynamics models to relate the main factors including adopter's satisfaction with PV products and systems, WoM, advertising, and competition with PV goals including the number of PV installations, total generated power, and CO<sub>2</sub> emissions for rooftop buildings in Jordan.
- Perform a dynamic quantitative evaluation of the effects of the main factors on PV goals using simulation.
- Conduct sensitivity analysis to assess the impact of parameter uncertainties on PV predictions and determine optimal parameter values.
- Provide practical implications of the results of this research and feedback to policymakers as well as manufacturers and suppliers of PV products and systems on how to expand the adoption of PV systems for rooftop residential buildings in Jordan.

The results of this research can provide valuable feedback to policymakers and manufacturers on the status of PV systems adoption with its impact on energy security and CO<sub>2</sub> emissions, the effectiveness of PV systems, levels of satisfaction with their characteristics, and their market share. Further, the predictions can provide valuable information on the effectiveness of marketing policies in increasing the adoption of PV systems. Finally, PV manufacturers can utilize the results in measuring satisfaction with the characteristics of their developed products and systems and conduct appropriate design changes when necessary to enhance adopters' satisfaction. The remainder of this research is outlined as follows. Section 2 reviews relevant previous studies on PV systems. Section 3 develops the system dynamics simulation models for predictions. Section 4 applies the developed models and discusses research results. Section 5 summarizes the research conclusions.

## 2. Literature Review

The impacts of renewable energy policies on energy security and CO<sub>2</sub> emission reduction have received significant research attention. For example, Hsu [37] used a system dynamics approach to evaluate the impacts of feed-in tariff (FiT) prices and subsidies to promote solar PV adoption in Taiwan. Aslani and Wong [38] investigated the effectiveness of renewable energy policies in increasing energy security, minimizing total policy costs, and maximizing the number of renewable energy systems in the United States. Ahmad et al. [39] employed a system dynamics model to assess the effect of FiT policy in promoting solar PV investments in Malaysia up to 2050. Radomes and Arango [40] analyzed the effects of subsidy and FiT policies on the diffusion of PV systems in Colombia using the breakeven and cost-benefit analyses. Young and Brans [41] analyzed the factors affecting a shift in a local energy system toward a 100% renewable energy community. Jain et al. [42] studied the impact of solar PV on power system dynamics using integrated transmission and distribution network models. Li et al. [43] reviewed PV poverty alleviation projects in China, identified the challenge and suggested policy recommendations. Njoh et al. [44] presented the implications of institutional frameworks for renewable energy policy administration for PV solar electrification projects in Esaghem. Nair et al. [45] examined

the impact of renewable energy on electricity generation and energy security in Malaysia. Karna and Singh [46] proposed a system dynamics framework for analyzing the viability of solar PV in Province-2 of Nepal. Al-Refaie and Lepkova [3] developed a system dynamics model to examine the impacts of renewable energy policies on CO<sub>2</sub> emissions reduction and energy security using system dynamics for the case of the small-scale sector in Jordan up to 2050. Two energy policies were studied, including the feed-in tariff and subsidy. Results showed that government investment in PV adoption results in 100% energy security and a significant reduction of CO<sub>2</sub> emissions. Sensitivity analysis and optimization were finally conducted to test the robustness of PV goals under parameter uncertainties and find the optimal values for the subsidy share. Albatayneh et al. [47] integrated environmental solution-virtual environment software to predict the reduction and increase in heating and cooling loads connected to the roof floor each month for a middle-income home in Jordan's capital, Amman. They constructed mono-crystalline PV modules for rooftop PV installations with a total U-value of 6.87 W/m<sup>2</sup> K, a total thickness of 0.60 cm, and a net R-value of 0.0055 m<sup>2</sup> K/W. The studied building included a total of 12 PV panels each with dimensions of 1.70 × 1.00 m<sup>2</sup>. The total installed power of the building was 480 kW. The energy simulation results for an area of 180 m<sup>2</sup> revealed a total energy demand of 5693.9 kWh/year.

On the other hand, adopters' satisfaction with rooftop PV systems, advertising, and/or competition have received significant research attention. For example, Mukai et al. [48] examined causal factors affecting adopters' satisfaction with PV systems to evaluate the extent to which residential PV system users understand specifications, reliability, and failure risks in Kakegawa City. The study showed weak adopters' understanding of the basic specifications of their residential PV systems and poor knowledge about proper maintenance. Furthermore, they confirmed the strong causal relationship between adopters' expectations of financial return from the PV system and their level of satisfaction. Komatsu et al. [11] analyzed the characteristics of households installing solar PV systems in Bangladesh. They quantitatively identified the factors that affect adopters' satisfaction with PV systems. Then, the determinants of users' satisfaction and households' perceptions of the benefits of PV systems, including the quality of PV equipment and reduction in energy costs, were evaluated. Further, econometric analysis was conducted, and the results revealed that poor experiences with the frequency of battery repairs and replacement in PV systems negatively influences the satisfaction of households with PV systems. Moreover, a key finding was that the quality of PV equipment plays a significant role in improving adopter's satisfaction with PV systems. Kim et al. [49] developed a model of solar power technology adoption using structural analysis. Results revealed that the system quality, perceived benefits, and perceived trust have positive influences on public attitudes. Additionally, public attitudes toward and satisfaction with solar technologies were found to have positive impacts on the adoption of solar technologies. Sweeney et al. [50] adopted the self-determination theory to explain WoM about energy-saving behavior using two samples of university students in Australia. They stated that independence-seeking behavior and word-of-mouth communications stimulate and change customers' behavior toward using renewable energy. Stigka et al. [51] surveyed the advantages of renewable energy resources from the perspective of 200 respondents from one of the Malaysian Government-Linked Universities. They found that users' attitudes toward renewable energy and the lower social costs of energy lead to social adoption. Tarigan [52] simulated and analyzed the rooftop PV on building roofs of the University of Surabaya, Indonesia for electric power generation. They also calculated the reduction in greenhouse gas (GHG) emissions that could be obtained with PV systems mounted on the building roofs. It was found that about 10,353 m<sup>2</sup> of the rooftop area of the university buildings could be used for panel installation. The total capacity of the panels was found to be about 2070 kWp, with total electricity production of about 3180 MWh per year and could supply up to 80% of the campus energy demand. The system would serve as a means of reducing 3367.6, 2477.2, or 1195.7 tons of CO<sub>2</sub> to the atmosphere in comparison with the same amount of electricity produced by burning coal, oil, or natural

gas, respectively. The unit cost of PV electricity ranged from USD 0.10 to 0.20 per kWh. Sharifi et al. [53] analyzed advertising effectiveness toward renewable energy technologies adoption. A neural network analysis was employed to identify advertising effectiveness based on the Attention, Interest, Desire, and Action (AIDA) framework. The results of the AIDA model with neural networks analysis revealed that the attraction of customers' attention toward using RETs via advertising activities would affect the adoption of the technologies by providing customers with necessary information about the advantages of renewable energy and related technologies to facilitate the decision-making of customers. Lopez-Ruiz et al. [54] explored the extent to which solar rooftop deployment at the residential scale in Riyadh could be cost-efficient and could accelerate decarbonization in Saudi Arabia. The study revealed that the maximum aggregate solar power capacity at the residential level would be around 400 MW. Also, the current residential electricity tariff does not incentivize PV solar rooftop deployment. Gernaat et al. [55] implemented rooftop PV in the Integrated Assessment Model to examine its possible role in energy and climate scenarios. The global technical and economic potential to derive regional cost-supply curves for rooftop PV were calculated. Then, the new decision in the IM-AGE model allowed household investment in rooftop PV based on the comparison of the wholesale electricity price with the price of rooftop PV. Results showed that adding rooftop PV could lead to an 80–280% increased share of photovoltaic electricity production in 2050. Martinopoulos [56] conducted a complete life-cycle impact assessment for typical PV systems throughout Europe and then calculated environmental impact, sustainability, energy return on energy invested, and payback period. The results showed that the energy return on energy invested ranges from 1.64 to almost 5 depending on location, while the simple payback period is less than 11 years in most cases, and as low as 5, without any subsidy. Agathokleous and Kalogirou [57] analyzed various scenarios for the installation of PV roof systems in existing and future households of Cyprus Island until 2050. Results showed that the electricity demand in the domestic sector could be 100% covered when over 70% of the existing residential stock installs a 3 kW roof PV system. Haryadi et al. [58] examined customer interest in using rooftop PV in Indonesia's electricity market using primary survey data from households and industries. Then, they employed logit model regression to analyze the impact of the demographic background of respondents. Exploratory factor analysis was used to understand the reasons why the existing users utilize rooftop PV at their homes. The results showed that education, residence location, and income can positively and significantly influence the probability of installing rooftop PV. Fakhraian et al. [59] conducted a complete systematic review of various developed methodologies published in the current state of the art, and identified vital factors for urban rooftop solar photovoltaic potential assessment as well as to identify the best available methods to create a complete global basis for future studies. Maqbool et al. [60] explored stakeholders' satisfaction with renewable energy projects using a structural equation modeling approach. Qadourah [61] examined the feasibility of installing PV systems on apartment building rooftops in Jordan's various climate areas and determined the potential power generation from such systems over their lifetime. Polysun 12 simulation software was adopted to estimate electricity production and assess electricity consumption and production under different tariff schemes and distinct tilt angles, azimuth angles, space between arrays, and accordingly different capacity and installation areas. Gomez-Exposito et al. [62] assessed on a large-scale basis the expected contribution of rooftop PV to the future electricity mix in Spain. Several sustainable scenarios were evaluated, each comprising different shares of centralized renewables, rooftop PV and storage. Results showed that a sustainable, almost emissions-free electricity system for Spain is possible at a cost that can be even lower than current wholesale market prices. Pan et al. [63] studied four installation scenarios based on rooftop area data and analyzed the technical and economic potential of PV power generation on the rooftops of urban buildings in China. The results showed that the rooftop area in Guangzhou suitable for PV installation is 391.7 km<sup>2</sup>, with a maximum potential power generation capacity of 44.06–72.12 billion kWh per year. The optimal economics

were reached with a 20° installation tilted angle and monocrystalline silicon PV panel material, with a 6-year payback period.

Still, few research efforts have been directed toward modeling the causal relationships between adopters' satisfaction with PV systems, WoM, and advertising and competition and predict their impacts on PV goals for rooftop residential buildings in Jordan. In addition, this research examines the impacts of the adoption of the subsidy policy by government with these factors on energy security and sustainability.

### 3. Model Development

System dynamics is an effective approach for examining the nonlinear behavior of complex systems over time [64]. The system dynamics approach involves the development of computer simulation models that portray processes of accumulation and feedback and that may be tested systematically to determine effective policies for overcoming policy resistance [65,66].

### 3.1. Effects of Satisfaction Model and Word of Mouth

Jordan has a massive solar energy potential, as it is located within the world's solar belt, with average solar radiation ranging between 5 and 7 kWh/m<sup>2</sup>. The majority of Jordanian cities have sun irradiation of greater than 5.3 kWh/m<sup>2</sup>/day [61]. The satisfaction model is displayed in Figure 1. The model is based on the idea that an increase in overall satisfaction results in positive WoM that leads to an increase in the annual number of PV adopters, thereby increasing the accumulated power generated by PV systems and reducing CO<sub>2</sub> emissions.

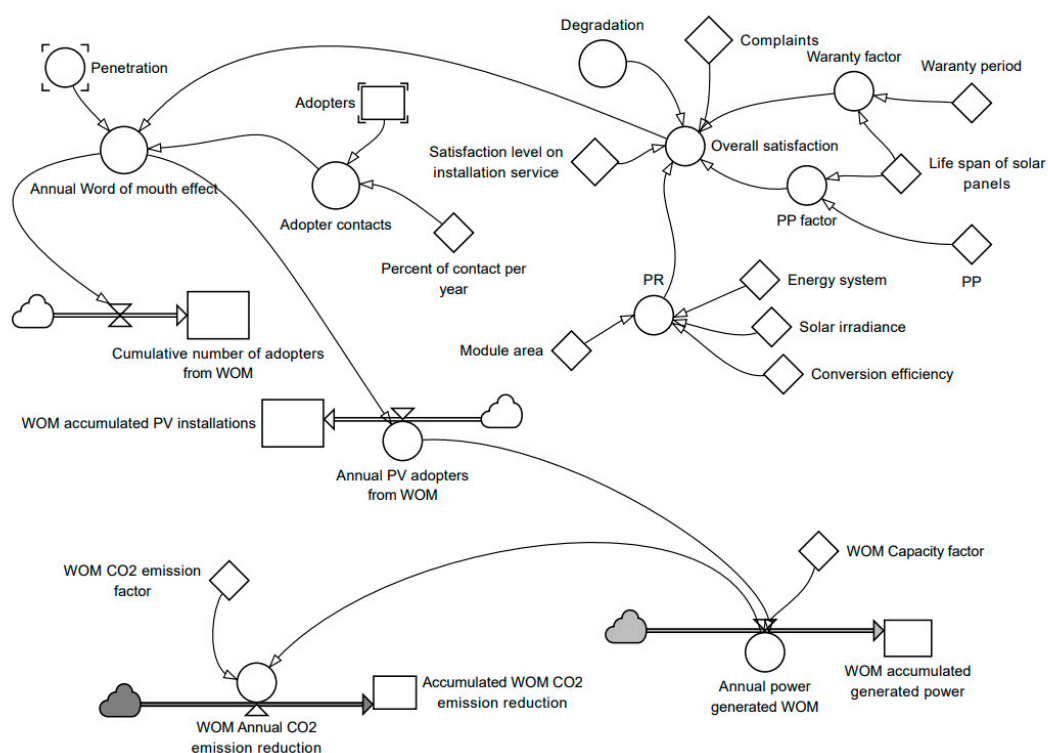


**Figure 1.** Overall satisfaction model.

The main variables in the developed overall satisfaction model shown in Figure 1 are presented as follows. Assume that the installed PV system has L life span and W warranty period. The overall satisfaction (OS) is driven by the satisfaction of the PV adopters with

installation services (S), warranty factor (WF), payback period (PP), performance ratio (PR), degradation (D), and complaints (C). The overall satisfaction is estimated as:

$$OS = (PR + WF + PP + S)/4 - C - D \quad (1)$$

where

$$WF = 2 \times W/L \quad (2)$$

and

$$PP \text{ factor} = L/(10 \times PP) \quad (3)$$

Satisfaction with PV installation services is collected from adopters. The respondents can evaluate their experience based on a Likert scale. The average score is then used as a measure of satisfaction level. Under the standard test conditions, it is assumed that PV modules can work quite reliably with minimal service interruption for a 20- to 25-year duration [67]. The main mechanical parts of a PV system typically have a warranty period of 10 years [68,69]. The warranty covers the integrity of the product and protects against problems, such as manufacturing flaws, environmental issues, or premature wear and tear. The payback period (PP) of a PV system is the length of time it takes for the cash flows it earns to cover its initial capital costs. On average, the payback period factor (PP) for the different facilities in Jordan is around 3.4 years [70]. In practice, degradation can occur as a result of manufacturing flaws, such as poor-quality material or assembly, or flawed cell packaging. Generally, a fixed rate of degradation is assumed to be around 0.65% annually. Further, the adopters' complaints negatively affect adopters' satisfaction and can thus reduce the total number of PV installations. Possible complaints can include O&M, cost inflation, low product and service qualities, taxes, and others.

Further, the performance ratio (PR) is an important value used to assess the quality of the PV system. It measures the performance of a PV system while taking into account the environmental factors (temperature, solar irradiation), where solar irradiation ( $\text{kW}/\text{m}^2$ ) is the amount of power that is received from the sun per  $\text{m}^2$  as a form of electromagnetic radiation. Based on standard test conditions, the solar irradiation (SI) is equal to  $1 \text{ kW}/\text{m}^2$  [71,72]. PR depends on the module area (MA) and the conversion efficiency (CE) of the installed PV modules. As a module area increases, the module efficiency also increases, thus increasing in the energy system (E). Generally, the value of PR ranges from 60% to 90% due to different environmental conditions [73].

$$PR = ES/(SI \times MA \times CE) \quad (4)$$

Furthermore, PV system losses occur from factors that prevent sunlight from entering solar modules, such as shadows, soil, snow, and reflections. Conversion efficiency is set at 20%. System losses are caused by variables such as flawed wire connections and inverter inefficiencies. Relative module and thermal losses occur from increasing PV cell temperature during the conversion of sunlight to electricity.

In reality, satisfied adopters can tell up to five out of 20 nonadopters about their experience with PV systems. This kind of information sharing is called "Word of Mouth (WoM)" which is a kind of communication that aims to pass information from one to another in a variety of ways, such as face-to-face, phone, email, and text messaging. WoM has a major influence on PV nonadopters and is considered effective in creating new adopters. WoM depends on potential contacts with non-adopters, penetration, and overall satisfaction. Given the percent contact per year (PCY), increasing the adopter contact (AC) between adopters (AD) of the PV systems results in converting nonadopters (NAD) to AD. Let penetration (P) be the ratio of AD to NAD, or mathematically,

$$P = AD/NAD \quad (5)$$

Then, the annual number of adopters (person) due to WoM effect (adopters/year),  $AWOMp$ , is calculated as given in Equation (6).

$$AWOMp = AC \times (1 - P) \times OS \quad (6)$$

where

$$AC = AD \times PCY \quad (7)$$

Assuming each adopter will install a  $Vp$  (kW/installed PV system), then the annual PV installation (kW/year),  $AWOMi$ , is calculated as follows

$$AWOMi = Vp \times AWOMp \quad (8)$$

Let  $CF$  denote the capacity factor. Then, the annual generated power ( $AWOMe$ ) can be estimated as stated in Equation (9).

$$AWOMe = AWOMi \times 360 \times 24 \text{ hours} \times CF \quad (9)$$

Finally, given that 1 kW results in a reduction of  $RC$  (kg- $CO_2$ ). The corresponding total annual reduction in  $CO_2$  emissions (kg $CO_2$ /year),  $AWOMc$ , is estimated using Equation (10).

$$AWOMc = AWOMi \times RC \quad (10)$$

### 3.2. Effect of Competition

In Jordan, there are more than 50 contracting companies that are specialized in selling and installing PV systems. These companies compete with each other to provide unique product quality, after-sale services, advertisement, and reputation. Competition provides opportunities for companies to improve the performance of their products and services, which results in fulfilling adopters' needs and includes higher-quality products, increased value of services, and enhanced satisfaction. The developed system dynamics model to examine the effects of competition on PV goals is shown in Figure 2.

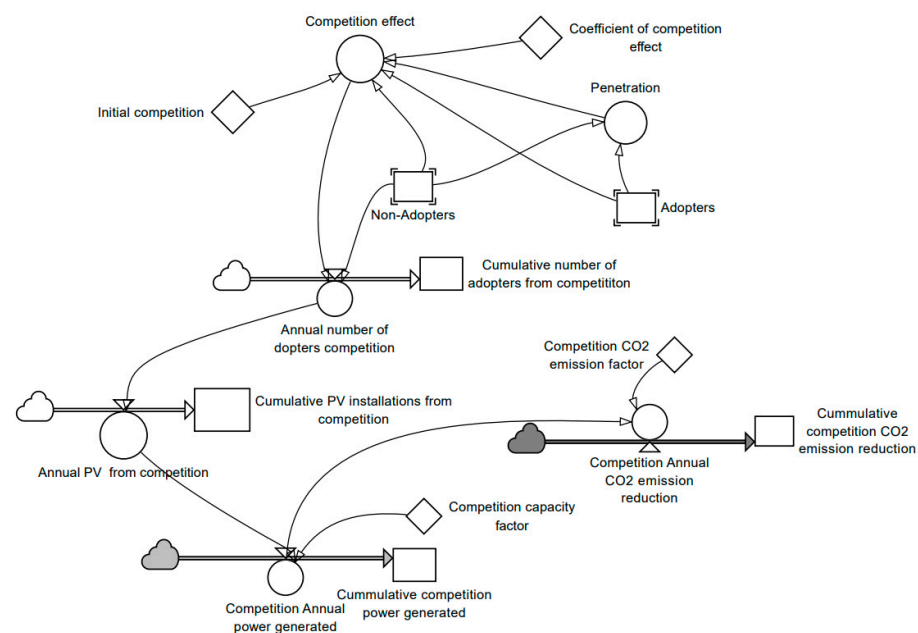


Figure 2. Competition model.

The coefficient of competition effect (CCE) is defined as the probability each company has to be selected by the consumer for PV system installation. Given the initial competition (IC), the competition effect ( $\text{year}^{-1}$ ), COE, is calculated as:

$$\text{COE} = \text{CCE} \times (\text{AD}/(\text{IC} \times \text{NAD})) / (1 - P) \quad (11)$$

Then, the annual number of PV adopters (adopter/year), ACOMP, is calculated using Equation (12).

$$\text{ACOMP} = \text{CCE} \times \text{NAD} \quad (12)$$

Then, the number of PV installations (kW/year) due to competition (ACOMi) is calculated as follows:

$$\text{ACOMi} = \text{ACOMP} \times V_p \quad (13)$$

Then, the annual corresponding generated power (kWh/year), ACOMe, and annual reduction in CO<sub>2</sub> emissions ( $\text{kg} \cdot \text{CO}_2/\text{year}$ ), ACOMe, are calculated using Equations (14) and (15), respectively.

$$\text{ACOMe} = \text{ACOMi} \times \text{NAD} \times \text{CF} \quad (14)$$

$$\text{ACOMc} = \text{ACOMe} \times \text{RC} \quad (15)$$

### 3.3. Effect of Advertising

Generally, advertising is a method used to bring products or services to the public's awareness and distinguish firms from their competition. As more companies invest in PV advertising efforts, the percentage of PV products and services may increase. As a result, the number of PV adopters will increase, which leads to increasing the generated power and reducing CO<sub>2</sub> emissions. The developed advertising model is displayed in Figure 3.

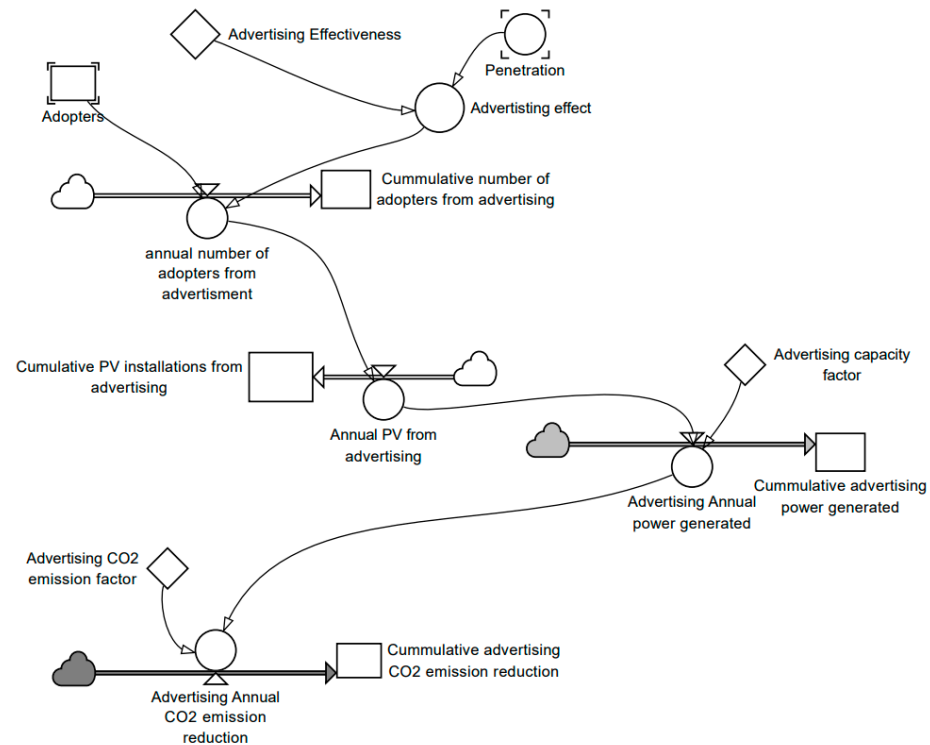


Figure 3. Advertising model.

In Figure 3, the advertising effect (DVe) depends on advertising effectiveness (DV) and penetration (P). Then, DVe ( $\text{year}^{-1}$ ) can be calculated using Equation (16).

$$\text{DVe} = \text{DV} \times (1 - P) \quad (16)$$

The annual number of adopters due to competition (adopter/year), ADVe, is obtained using Equation (17).

$$\text{ADVp} = \text{DVe} \times \text{AD} \quad (17)$$

Then, the total annual PV installation (kW/year), ADVi, is estimated as:

$$\text{ADVp} = \text{DVe} \times \text{Vp} \quad (18)$$

Consequently, the corresponding annual generated power (kWh/year), ADVe, is calculated as given in Equation (19).

$$\text{ADVe} = \text{ADVi} \times \text{NAD} \times \text{CF} \quad (19)$$

Finally, the total reduction in CO<sub>2</sub> emissions ( $\text{kg} \cdot \text{CO}_2$ ), ADVc, is estimated using Equation (20).

$$\text{ADVc} = \text{ADVe} \times \text{Vp} \quad (20)$$

#### 4. Research Results and Discussion

Simulation was performed using Powersim 2005 Software to predict the expected PV installations (kW), generated power (kWh), and CO<sub>2</sub> emission reduction ( $\text{kg} \cdot \text{CO}_2$ ) during the years 2020 to 2035. The model parameters are displayed in Table 1.

**Table 1.** Model parameters.

| Parameter              | Value   | Unit               | Parameter                               | Value | Unit                    |
|------------------------|---------|--------------------|-----------------------------------------|-------|-------------------------|
| Adopter (initial)      | 465,000 | person             | Complaints                              | 5     | %                       |
| Module area            | 5.6     | m <sup>2</sup>     | Advertising effectiveness               | 10    | %                       |
| Warranty period        | 10      | years              | Conversion efficiency                   | 20    | %                       |
| Payback period         | 3.4     | years              | Capacity factor                         | 20    | %                       |
| Energy system          | 1760    | kWh                | Degradation dissatisfaction             | 0.07  | %                       |
| Solar irradiance       | 1800    | kWh/m <sup>2</sup> | Satisfaction with installation services | 0.95  |                         |
| Electricity price      | 0.268   | USD/kWh            | O&M inflation                           | 5     | %                       |
| Initial PV cost        | 3770    | USD/kW             | Coefficient of competition              | 15    | %                       |
| Non-adopters           | 2       | Million person     | Initial competition                     | 50    | company                 |
| Lower limit of PV cost | 1200    | USD/kW             | Payback period                          | 3.4   | years                   |
| Life span              | 25      | years              | CO <sub>2</sub> emission factor         | 0.633 | kg·CO <sub>2</sub> /kWh |
| PV power               | 3       | kW/panel           | O&M inflation rate                      | 5     | %                       |

##### 4.1. Results of Overall Satisfaction, Competition and Advertising Models

The obtained simulation results for the developed models are presented as follows:

##### (a) Results of the satisfaction model

The simulation results of PV goals for the satisfaction model include:

- The cumulative PV installations (kW) increase linearly over time, as shown in Figure 4a. The PV installations are expected to increase from 8446 kW in 2021 to 88,433 kW in 2030. The cumulative PV installations will reach 184,310 kW at the beginning of 2040;
- In Figure 4b, the cumulative generated power (kWh) increases linearly over time. The cumulative generated power will increase from 14,560 kWh in 2021 to 152,813 kWh in 2030. The cumulative PV installations will reach 318,488 kWh at the beginning of 2040;
- The cumulative CO<sub>2</sub> emission reductions, as shown in Figure 4c, increase linearly over time. The cumulative CO<sub>2</sub> emission reductions increase from 9239 tons in 2021 to 96,730 tons of CO<sub>2</sub> in 2030. The cumulative PV installations will reach 201,603 tons of CO<sub>2</sub> at the beginning of 2040.

(b) Results of the competition model

Further, the obtained simulation results of PV goals for the competition model are displayed in Figure 5, where the following remarks are obtained:

- In Figure 5a, the cumulative PV installations (kW) increase nonlinearly over time. The PV installations (=5452 kW) in 2021 will increase to 61,036 kW and 139,923 kW in the year 2030 and at the beginning of 2040, respectively;
- In Figure 5b, the cumulative generated power (kWh) increases nonlinearly over time. The cumulative generated power (=9.4 GWh) in the year 2021 will increase to 105.5 GWh and 241.8 GWh in the years 2030 and 2040, respectively;
- The cumulative CO<sub>2</sub> emission reductions increase nonlinearly over time, as shown in Figure 5c. The cumulative CO<sub>2</sub> emission reductions (=5964 tons of CO<sub>2</sub>) in the year 2021 will increase to 66,763 and 153 tons of CO<sub>2</sub> in the years 2030 and 2040, respectively.

(c) Results for the advertising model

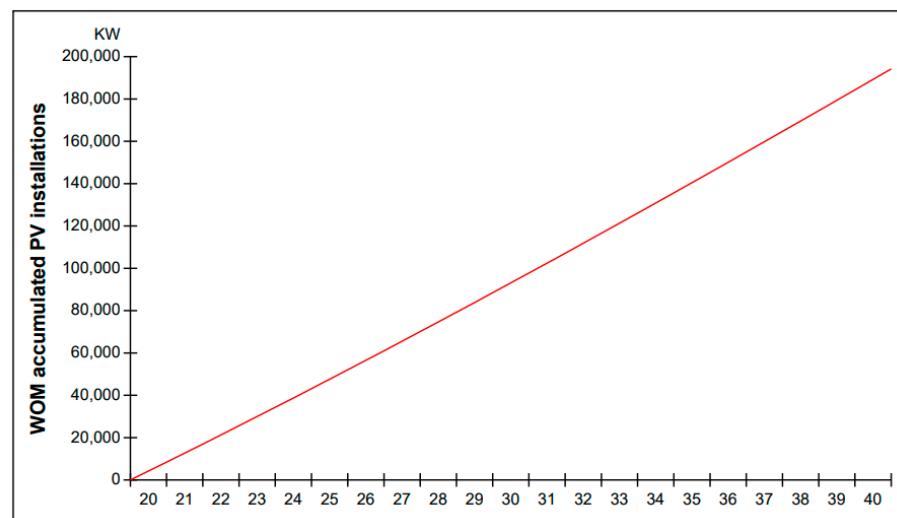
The obtained PV results for the advertising model are:

- In Figure 6a, the cumulative PV installations (=10,706 MW) in 2021 will increase to 112.1 MW and 233.6 MW in the year 2030 and at the beginning of 2040, respectively;
- The cumulative generated power (kWh) increases nonlinearly over time, as shown in Figure 6b. The cumulative generated power (=18.5 GWh) in the year 2021 will increase to 193.7 and 403.7 GWh in the years 2030 and 2040, respectively;
- The cumulative CO<sub>2</sub> emission reductions, shown in Figure 6c, increase nonlinearly over time. The cumulative CO<sub>2</sub> emission reductions (=11.711 million kg CO<sub>2</sub>) in the year 2021 will increase to 122.6 and 255.6 million kg CO<sub>2</sub> in the years 2030 and 2040, respectively.

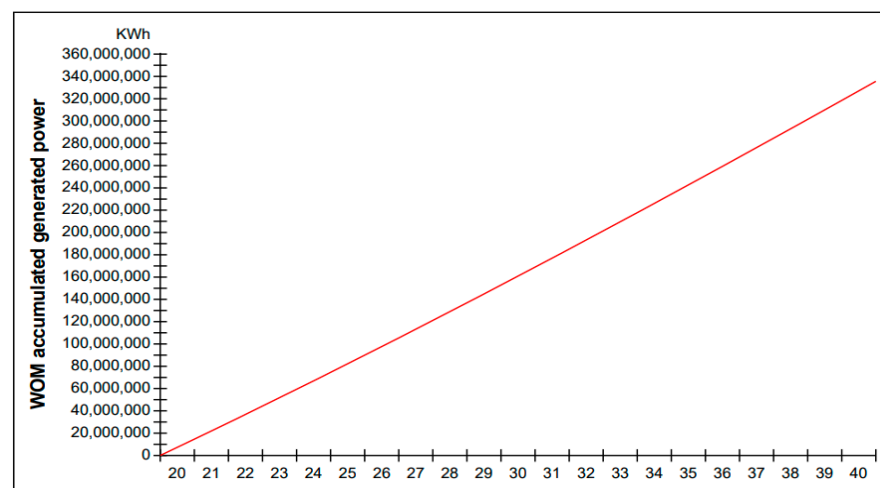
#### 4.2. Results of the Combined Effects and PV Cost Models

Simulation was conducted to evaluate the combined effects of overall satisfaction, competition, and advertising models on PV goals as shown in Figure 7. The obtained simulation results for the cumulative PV installations, generated power, and CO<sub>2</sub> emission reduction are depicted in Figure 8, where the following remarks are obtained:

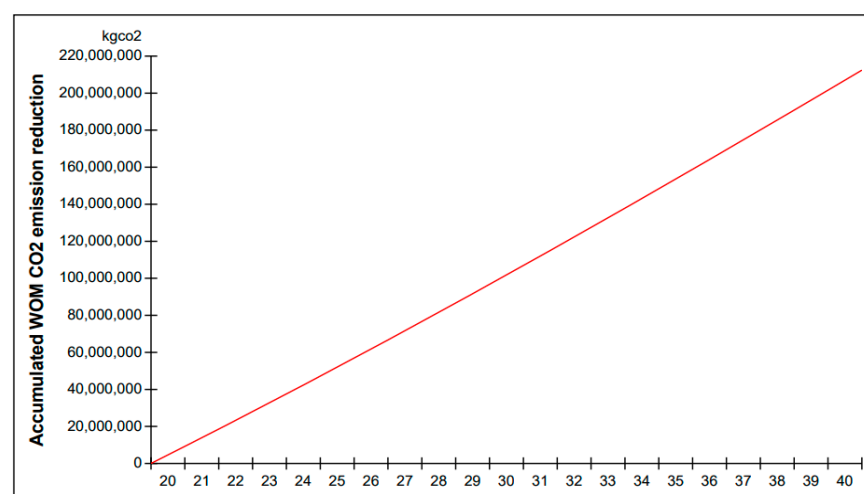
- Figure 8a reveals that the total cumulative PV installations (=24.6 MW) in 2021 are expected to increase to 262 and 558 MW in the year 2030 and at the beginning of 2040, respectively;
- As depicted in Figure 8b, the cumulative total generated power (kWh) (=42.5 GWh) in the year 2021 can reach 452 and 964 GWh in the years 2030 and 2040, respectively.
- The cumulative total CO<sub>2</sub> emission reductions, as shown in Figure 8c, increase nonlinearly over time. The cumulative CO<sub>2</sub> emission reductions (=27 million kg-CO<sub>2</sub>) in the year 2021 may reach 262 and 558 million kg CO<sub>2</sub> in the years 2030 and 2040, respectively.



(a)

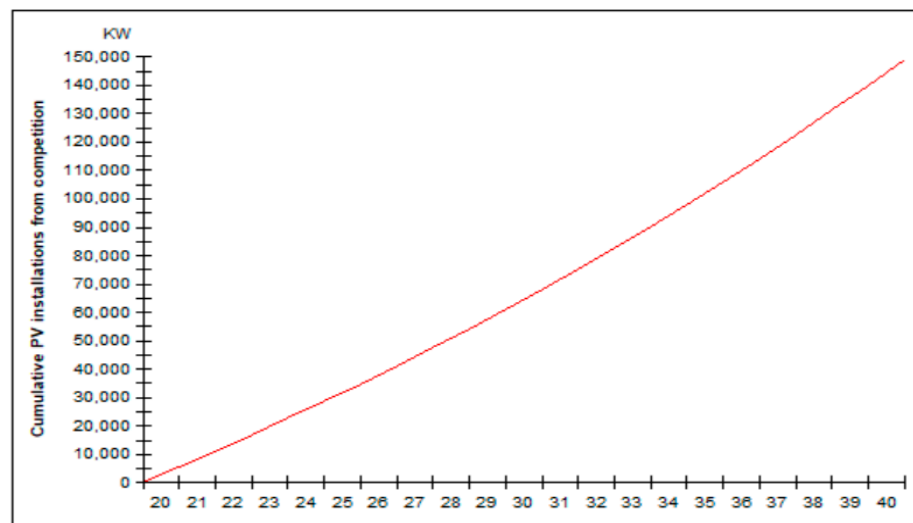


(b)

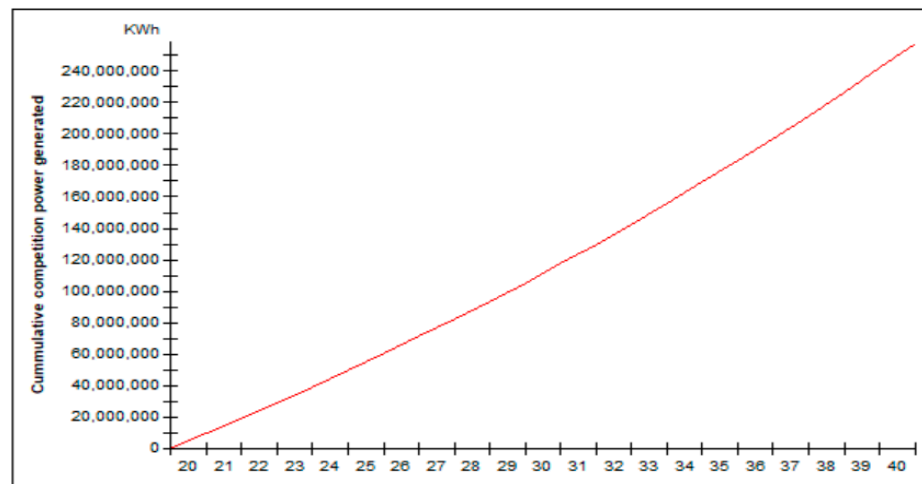


(c)

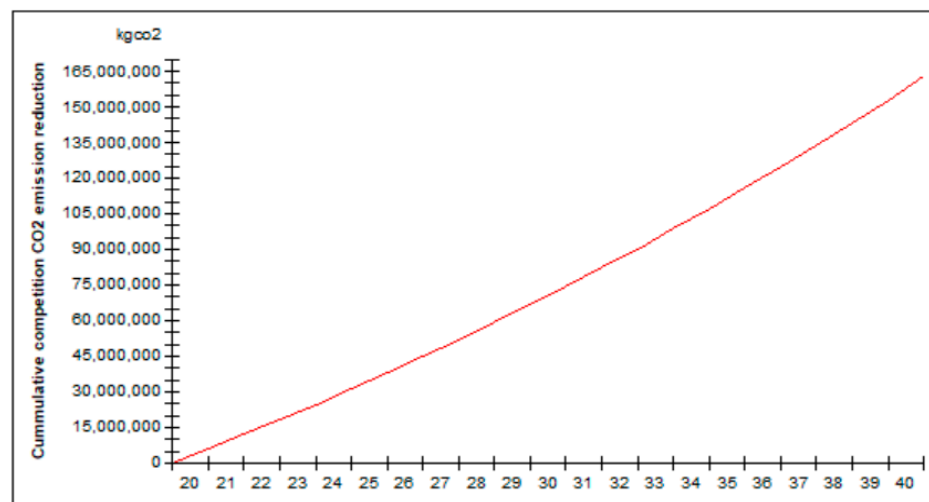
**Figure 4.** WoM effects. (a) Cumulative PV installations. (b) Cumulative power generated. (c) Cumulative CO<sub>2</sub> emission reduction.



(a)

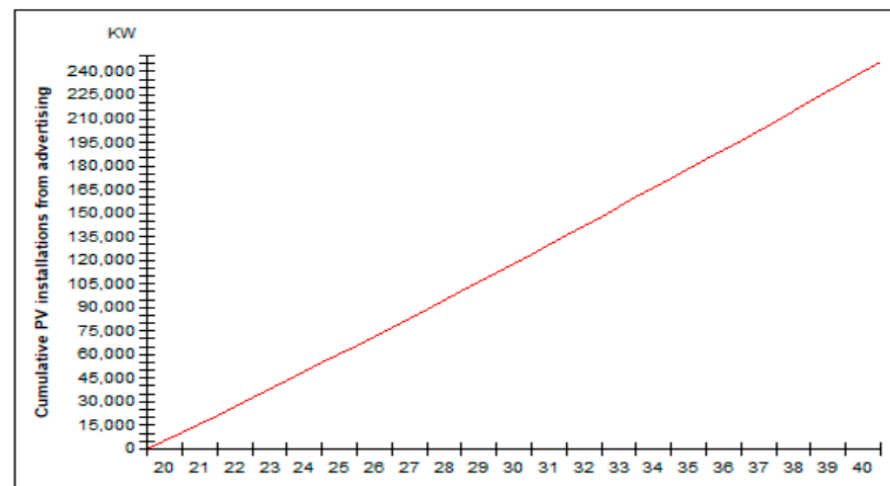


(b)

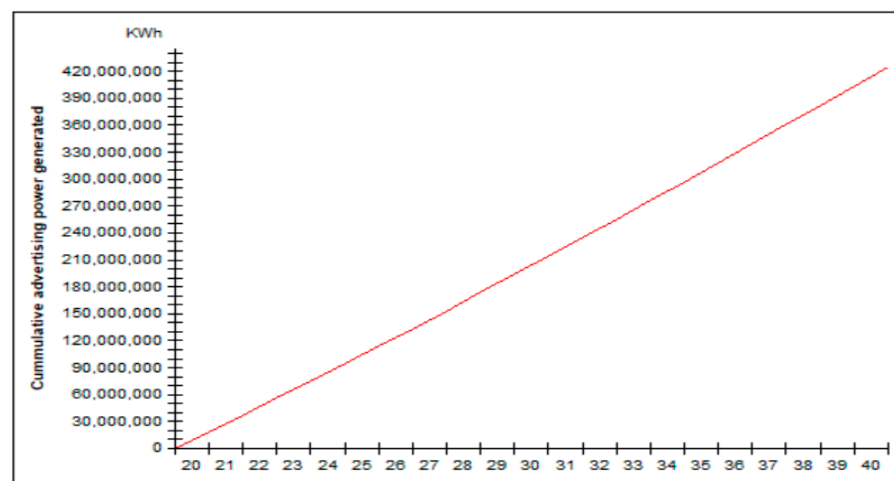


(c)

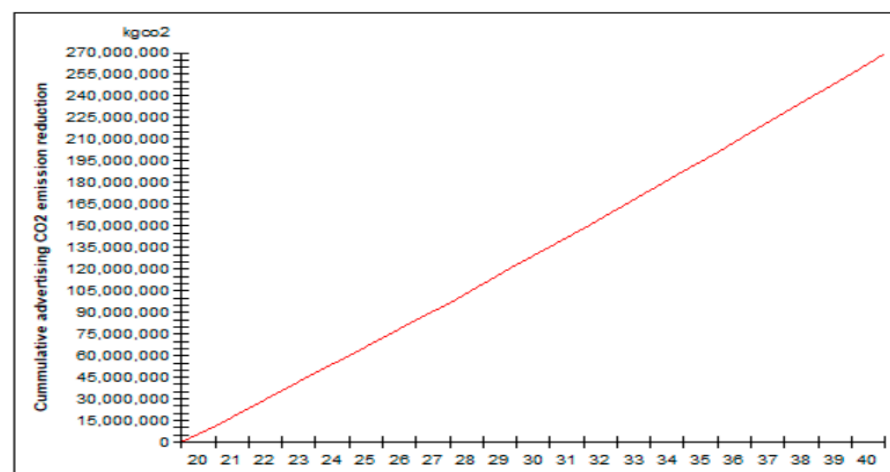
**Figure 5.** Competition effects. (a) Cumulative PV installations; (b) Cumulative power generated; (c) Cumulative CO<sub>2</sub> emission reduction.



(a)



(b)



(c)

**Figure 6.** Advertising effects. (a) Cumulative PV installation; (b) Cumulative power generated; (c) Cumulative CO<sub>2</sub> emission reductions.

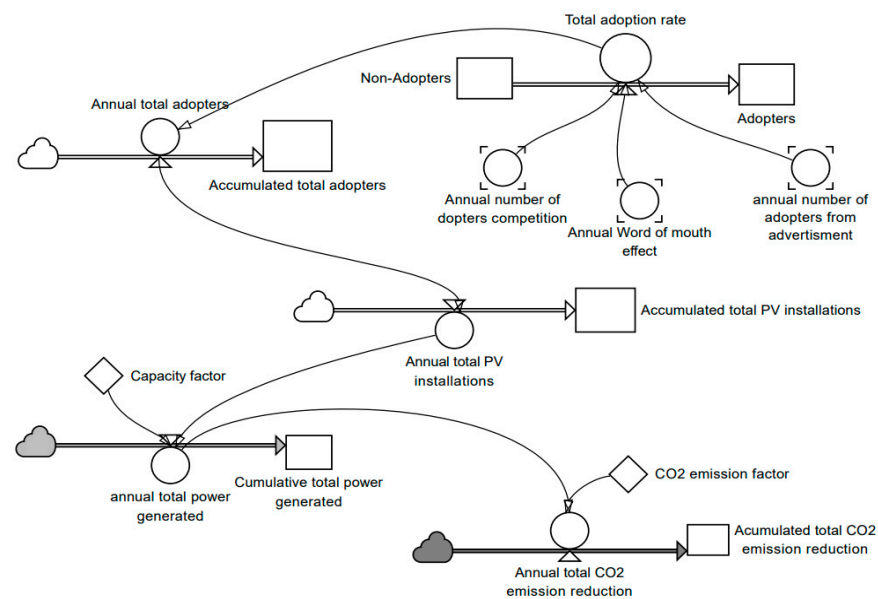


Figure 7. Combined model.

Further, the system cost model is shown in Figure 9. The model includes the system cost (USD) and operating and maintenance (O&M) costs at an inflation rate of 5% and inflation factor. Combining the three effects, a simulation was run to predict the cost of the PV system (\$) over time, as shown in Figure 10, where it is expected that the cost of the PV system will decrease from USD 3770 in the year 2021 to USD 915 and USD 1009 in the years 2030 and 2040.

#### 4.3. Sensitivity Analysis

Sensitivity analysis was conducted to examine the influence of some parameters on the resulting PV goals. Table 2 summarizes the assumption variables (competition effect, advertising effectiveness, and percent contact) and the decision variables (conversion efficiency and satisfaction with PV services) in the sensitivity analysis. Table 3 displays the optimal PV installations, CO<sub>2</sub> emission reductions, and generated power.

Table 2. Assumption and decision variables.

| (a) Assumptions                       |                       |                                         |
|---------------------------------------|-----------------------|-----------------------------------------|
| Factor                                | Distribution          | Parameters                              |
| Coefficient of competition effect     | Normal                | Mean = 0.25 Standard deviation = 0.02   |
| Advertising effectiveness             | Triangular            | Min = 0.01 Max = 0.05 Peak = 0.05       |
| Percent of contact per year           | Normal                | Mean = 0.01 Standard deviation = 0.0001 |
| (b) Decision variables                |                       |                                         |
| Factor                                | Parameters            | Actual                                  |
| Conversion efficiency                 | Min = 0.02 Max = 0.25 | 0.21                                    |
| Satisfaction level with installations | Min = 0.01 Max = 0.86 | 0.89                                    |

**Table 3.** Results of sensitivity analysis.

| Factor                                                      | 25 Percentile | 50 Percentile | 75 Percentile |
|-------------------------------------------------------------|---------------|---------------|---------------|
| Cumulative generated power (GWh)                            | 2159          | 2535          | 2978          |
| Cumulative CO <sub>2</sub> reductions (kg·CO <sub>2</sub> ) | 1366          | 1605          | 1885          |
| Cumulative PV adopters (MW)                                 | 1250          | 1467          | 1723          |

Figure 11 displays the results of sensitivity analysis for the three PV goals, where the differences between the 25th percentile and 75th percentile increase over time. This result supports the significant long-term positive impacts due to variations in WoM, competition, and advertising on PV goals. In practice, suppliers and manufacturers should regularly assess the feedback on the satisfaction levels of the delivered PV products, handle customer complaints effectively, upgrade the technical capabilities of PV systems (payback period, warranty, conversion, and system efficiencies), and adopt effective advertising means to increase overall satisfaction with PV systems and thereby support achieving energy sustainability in residential buildings.

#### 4.4. Integrated Model with Subsidy Policy

The subsidy model is displayed in Figure 12. Simulation was run for the combination of the subsidy policy with the integrated model. The subsidy proportion (SP) of 15% of the cost of a PV system (CPV) is offered by the government to encourage PV installations. The electricity price (EC) is USD 0.268/kWh. The annual subsidy cost (SC) is calculated as stated in Equation (21).

$$SC = CPV \times SP \quad (21)$$

Then, the annual subsidy effect (kW), ASe, is estimated using Equation (22).

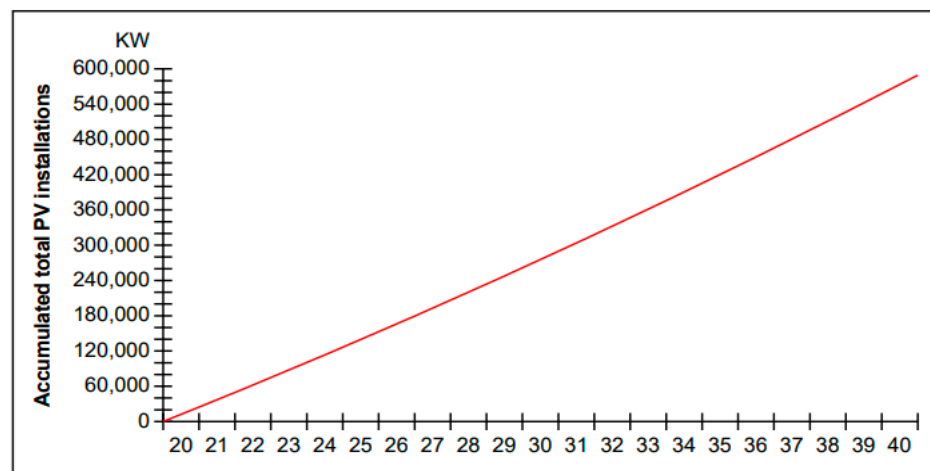
$$ASe = NAD \times CF \times EC \times 360 \times 24 \times (CPV - SC) \quad (22)$$

From Figure 13, the following remarks are obtained:

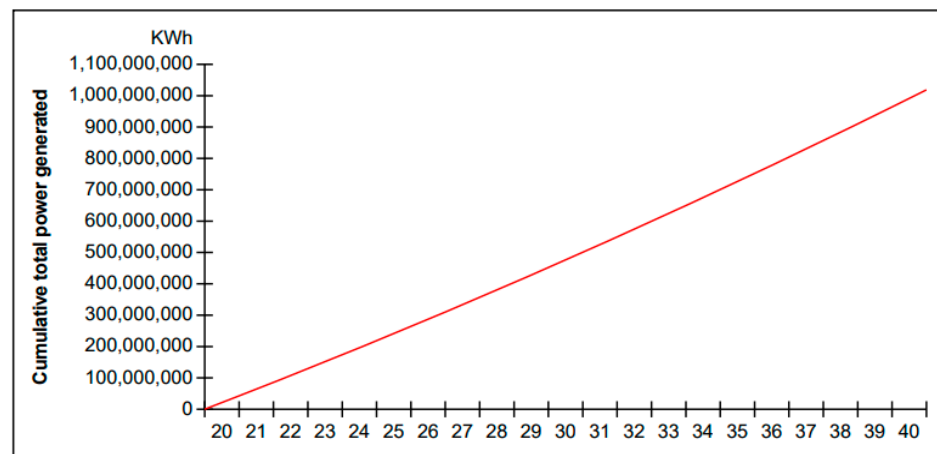
- The total cumulative PV installations in 2021 (=298 MW), as shown in Figure 13a, may reach 7.14 and 17.2 GW in the year 2030 and at the beginning of 2040, respectively;
- In Figure 13b, the cumulative total generated power (kWh) (=514.22 GWh) in the year 2021 increases to 12.34 and 31.33 TWh in the years 2030 and 2040, respectively.
- The cumulative total CO<sub>2</sub> emission reductions, as depicted in Figure 13c, increase nonlinearly over time. The cumulative CO<sub>2</sub> emission (=325.5 million kg CO<sub>2</sub>) in the year 2021 is expected to be reduced by 7.81 and 19.83 million tons CO<sub>2</sub> in the years 2030 and 2040, respectively.

#### 4.5. Discussion

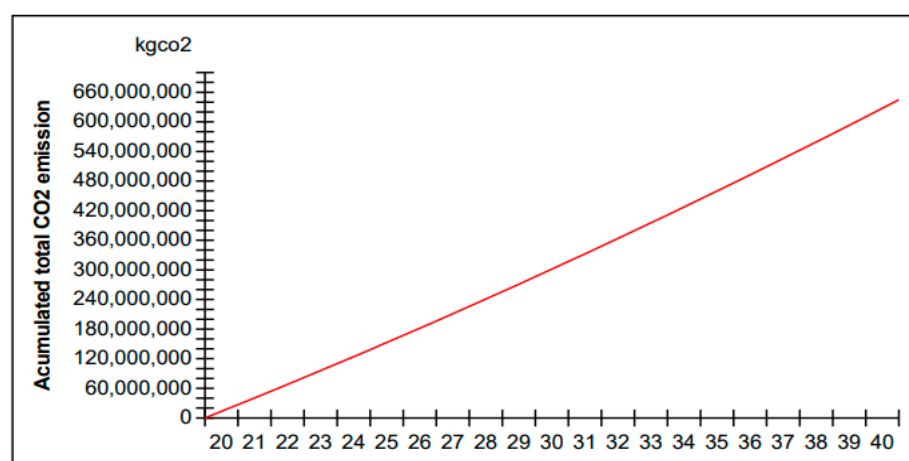
This research evaluated quantitatively the individual and combined impacts of satisfaction with rooftop PV systems, advertising, and competition on PV goals to the year 2040. Figure 14 displays the comparison between the factor effects on PV goals. The results show the positive impact of WoM, advertising, and competition on PV goals over time. This result supports the hypotheses of this research and is consistent with the findings of the previous studies. Meanwhile, advertising has the largest impact on PV goals, followed by WoM. Consequently, effective advertising policies should be adopted to promote high-quality rooftop PV systems and motivate the adoption of renewable electricity.



(a)



(b)



(c)

**Figure 8.** Combined effects. (a) Cumulative PV installations; (b) Cumulative power generated; (c) Cumulative CO<sub>2</sub> emission reductions.

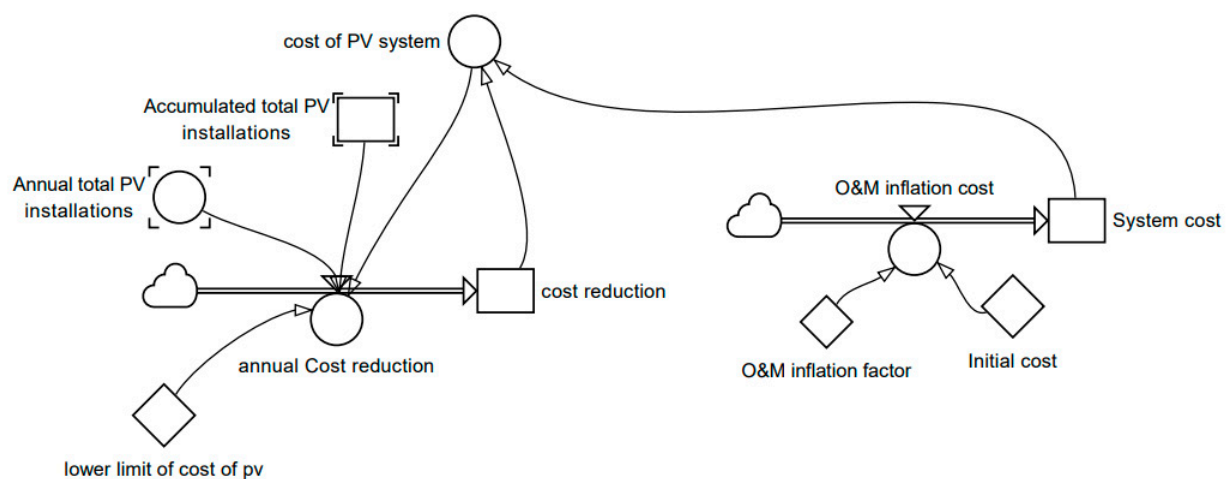


Figure 9. System cost model.

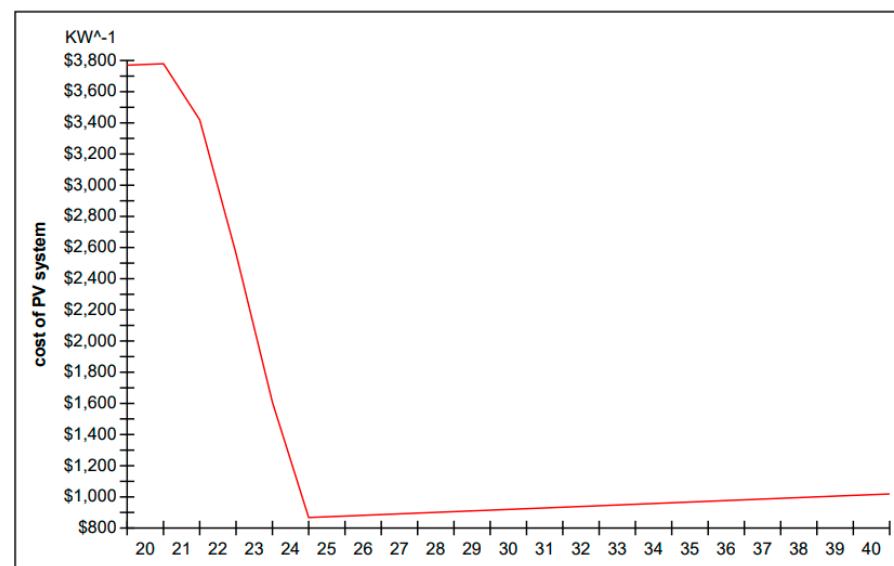
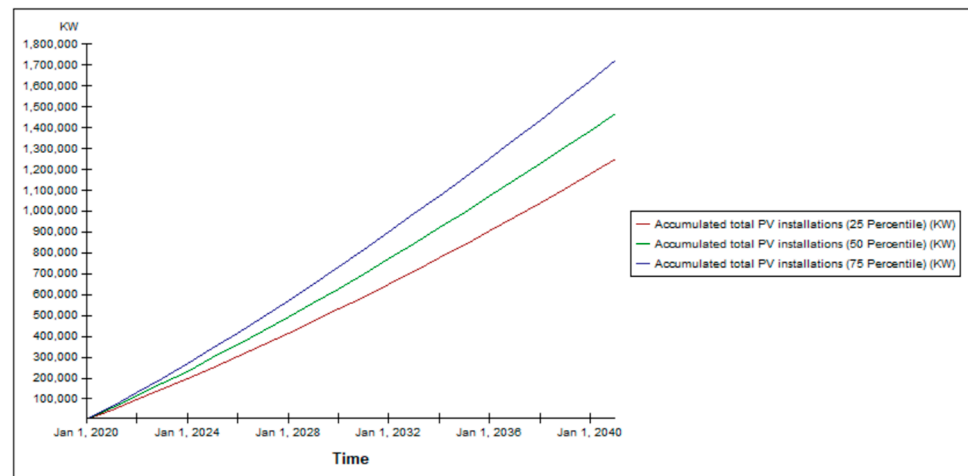


Figure 10. The cost of PV system (USD).

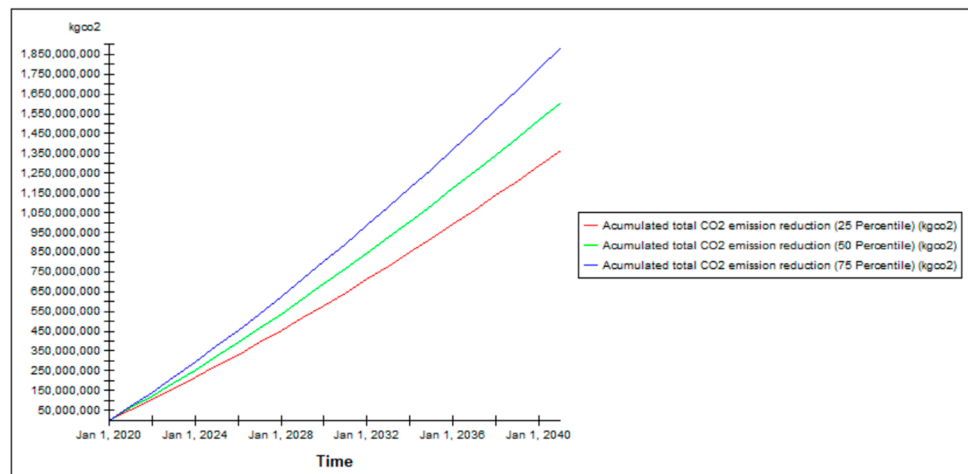
Further, manufacturers and suppliers should continually assess the feedback on the product and service quality of the delivered PV systems and enhance the efficiency of PV systems to enhance adopters' satisfaction with PV systems and maximize the economic and environmental benefits gained from the adoption of solar PV systems. Finally, competing PV companies should work closely with adopters to understand their requirements, design and develop high quality PV products and systems at affordable prices, and continually review the PV designs and operation, enhance product and service quality, and offer a wide range of innovative PV products and systems. Furthermore, the adoption of subsidy policy by government has had a significant impact on the adoption of rooftop PV installations. Consequently, government should invest in promoting the adoption of renewable energy solar systems on building rooftops.

Finally, effective manufacturer and supplier efforts in advertising and competition, together with satisfaction with rooftop PV systems and the adoption of subsidy policy, can lead to a significant amount of generated energy that can be sufficient to attain energy security and sustainability. Consequently, policy-makers in the energy sector should monitor the status of adoption of renewable energy and evaluate the influence of subsidies to determine the most attractive subsidy proportion. Future research may consider the use

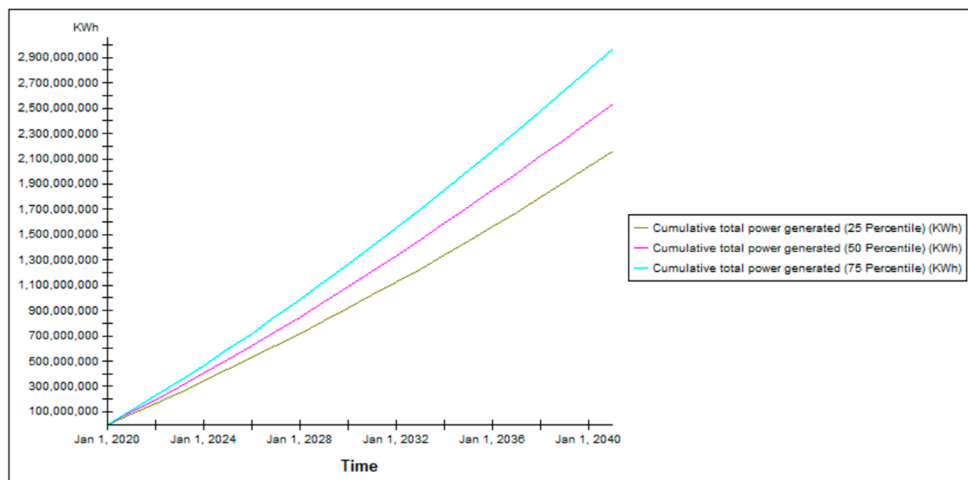
of machine learning techniques to model and predict PV goals under various combinations of model factors and energy policies.



(a)



(b)



(c)

**Figure 11.** Results of sensitivity analysis. (a) Accumulated PV installations; (b) Accumulated CO<sub>2</sub> emission reductions; (c) Accumulated generated power.

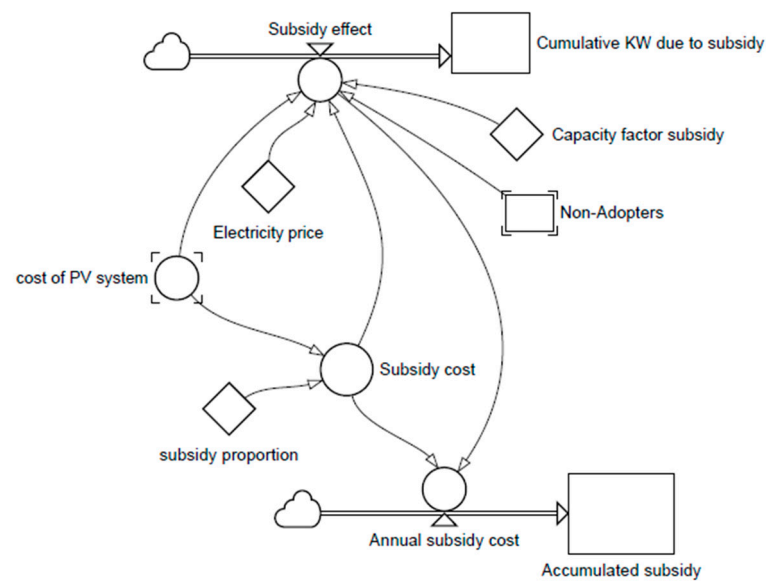
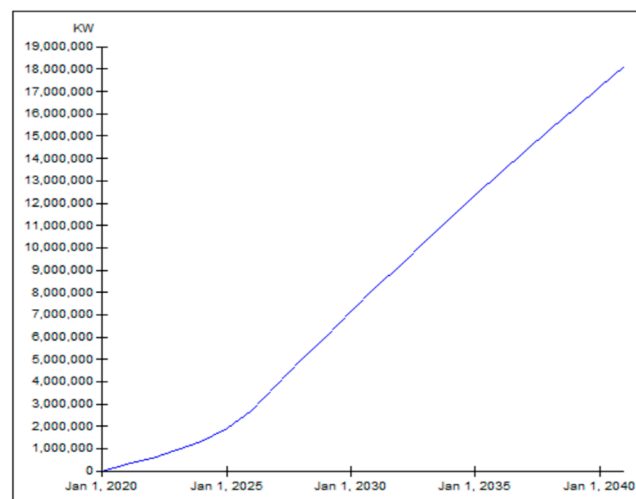
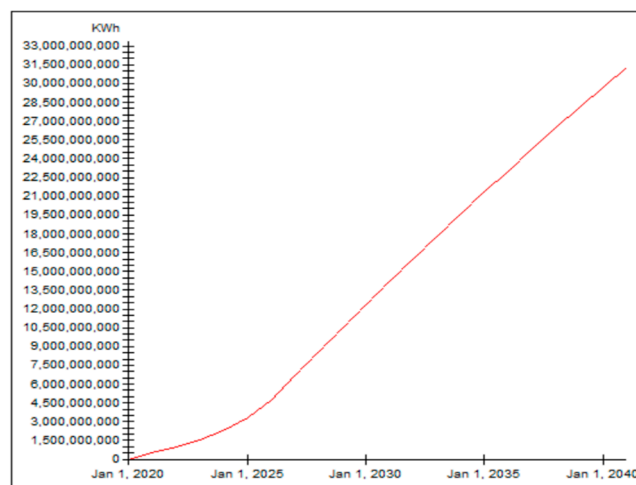


Figure 12. Subsidy model.

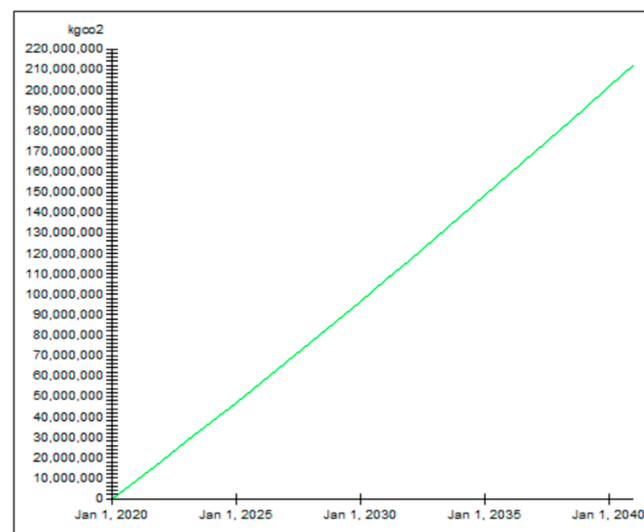


(a)



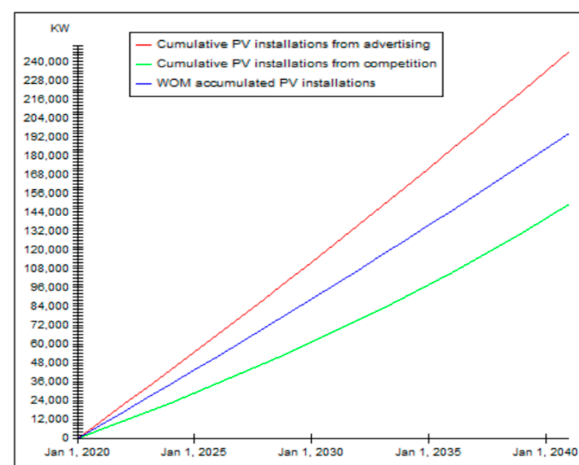
(b)

Figure 13. Cont.

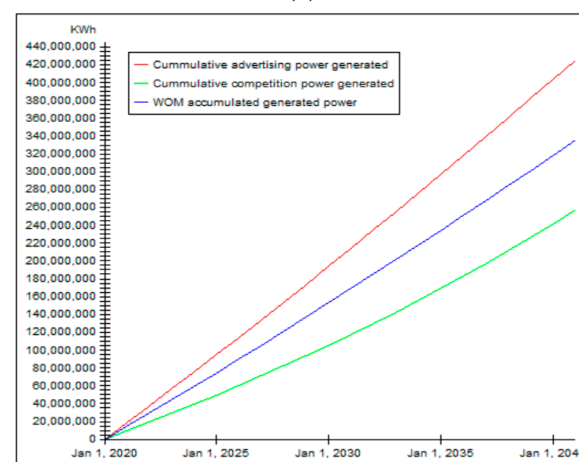


(c)

**Figure 13.** Results of subsidy and integrated model. (a) Accumulated PV installations; (b) Accumulated generated power; (c) Accumulated CO<sub>2</sub> emission reductions.

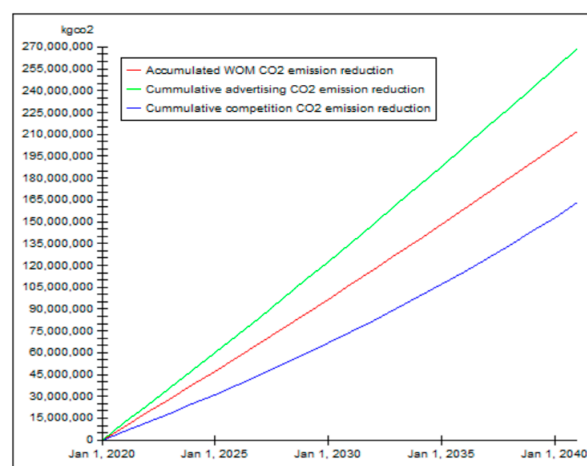


(a)



(b)

**Figure 14.** Cont.



(c)

**Figure 14.** Comparison between factor effects on PV goals. (a) Cumulative PV installations (kW); (b) Cumulative generated power (kWh); (c) Cumulative CO<sub>2</sub> emission reductions (kg·CO<sub>2</sub>).

## 5. Conclusions

The research predicted the impacts, to the year 2040, of adopters' overall satisfaction with PV systems, advertising, and competition on the number of rooftop PV installations, generated electric power, and the reduction in CO<sub>2</sub> emissions for residential buildings in Jordan using system dynamics. Results revealed that the predicted cumulative PV installations, generated power, and CO<sub>2</sub> emission reductions will reach 558 MW, 964 GWh, and 558 million kg·CO<sub>2</sub> in 2030, respectively. A sensitivity analysis was then performed to examine the impacts of uncertainty in model parameters, including the competition effect, advertising effectiveness, and percent of contact per year. The optimization results for conversion efficiency and satisfaction level of 0.21 and 0.89, respectively, showed that the expected cumulative PV installations, generated power, and CO<sub>2</sub> emission reductions in the year 2040 will reach 1.5 GW, 2.98 TWh, and 1.6 million tons kg·CO<sub>2</sub>, respectively. Further, the adoption of subsidy policy was examined. The results revealed a significant influence of subsidy adoption on motivating the adoption of rooftop PV systems in Jordan. In conclusion, continual assessment of the feedback on overall satisfaction with installed rooftop PV services and products, adoption of advanced technological products in PV systems, and implementation of effective advertising policies will result in significant energy gains in residential building and reduction in the dependence on environmentally unfriendly and scarce energy resources. Finally, subsidy policy is a key driver to foster huge gains in energy security and sustainability. Thus, government should invest in promoting and motivating the adoption of rooftop PV systems in Jordan.

**Author Contributions:** Conceptualization, methodology, A.A.-R.; software, A.A.-R.; validation, A.A.-R., N.L. and C.H.; formal analysis, A.A.-R., N.L. and C.H.; investigation, A.A.-R. and N.L.; resources, A.A.-R., N.L. and C.H.; data curation, A.A.-R., N.L. and C.H.; writing—original draft preparation, A.A.-R., N.L. and C.H.; writing—review and editing, A.A.-R., N.L. and C.H.; visualization, A.A.-R.; supervision, A.A.-R., N.L. and C.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** This research is supported by the Deanship of Scientific Research at the University of Jordan, project ID (273).

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

## References

1. Zografakis, N.; Sifaki, E.; Pagalou, M.; Nikitaki, G.; Psarakis, V.; Tsagarakis, K.P. Assessment of public acceptance and willingness to pay for renewable energy sources in Crete. *Renew. Sust. Energ. Rev.* **2010**, *14*, 1088–1095. [\[CrossRef\]](#)
2. Pereira, L.; Cavaleiro, J.; Barros, L. Economic assessment of solar-powered residential battery energy storage systems: The case of Madeira Island, Portugal. *Appl. Sci.* **2020**, *10*, 7366. [\[CrossRef\]](#)
3. Al-Refaie, A.; Lepkova, N. Impacts of renewable energy policies on CO<sub>2</sub> emissions reduction and energy security using system dynamics: The case of small-scale sector in Jordan. *Sustainability* **2022**, *14*, 5058. [\[CrossRef\]](#)
4. Honrubia-Escribano, A.; Ramirez, F.J.; Gómez-Lázaro, E.; Garcia-Villaverde, P.M.; Ruiz-Ortega, M.J.; Parra-Requena, G. Influence of solar technology in the economic performance of PV power plants in Europe. A Comprehensive Analysis. *Renew. Sustain. Energy Rev.* **2018**, *82*, 488–501. [\[CrossRef\]](#)
5. Reimuth, A.; Locherer, V.; Danner, M.; Mauser, W. How Does the Rate of Photovoltaic Installations and Coupled Batteries Affect Regional Energy Balancing and Self-Consumption of Residential Buildings? *Energies* **2020**, *13*, 2738. [\[CrossRef\]](#)
6. Bódis, K.; Kougiass, I.; Jäger-Waldau, A.; Taylor, N.; Szabó, S. A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109309. [\[CrossRef\]](#)
7. Monna, S.; Juaidi, A.; Abdallah, R.; Itma, M. A Comparative Assessment for the Potential Energy Production from PV Installation on Residential Buildings. *Sustainability* **2020**, *12*, 10344. [\[CrossRef\]](#)
8. Wang, H.; Oguz, E.; Jeong, B.; Zhou, P. Life cycle and economic assessment of a solar panel array applied to a short route ferry. *J. Clean. Prod.* **2019**, *219*, 471–484. [\[CrossRef\]](#)
9. Podsakoff, P.M.; MacKenzie, S.B.; Lee, J.Y.; Podsakoff, N.P. Common method biases in behavioral research: A critical review of the literature and recommended remedies. *J. Appl. Psychol.* **2003**, *88*, 879–903. [\[CrossRef\]](#)
10. Ahmad, W.; Zhang, Q. Green purchase intention: Effects of electronic service quality and customer green psychology. *J. Clean. Prod.* **2020**, *267*, 122053. [\[CrossRef\]](#)
11. Komatsu, S.; Kaneko, S.; Ghosh, P.P.; Morinaga, A. Determinants of user satisfaction with solar home systems in rural Bangladesh. *Energy* **2013**, *61*, 52–58. [\[CrossRef\]](#)
12. Jacoby, J.; Jaccard, J.J. The sources, meaning, and validity of consumer complaint behavior: A psychological analysis. *J. Retail* **1981**, *57*, 4–24.
13. Al-Refaie, A.; Bata, N.; Eteiwi, D.; Jalham, I. Examining Factors that Affect Passenger's Overall Satisfaction and Loyalty: Evidence from Jordan Airport. *Jordan J. Mech. Ind. Eng.* **2014**, *8*, 94–101.
14. Al-Refaie, A.; Tahat, M.D.A.; Bata, N. CRM/e-CRM effects on banks performance and customer-bank relationship quality. *Int. J. Enterp. Inf. Syst.* **2014**, *10*, 62–80. [\[CrossRef\]](#)
15. Gharaibeh, B.; Al-Refaie, A.; Goussous, J.; Shurrah, M. Effect of CCMS on customer satisfaction and loyalty in Jordanian banks. *Information* **2012**, *15*, 6227–6237.
16. Buttle, F.A. Word of mouth: Understanding and managing referral marketing. *J. Strateg. Mark.* **1998**, *6*, 241–254. [\[CrossRef\]](#)
17. Murtiasih, S.; Siringoringo, H. How word of mouth influence brand equity for automotive products in Indonesia. *Procedia Soc. Behav. Sci.* **2013**, *81*, 40–44. [\[CrossRef\]](#)
18. Qu, M.; Ahponen, P.; Tahvanainen, L.; Gritten, D.; Mola-Yudego, B.; Pelkonen, P. Chinese university students' knowledge and attitudes regarding forest bio-energy. *Renew. Sust. Energ. Rev.* **2011**, *15*, 3649–3657. [\[CrossRef\]](#)
19. Pagiaslis, A.; Krontalis, A.K. Green consumption behavior antecedents: Environmental concern, knowledge, and beliefs. *Psychol. Mark.* **2014**, *31*, 335–348. [\[CrossRef\]](#)
20. Jalilvand, M.R.; Heidari, A. Comparing face-to-face and electronic word-of-mouth in destination image formation: The case of Iran. *Inf. Technol. People* **2017**, *30*, 710–735. [\[CrossRef\]](#)
21. Wilcox, G.B.; Kang, E.Y.; Chiles, L.A. Beer, wine, or spirits? Advertising's impact on four decades of category sales. *Int. J. Advert.* **2015**, *34*, 641–657. [\[CrossRef\]](#)
22. Fraj, E.; Martinez, E. Environmental values and lifestyles as determining factors of ecological consumer behaviour: An empirical analysis. *J. Consum. Mark.* **2006**, *23*, 133–144. [\[CrossRef\]](#)
23. Chen, K.K. Assessing the effects of customer innovativeness, environmental value and ecological lifestyles on residential solar power systems install intention. *Energy Policy* **2014**, *67*, 951–961. [\[CrossRef\]](#)
24. Hansla, A.; Gamble, A.; Juliusson, A.; Gärling, T. Psychological determinants of attitude towards and willingness to pay for green electricity. *Energy Policy* **2008**, *36*, 768–774. [\[CrossRef\]](#)
25. Sun, P.C.; Wang, H.M.; Huang, H.L.; Ho, C.W. Consumer attitude and purchase intention toward rooftop photovoltaic installation: The roles of personal trait, psychological benefit, and government incentives. *Energy Environ.* **2020**, *31*, 21–39. [\[CrossRef\]](#)
26. Faiers, A.; Neame, C. Consumer attitudes towards domestic solar power systems. *Energy Policy* **2006**, *34*, 1797–1806. [\[CrossRef\]](#)
27. Pérez-Lombard, L.; Ortiz, J.; Pout, C. A review on buildings energy consumption information. *Energy Build.* **2008**, *40*, 394–398. [\[CrossRef\]](#)
28. Ministry of Energy and Mineral Resources (MEMR 2019). *Energy 2019—Facts & Figures*; MEMR: Amman, Jordan, 2019. Available online: [https://www.memr.gov.jo/ebv4.0/root\\_storage/en/eb\\_list\\_page/brchure\\_2019.pdf](https://www.memr.gov.jo/ebv4.0/root_storage/en/eb_list_page/brchure_2019.pdf) (accessed on 21 October 2022).
29. Al-Refaie, A.; Hammad, M.; Li, M.H. DEA window analysis and Malmquist index to assess energy efficiency and productivity in Jordanian industrial sector. *Energy Effic.* **2016**, *9*, 1299–1313. [\[CrossRef\]](#)

30. Aslani, A.; Helo, P.; Naaranoja, M. Role of renewable energy policies in energy dependency in Finland: System dynamics approach. *Appl. Energy* **2014**, *113*, 758–765. [\[CrossRef\]](#)
31. Jeon, C.; Shin, J. Long-term renewable energy technology valuation using system dynamics and Monte Carlo simulation: Photovoltaic technology case. *Energy* **2014**, *66*, 447–457. [\[CrossRef\]](#)
32. Mokhtara, C.; Negrou, B.; Settou, N.; Bouferrouk, A.; Yao, Y. Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101468. [\[CrossRef\]](#)
33. Baniyounes, A.M. Renewable Energy Potential in Jordan. *Int. J. Appl. Eng. Res.* **2017**, *12*, 8323–8331.
34. Mihalakakou, G.; Psiloglou, B.; Santamouris, M.; Nomidis, D. Application of renewable energy sources in the Greek islands of the South Aegean Sea. *Renew. Energy* **2002**, *26*, 1–19. [\[CrossRef\]](#)
35. Kiwan, S.; Al-Gharibeh, E. Jordan toward a 100% renewable electricity system. *Renew. Energy* **2020**, *147*, 423–436. [\[CrossRef\]](#)
36. Koch, H.; Lechner, S.; Erdmann, S.; Hofmann, M. Assessing the Potential of Rooftop Photovoltaics by Processing High-Resolution Irradiation Data, as Applied to Giessen, Germany. *Energies* **2022**, *15*, 6991. [\[CrossRef\]](#)
37. Hsu, C.-W. Using a system dynamics model to assess the effects of capital subsidies and feed-in tariffs on solar PV installations. *Appl. Energy* **2012**, *100*, 205–217. [\[CrossRef\]](#)
38. Aslani, A.; Wong, K.-F.V. Analysis of renewable energy development to power generation in the United States. *Renew. Energy* **2014**, *63*, 153–161. [\[CrossRef\]](#)
39. Ahmad, S.; Tahar, R.; Muhammad-Sukki, M.F.; Munir, A.B.; Abdul Rahim, R. Role of feed-in tariff policy in promoting solar photovoltaic investments in Malaysia: A system dynamics approach. *Energy* **2015**, *84*, 808–815. [\[CrossRef\]](#)
40. Radomes, A.A., Jr.; Arango, S. Renewable energy technology diffusion: An analysis of photovoltaic-system support schemes in Medellín, Colombia. *J. Clean. Prod.* **2015**, *92*, 152–161. [\[CrossRef\]](#)
41. Young, J.; Brans, M. Analysis of factors affecting a shift in a local energy system towards 100% renewable energy community. *J. Clean. Prod.* **2017**, *169*, 117–124. [\[CrossRef\]](#)
42. Jain, H.; Broadwater, R.P.; Dilek, M.; Bank, J. Studying the impact of solar PV on power system dynamics using integrated transmission and distribution network models. *J. Energy Eng.* **2018**, *144*, 04017072. [\[CrossRef\]](#)
43. Li, Y.; Zhang, Q.; Wang, G.; McLellan, B.; Liu, X.F.; Wang, L. A review of photovoltaic poverty alleviation projects in China: Current status, challenge and policy recommendations. *Renew. Sustain. Energy Rev.* **2018**, *94*, 214–223. [\[CrossRef\]](#)
44. Njoh, A.J.; Etta, S.; Essia, U.; Ngyah-Etchutambe, I.; Enomah, L.E.; Tabrey, H.T.; Tarke, M.O. Implications of institutional frameworks for renewable energy policy administration: Case study of the Esaghem, Cameroon community PV solar electrification project. *Energy Policy* **2019**, *128*, 17–24. [\[CrossRef\]](#)
45. Nair, K.; Shadman, S.; Chin, C.M.M.; Sakundarini, N.; Yap, E.H.; Koyande, A. Developing a system dynamics model to study the impact of renewable energy in the short- and long-term energy security. *Mater. Sci. Energy Technol.* **2021**, *4*, 391–397. [\[CrossRef\]](#)
46. Karna, S.K.; Singh, R. A Framework for Assessing the Viability of Solar PV in Province-2 of Nepal Using System Dynamics Approach. In *Advances in Systems Engineering: Select Proceedings of NSC 2019*; Springer: Singapore, 2021; pp. 827–836.
47. Albatayneh, A.; Albadaine, R.; Juaidi, A.; Abdallah, R.; Montoya, M.D.G.; Manzano-Agugliaro, F. Rooftop photovoltaic system as a shading device for uninsulated buildings. *Energy Rep.* **2022**, *8*, 4223–4232. [\[CrossRef\]](#)
48. Mukai, T.; Kawamoto, S.; Ueda, Y.; Saijo, M.; Abe, N. Residential PV system users' perception of profitability, reliability, and failure risk: An empirical survey in a local Japanese municipality. *Energy Policy* **2011**, *39*, 5440–5448. [\[CrossRef\]](#)
49. Kim, H.; Park, E.; Kwon, S.J.; Ohm, J.Y.; Chang, H.J. An integrated adoption model of solar energy technologies in South Korea. *Renew. Energy* **2014**, *66*, 523–531. [\[CrossRef\]](#)
50. Sweeney, J.C.; Webb, D.; Mazzarol, T.; Soutar, G.N. Self-determination theory and word of mouth about energy-saving behaviors: An online experiment. *Psychol. Mark.* **2014**, *31*, 698–716. [\[CrossRef\]](#)
51. Stigka, E.K.; Paravantis, J.A.; Mihalakakou, G.K. Social acceptance of renewable energy sources: A review of contingent valuation applications. *Renew. Sust. Energy Rev.* **2014**, *32*, 100–106. [\[CrossRef\]](#)
52. Tarigan, E. Simulation and feasibility studies of rooftop PV system for university campus buildings in Surabaya, Indonesia. *Int. J. Renew. Energy Res.* **2018**, *8*, 895–908. [\[CrossRef\]](#)
53. Sharifi, M.; Pool, J.K.; Jalilvand, M.R.; Tabaeian, R.A.; Jooybari, M.G. Forecasting of advertising effectiveness for renewable energy technologies: A neural network analysis. *Technol. Forecast. Soc. Change* **2019**, *143*, 154–161. [\[CrossRef\]](#)
54. Lopez-Ruiz, H.G.; Blazquez, J.; Vittorio, M. Assessing residential solar rooftop potential in Saudi Arabia using nighttime satellite images: A study for the city of Riyadh. *Energy Policy* **2020**, *140*, 111399. [\[CrossRef\]](#)
55. Gernaat, D.E.; de Boer, H.S.; Dammeier, L.C.; van Vuuren, D.P. The role of residential rooftop photovoltaic in long-term energy and climate scenarios. *Appl. Energy* **2020**, *279*, 115705. [\[CrossRef\]](#)
56. Martinopoulos, G. Are rooftop photovoltaic systems a sustainable solution for Europe? A life cycle impact assessment and cost analysis. *Appl. Energy* **2020**, *257*, 114035. [\[CrossRef\]](#)
57. Agathokleous, R.A.; Kalogirou, S.A. PV roofs as the first step towards 100% RES electricity production for Mediterranean islands: The case of Cyprus. *Smart Energy* **2021**, *4*, 100053. [\[CrossRef\]](#)
58. Haryadi, F.N.; Hakam, D.F.; Ajija, S.R.; Simaremare, A.A.; Aditya, I.A. The analysis of residential rooftop PV in Indonesia's electricity market. *Economies* **2021**, *9*, 192. [\[CrossRef\]](#)

59. Fakhraian, E.; Forment, M.A.; Dalmau, F.V.; Nameni, A.; Guerrero, M.J.C. Determination of the urban rooftop photovoltaic potential: A state of the art. *Energy Rep.* **2021**, *7*, 176–185. [\[CrossRef\]](#)
60. Maqbool, R.; Deng, X.; Rashid, Y. Stakeholders' satisfaction as a key determinant of critical success factors in renewable energy projects. *Energy Sustain. Soc.* **2020**, *10*, 28. [\[CrossRef\]](#)
61. Qadourah, J.A. Energy and economic potential for photovoltaic systems installed on the rooftop of apartment buildings in Jordan. *Results Eng.* **2022**, *16*, 100642. [\[CrossRef\]](#)
62. Gomez-Exposito, A.; Arcos-Vargas, A.; Gutierrez-Garcia, F. On the potential contribution of rooftop PV to a sustainable electricity mix: The case of Spain. *Renew. Sustain. Energy Rev.* **2020**, *132*, 110074. [\[CrossRef\]](#)
63. Pan, D.; Bai, Y.; Chang, M.; Wang, X.; Wang, W. The technical and economic potential of urban rooftop photovoltaic systems for power generation in Guangzhou, China. *Energy Build.* **2022**, *277*, 112591. [\[CrossRef\]](#)
64. Al-Refaie, A.; Abdelrahim, D.A.Y. A system dynamics model for green logistics in a supply chain of multiple suppliers, retailers and markets. *Int. J. Bus. Perform. Supply Chain Model.* **2021**, *12*, 259–281. [\[CrossRef\]](#)
65. Fontes, C.H.D.O.; Freires, F.G.M. Sustainable and renewable energy supply chain: A system dynamics overview. *Renew. Sustain. Energy Rev.* **2018**, *82*, 247–259. [\[CrossRef\]](#)
66. Moumouni, Y.; Ahmad, S.; Baker, R.J. A system dynamics model for energy planning in Niger. *Int. J. Energy Power Eng.* **2014**, *3*, 308–322. [\[CrossRef\]](#)
67. Azzopardi, B.; Emmott, C.J.; Urbina, A.; Krebs, F.C.; Mutale, J.; Nelson, J. Economic assessment of solar electricity production from organic-based photovoltaic modules in a domestic environment. *Energy Environ. Sci.* **2011**, *4*, 3741–3753. [\[CrossRef\]](#)
68. Monteith, J.L. Solar radiation and productivity in tropical ecosystems. *J. Appl. Ecol.* **1972**, *9*, 747–766. [\[CrossRef\]](#)
69. Benganem, R.; Maafi, A. Measurement system for solar radiation. In Proceedings of the IEEE Instrumentation and Measurement Technology Conference Sensing, Processing, Networking, IMTC Proceedings, Victoria, BC, Canada, 19–21 May 1997; IEEE: Piscataway, NJ, USA, 1997; Volume 2, pp. 932–935. [\[CrossRef\]](#)
70. Formica, T.J.; Khan, H.A.; Pecht, M.G. The effect of inverter failures on the return on investment of solar photovoltaic systems. *IEEE Access* **2017**, *5*, 21336–21343. [\[CrossRef\]](#)
71. Solar Review. Solar Panel Cost Jordan: Prices & Data. 2022. Available online: <https://www.solarreviews.com/solar-panel-cost/new%20york/jordan> (accessed on 11 September 2023).
72. IRENA. Renewable Capacity Statistics. 2022. Available online: <https://www.irena.org/Publications/2022/Apr/Renewable-Capacity-Statistics-2022> (accessed on 26 April 2022).
73. Yadav, S.K.; Bajpai, U. Performance evaluation of a rooftop solar photovoltaic power plant in Northern India. *Energy Sustain. Dev.* **2018**, *43*, 130–138. [\[CrossRef\]](#)

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.