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The Role of Earth Observation Satellites in Maximizing Renewable Energy Production: Case Studies Analysis for Renewable Power Plants

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Abstract: This paper is based on a novel approach towards clean energy production, i.e., space innovative applications toward sustainable development. Specifically, the role of Earth observation (EO) satellites in maximizing renewable energy production is considered to show the enormous potential in exploiting sustainable energy generation plants when the Earth is mapped by satellites to provide some peculiar parameters (e.g., solar irradiance, wind speed, precipitation, climate conditions, geothermal data). In this framework, RETScreen clean energy management software can be used for numerical analysis, such as energy generation and efficiency, prices, emission reductions, financial viability and hazard of various types of renewable-energy and energy-efficient technologies (RETs), based on a large database of satellite parameters. This simplifies initial assessments and provides streamlined processes that enable funders, architects, designers, regulators, etc. to make decisions on future clean energy initiatives. After describing the logic of life cycle analysis of RETScreen, two case studies (Mexicali and Toronto) on multiple technologies power plant are analyzed. The different results obtained, when projecting the two scenarios, showed how the software could be useful in the pre-feasibility phase to discriminate the type of installation not efficient for the selected location or not convenient in terms of internal rate of return (IRR) on equity.

Keywords: renewable energy; space industry; RETScreen

1. Introduction

Finding an effective way to deal with current resource depletion and climate change will require soon a complete transformation of existing unsustainable energy systems [1]. The space industry has come to represent an icon of knowledge-creation processes in technology-intensive industries [2]. The industry is not merely comprised of launches and satellites, but now includes direct consumer applications and personal entertainment [3]. Therefore, the space industry has some history of expansion, and its growth is expected to accelerate [4]. An input-output analysis is useful for predicting which industries will benefit from their growth and to inform the government, which may want to use this information for policy making or investment decisions [5]. For example, space tourism is becoming a topic of great media interest thanks to technological evolution in the aerospace sector and with the reduced costs of access to space [6]. Moreover, space-based applications are already helping emerging nations in reaching social equity, but often their demands come after the excellent attempts taken in industrialized nations to guarantee that all helpful space-based information and features are put to greatest use for social reasons [7]. Space applications are mainly based on closed-loop systems (i.e., circular), due to two main reasons: (i) to guarantee a satellite mission, the platform should be autonomously powered; (ii) then, the spatial missions need regenerative processes to deal with limited available resources, for example air and water. Moreover, the very high costs for projecting and producing space technologies become more affordable when the system is reusable (to give an example, this is what happens for new launchers project). Therefore, the space industry is a clear example of a circular economy model.

The circular economy (CE) approach has the ambition of making better use of resources/materials through reuse, recycling and recovery with the aim of minimizing the energy and environmental impact of resource extraction and processing [8,9]. This mission is mainly pursued by redesigning the life cycle of the product, in order to have minimal input and minimal production of system waste [10]. A transition to a circular economy is required, not only because we need to overcome the limits of a linear economy, but also because scarcity of resources usually required a dependence on foreign countries on supply and a strong impact on environmental conditions due to virgin material extractions and "old" manufacturing process with no recycling objectives [11]. CE drives sustainable consumption and steers public and private investment, which eventually lead to sustainable development [12]. The sustainable development goals (SDGs) convey worldwide aspirations and urge all potential donors to help meet their difficulties [13]. Given the significant part that the space domain has already performed in growth initiatives and the excellent chance to increase its input, space operators are called on to take advantage of the momentum of the SDGs, not only to concentrate on how they can further participate, but also how they can become a more integrated component of a society struggling with growth in a wider global sense, thereby optimizing efficiency and input [14].

The following mapping, shown in Table 1, may be suggested to evaluate the space potential in order to pursue SDGs.

Table 1. Space contribution to SDGs [15].

SDG Topic	Actual or Possible Contribution of Space
SDG 1: No Poverty	Improved communications and more environmental data as a driver of growth, better logistics management by the use of sat/nav
SDG 2: Zero Hunger	EO data for optimized agriculture and livestock management, more efficient crop markets, better delivery systems using sat/nav
SDG 3: Good Health and Well-Being	E- health including telemedicine and medical tele-training and learning
SDG 4: Quality Education	Tele-learning
SDG 5: Gender Equality	Female empowerment by telecoms links to the information society, tele-learning, telecoms enabling small businesses of women
SDG 6: Clean Water and Sanitation	EO data for water management, water detection, and water pollution monitoring
SDG 7: Affordable & Clean Energy	EO data for renewable energy management, grid management
SDG 8: Decent Work and Economic Growth	Space services as enabler of economic growth and high quality jobs in all economic sectors
SDG 9: Industry, Innovation and Infrastructure	Space as enablers of innovation both in own sector and others, space based data and communication abilities key for industrial processes, space telecoms compensates for lack of terrestrial networks, EO for lack of in-situ stations, sat/nav important for best use of transport infrastructure and banking systems
SDG 10: Reduced Inequalities	Access to information society through telecoms is a leveler, fosters transparency and hence helps fight against corruption, space services as an enabler of work opportunity
SDG 11: Sustainable Cities and Communities	EO data for pollution monitoring, energy management and land use planning, sat/nav for traffic management, telecoms for efficient information exchange

Table 1. *Cont.*

SDG Topic	Actual or Possible Contribution of Space
SDG 12: Responsible consumption and production	EO data for optimized supply management, energy management, sat/nav for logistics management in production
SDG 13: Climate Action	EO data key for climate change monitoring and definition of mitigation strategies
SDG 14: Life below Water	EO data key for monitoring the health of oceans and other water systems, for fisheries management and policing
SDG 15: Life on Land	EO data for bio-diversity monitoring, pollution monitoring, land use management and policing
SDG 16: Peace Justice and Strong Institutions	Telecoms empower civil society by connecting to the information society, e-voting enabled by telecoms, legal evidence, treaty compliance monitoring, security management through EO systems
SDG 17: Partnerships	Space community is a part of an international fabric of partnerships. Possibilities of reinforcement of links with development actors

Space technology has quickly followed and performed a significant part in economic development initiatives (coping with the majority of SDGs content) [16]. This is true in both emerging and industrialized countries. In emerging nations, where terrestrial infrastructure is often inadequate or missing, space-based applications give excellent benefits as they mainly eliminate the need for such infrastructure [17]. EO satellites are among the most relevant source of data even in industrialized countries, and they are often essential to guide policy governance providing information that is fundamental to watershed and fisheries management and to tracking pollution areas [18].

Through its SDG7 (affordable and clean energy) initiatives, the European Space Agency (ESA) promotes initiatives to guarantee inexpensive, safe, viable and contemporary energy for all. ESA is using its satellite technologies to create safe power alternatives that can substitute natural emissions producing greenhouse gasses that account for at least 70% of worldwide warming caused by human activity. Through the agency and its utility suppliers' extensive cloud booking operations conducted by ESA, consumers can build networks to support sustainable development in multiple industries, including energy, and assist in making the 17 SDGs a fact by 2030 [19].

Outside the European area, the National Aeronautics and Space Administration (NASA) has made a significant contribution to our awareness of Earth and the need for modern, greener technology in many ways. NASA's commitment to Earth, the atmosphere and green technologies continues today through solar arrays and fuel cells projects, EO satellite applications, more powerful spaceships, more efficient climate models and air, water and waste recycling processes. This is giving a strong enhancement for our planet's clean energy programs while advancing in highly technological research for science, aeronautics and space exploration tasks [20].

When talking about space technologies for clean energy generation, it is necessary to look at EO satellites for maximizing renewable energy production [21]. Satellites for EO provide a distinctive basis of data for anyone designing, implementing or assessing sustainable development initiatives. They can assist in reconstructing a sequence of occurrences by displaying a series of pictures over the span of a moment. High-resolution pictures can be used during a particular timeframe to investigate extremely focused phenomenon with a limited range of sight. In portraying national events that may involve more systemic and repeated compilation, low precision photography is easier.

Copernicus is the European Union (EU) EO and monitoring program, which looks to our planet and its environment for the ultimate benefit of all European citizens. It aims at providing accurate and easily accessible data to improve environment management and understanding of climate change effects [22]. Copernicus primarily draws on data collected from EO satellites, but it also depends on a large amount of information gathered in situ (meaning on-site or local) measurement systems made available by the Member States of the EU to the programme.

In Figure 1, the Sentinel family is displayed, which constitutes the space segment of the Copernicus program.

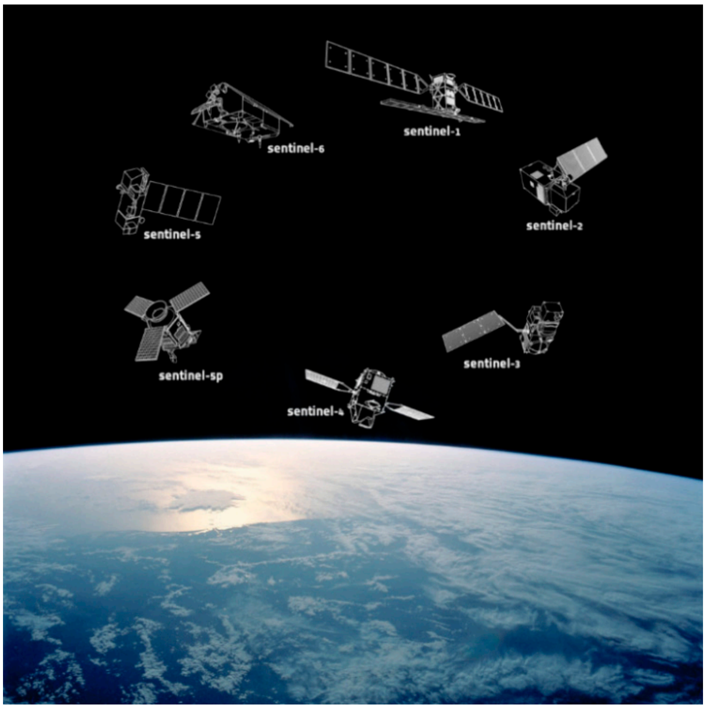

Figure 1. Copernicus EO satellite constellation [23].

Satellite programs for collecting climate data and, in general, for Earth monitoring are among the key sustainable development initiatives for SDGs, but this is not the end of the process: telemetry data properly post-processed are inserted in databases in order to allow very accurate analysis for certain type of project. For this scope, many software and tools have been developed with user-friendly interfaces, going from a basic-user level (a family that wants a domestic photovoltaic installation) to an advanced-user level (engineers working for investors in power plants or smart building programs). RETScreen, being the oldest tool conceived for exploiting databases of typical sets of data for Earth monitoring and consequently analyzing the feasibility of a power plant installation (traditional or renewable), has been adopted for describing how useful satellite missions are for renewable energy optimization in power plants, already existing or not [24].

The peculiarity of this study is to show how space-based research could produce significant enhancements to sustainability and, in particular, to renewable energy generation. Specifically, the novelty of this work comes from the emphasis given to one of the most innovative fields of study (i.e., space research) for finding solutions for our environment by trying to exploit already existing technologies to propose an innovative approach to clean energy generation. Our analyses show the results of two scenarios. The first one included a case study mixing multiple renewable technologies in a single installation; as a result, power, cost analysis, pollution analysis, financial analysis and risk analysis have been provided. The second scenario compared two equivalent (in terms of location and capacity) power plants, one provided with wind turbine and the other with photovoltaic technology.

The rest of the work is organized as follows. Section 2 introduces the materials and methods, Section 3 presents the results, whereas Section 4 discusses the findings; finally, Section 5 concludes.

2. Materials and Methods

Parameters should be accurately estimated in order to provide a reliable evaluation of renewable energy power plant installation. In Table 2, a typical set of data of the most significant parameters needed to evaluate Earth's conditions in order to better manage renewable resource plants is shown.

Table 2. Typical set of data for Earth monitoring [25].

Parameter Category	Specific Parameters
SOLAR GEOMETRY	• Solar noon • Daylight hour • Hourly solar angles from horizon
RADIATION	• All-sky insolation (Average, Min, Max) • Diffuse horizontal radiation (Average, Min, Max) • Direct normal radiation (Average, Min, Max) • Clear-sky insolation • Clear-sky days
ILLUMINANCE	• Illuminance on tilted surfaces at available GMT times • Illuminance on tilted surfaces over 24 hour period
SURFACE ALBEDO	• Surface albedo
CLOUDS	• Daylight cloud amount • Cloud amount at available GMT times • Frequency of cloud amount at available GMT times
METEOROLOGY (WIND)	• Wind speed at 50 m (Average, Min, Max) • Percent of time for ranges of wind speed at 50 m • Wind speed at 10 m for terrain similar to airports
METEOROLOGY (TEMPERATURE)	• Air temperature at 10 m • Daily temperature Range at 10 m • Dew point temperature at 10 m • Cooling degree days above 18 °C • Heating degree days below 18 °C • Earth skin temperature • Frost days
PRECIPITATION	• Precipitation

These data are not easy to exploit. First, you will need to receive telemetry collected by sensors on-board the satellite. Then, you need to implement statistical and numerical models and choose the best in describing a specifying phenomenon, In the end, you will give as an input to the model, satellite data in a proper format (data normalization is always required). Only when you reach the final point, can the output data be collected in a larger database and help you in designing and optimizing energy plants and sustainable buildings.

In recent times, a spread of tools and software has been noticed, providing the evidence to how sustainability and, specifically, renewable energies are becoming relevant in our modern circular economy.

For example, Google, with its "Project sunroof" tool, allows you in a user-friendly interface to evaluate if it is convenient to build photovoltaic panels in a certain area, by using satellite data. It is not relevant to this point to list the high number of clean energy software that have been developed across the years, but it's important to speak about the most relevant ones and the way in which they provide useful results for an accurate analysis of renewable energies plants, thanks to the availability of large amount of satellite data (all of the Earth's surface is mapped with more than one sensor).

HOMER (Hybrid Optimization Modeling Software) is able to design and analyze the power systems combining traditional and renewable technologies. This tool is very accurate, but it requires too much input data to build a proper scenario, so it is mainly used not for the feasibility study phase, but for the manufacturing phase [26].

Further tools have been developed, as databases or atlases, depicting only a small set of parameters; among these tools, we found the NASA Prediction of Worldwide Energy Resource (POWER) project aimed to improve the current renewable energy data set and to create a new database from new satellite systems. The POWER project is mainly addressed to renewable and sustainable energy [27].

In the European area, the S2S4E Decision Support Tool (DST) has been developed as an operational climate service for clean energy. The DST generates climate information adapted through energy indicators derived from climatic variables such as wind speed, solar radiation, precipitation, temperature and pressure reduced to the average sea level. These indicators provide information on the expected variability in hydroelectric, solar and wind energy production, as well as on electricity demand in the future.

Last, but not least, one of the oldest and largest adopted tools for clean energy management is RETScreen, developed by the Canadian Government with NASA cooperation. In 1996, RETScreen clean energy management software was developed by Natural Resources Canada; after that, in 1998 the software package was carried on by the Canadian government.

The tool can be used for numerical analysis in areas such as energy generation and efficiency, prices, emission reductions, financial viability and hazards of various types of clean energy and energy-efficient technologies. This simplifies initial assessments and provides streamlined processes that enable funders, architects, designers, regulators, etc. to make decisions on future clean energy initiatives. This software is able to exploit post-processed satellite data and guides you through a very simple path from system project to cost analysis, in order to understand if, for example, some smart building or energy plant realization is feasible or not. It includes modelling for many renewable energy systems and the expected costs for the plant characteristics so you will be able to have an approximate, but flexible, estimate on the project you are working on.

The tool has already been used for projecting many installations all over the world: (i) to validate the techno-economic and environmental sustainability of solar PV technology in Nigeria [28], (ii) to evaluate and compare economic policies to increase energy generation capacity in the Iranian household consumption sector [29], (iii) to provide a technical, financial, economic and environmental pre-feasibility study of geothermal power plants in Ecuador [30] and (iv) to provide a preliminary determination of the optimal size for renewable energy resources in buildings [31].

RETScreen Expert software in its latest available version (7.0) has been adopted to provide useful case studies of projects involving renewable energies in contrast with standard power production. The open-source version (only viewer mode) has limited features, but it is still reliable for feasibility analysis of many projects, starting from smart buildings to power plants [32].

The first case study to be proposed is a multiple technologies power plant, combining geothermal and hydric power [33], as shown in Figure 2. In particular, water and geothermal power have been exploited in different percentages, so that the combination can provide 35,033 MWh as electricity export to the grid, reducing CO2 emissions by 15,676 tCO2 (equivalent tons of CO2).

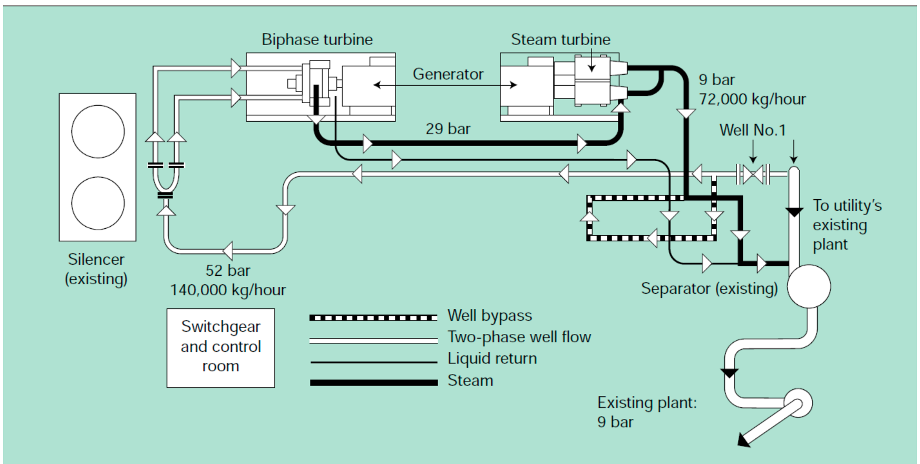

Figure 2. Schematic of the integrated biphase back-pressure system [26].

The type of power plant and the location are the first step choices to go through. For this case study, the installation place is in Mexico.

Mexico's renewable energy contributes 26% of Mexico's electricity generation. The majority of renewable energy adoption comes from hydro, geothermal, solar and wind power. Long-term efforts are being made to increase the use of renewable sources of energy. The sum of geothermal energy used and extracted ranks Mexico as number four in the world.

Starting from a template of RETScreen software, latitude, longitude and altitude of both selected location (Mexicali) and the facility to be set is provided. The climate zone is individuated automatically to be that of Ensenada (the closest place to the facility being mapped for climate reference).

Mexicali is the capital of the Mexican state of Baja California. It covers an area of more than 13,000 km^2 and it counts more than 900,000 inhabitants. The city is located on the border with the United States of America; in fact, its name is a crasis that derives from the union of the words México and California.

Thanks to having plenty of water, gas and electricity, Mexicali counts two major power plants, Cerro Prieto Power Station, one of the world largest installed geothermal power plants, and Sempra Thermoelectric, a combined-cycle gas turbine (CCGT) power plant with two gas turbines, a steam turbine and a heat recovery steam generator (HRSG).

This case study is inspired by a biphase turbine installed in Cerro Prieto to maximize a geothermal well that produces power from both the steam and the water. It has increased the power production of the plant by more than 40%.

On August 20, 1997, this biphase turbine was synchronized with the Commission Federal de Electricidad electrical grid. From that time until May 23, 2000, a period of two years and nine months, the power plant was in operation. The grid was supplied by a total of 77,549 kWh.

Pending replacement of the rotor with a newly designed, higher power rotor and replacement of the bearings and seals, the power plant was subsequently put in a standby state.

In Table 3, location details for the selected location (Mexicali) have been divided into different categories, expressing respectively the climate data for the location area (Ensenada), the climate data for the selected facility (Mexicali) and the origins of the climate data.

Table 3. Location details for Mexicali.

Parameter	Unit	Location Area	Facility Location	Source of Data
Latitude	N.A.	31.9	32.6	N.A.
Longitude	N.A.	−116.6	−115.5	N.A.
Climate zone	N.A.	3B-Warm-Dry		NASA
Elevation	M	270	2	NASA-Map
Heating design temperature	°C	7.0	N.A.	NASA
Cooling design temperature	°C	30.5	N.A.	NASA
Earth temperature amplitude	°C	17.9	N.A.	NASA

After evaluating the type of plant and the location, the software displays the target to be achieved with this project, in terms of electricity to export to the grid, the total revenue and the emissions reduction, shown in Table 4.

Table 4. Target to be reached with the proposed case.

Electricity Exported to Grid (MWh)	Electricity Export Revenue (USD)	GHG Emission Reduction (tCO_2)
35,033	1,471,400	15,767

After defining climate data related to the installation we decided to build, we have to deal with the benchmark module.

Benchmark metrics may derive from the RETScreen Benchmark Database index, company benchmarking initiatives, organisational expectations, market trends or any other relevant measure to better align the facility to performance goals.

The benchmark database collects indicative minimum and maximum energy production costs (also known as the "levelized cost of electricity" or LCOE) of different types of power generation systems; these costs come from considering the system operating conditions, the installation technology, the location and the operation and maintenance (O&M) costs of typical power plants already installed worldwide. There are also main factors used to measure the minimum and maximum range of values, for example fuel cost rate (for combustion power systems) and capacity factor (for renewable energy systems).

An example of benchmark analysis is provided in Figure 3:

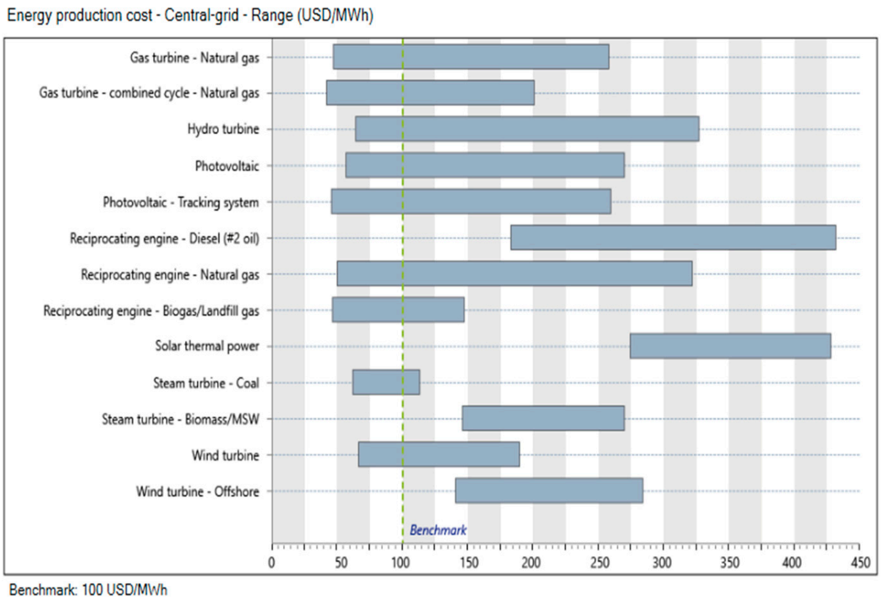

Figure 3. Benchmark setting for energy production (screenshot by authors using RETScreen).

After completion of this high-level benchmark assessment, the user can then conduct a more comprehensive viability report to better estimate the facility energy savings, elimination of greenhouse gases (GHG) pollution, cost savings and/or output capacity.

The system partition for this case study is depicted in Table 5.

Table 5. Definition of the system partition.

POWER SYSTEM – TOTAL	
Capacity	4167 kW
Electricity	35,033 MWh
GEOTHERMAL POWER	
Capacity	3167 kW
Electricity	26,273 MWh
HYDRO TURBINE	
Capacity	1000 kW
Electricity	8760 MWh

Toronto was chosen as the reference location, mainly because a lot of data are available and updated for Canadian territories (usually case studies or templates involving other countries are no more reliable especially for costs analysis). The city has both ground and satellite data to accurately map its territory characteristics. Moreover, Toronto is located in the extreme south-east of Canada, capital of the province of Ontario and most populous center of Canada with its 3,120,668 inhabitants. The city has shown its strong engagement in sustainable development, and in 2013, the City Council introduced a mandate to produce at least 5% of the electricity from renewable energy sources for all new installations. The use of solar photovoltaic, solar thermal, geothermal and biomass supports the environmental, energetic and economic objectives of the city.

Many initiatives have been set up for education and training of the community and even for helping in designing new smart buildings for commercial and personal use.

In Table 6, geographic and climate data for Toronto are provided.

Table 6. Location details for Toronto.

Parameter	Unit	Location Area	Facility Location	Source of Data
Latitude	N.A.	43.7	43.7	N.A.
Longitude	N.A.	−79.4	−79.4	N.A.
Climate zone	N.A.	6A-Cold-Humid		Ground+NASA
Elevation	M	107	91	Ground-Map
Heating design temperature	°C	−17.1	N.A.	Ground
Cooling design temperature	°C	28.8	N.A.	Ground
Earth temperature amplitude	°C	21.4	N.A.	NASA

Wind turbine and photovoltaic plants, both of 1,000 kW, are considered.

For the wind turbine system, the electricity produced will be around 3,000 MWh.

As a benchmark for energy production costs, RETScreen values are quite accurate for many installations in Canada, so it was automatically set at 100 CA$/MWh.

A benchmark analysis for the wind turbine case located in Toronto is shown in Figure 4.

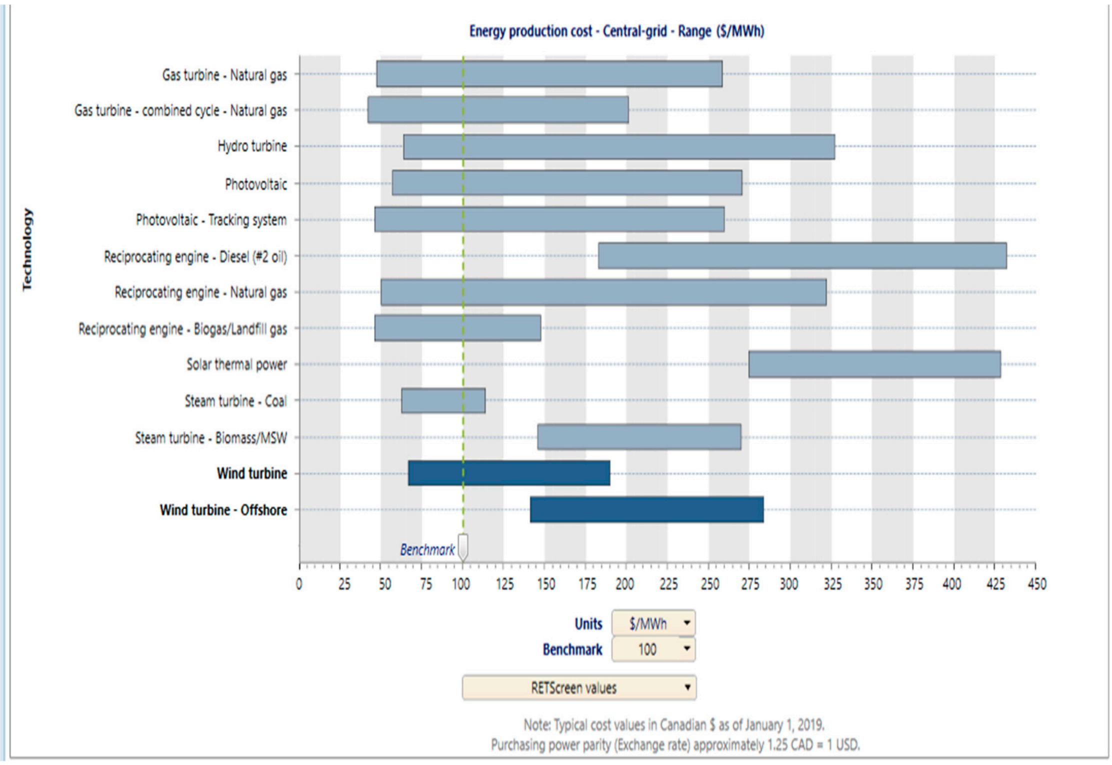

Figure 4. Benchmark setting for energy production (screenshot by author using RETScreen).

Below, in Table 7, the initial target values of the proposed case are presented.

Table 7. Target to be reached with the proposed case.

Electricity Exported to Grid (MWh)	Electricity Export Revenue (USD)	GHG Emission Reduction (tCO_2)
3197	319,740	302

The model of the wind turbine used for this project was manufactured by a Danish company, VESTAS. Many VESTAS turbines have been exported to Canada, as a symbol of European engagement in renewable energies.

The plant, using this wind turbine model, is able to produce 3197 MWh with initial costs of 2,309,703 CA$ (CA$/kW value is scaled with respect to the plant capacity and data are available in the software for defined range).

The electricity export rate value has been changing across the years. To give an example, many countries started with incentives for renewable energies investors, by rewarding them with a feed-in tariff or feed-in premium. In this way, the electricity was paid more for than the real cost per unit of the electricity exported to the central grid. Nowadays, this scenario is no longer relevant because bonuses for renewable energy plants have been largely reduced, so the actual price paid per MWh to sustainable power plants is similar to all other energy source plants.

Finally, the choice to put the electricity export rate at the same value as the benchmark energy production cost is good enough for an approximate evaluation.

Details about tailoring the wind turbine system are presented in Figure 5.

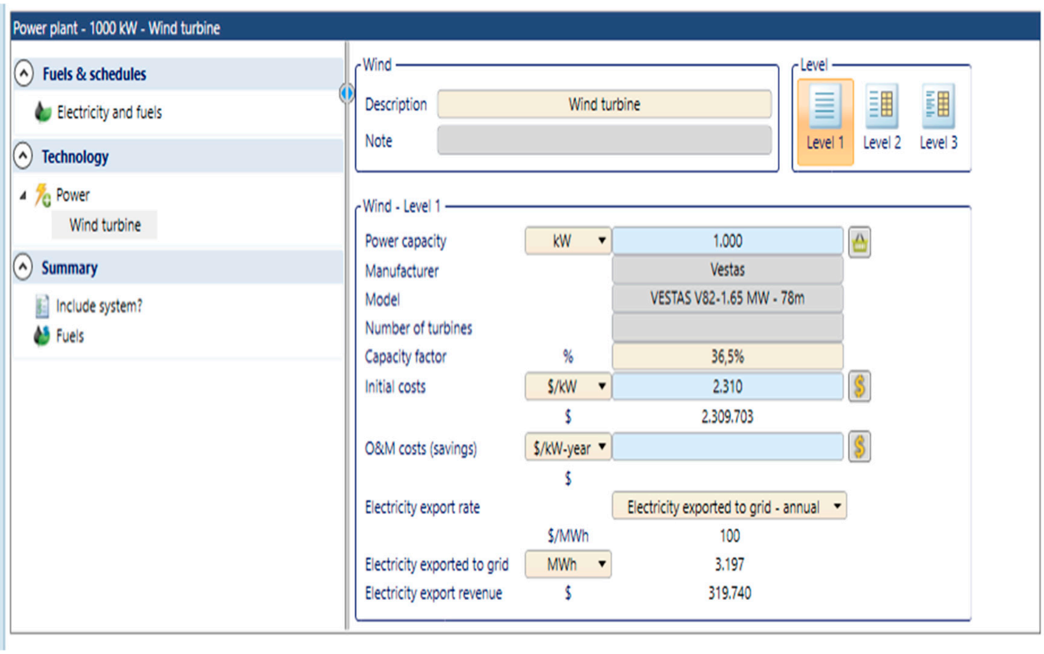

Figure 5. Tailoring the wind turbine system (screenshot by author using RETScreen).

For the photovoltaic system, the electricity produced will be around 1200 MWh and the benchmark value will be the same with respect to the previous project.

The initial target values of the proposed case are presented in Table 8.

Table 8. Target to be reached with the proposed case.

Electricity Exported to Grid (MWh)	Electricity Export Revenue (USD)	GHG Emission Reduction (tCO_2)
1218	121,764	120

In Figure 6, a benchmark analysis for the photovoltaic case located in Toronto is shown.

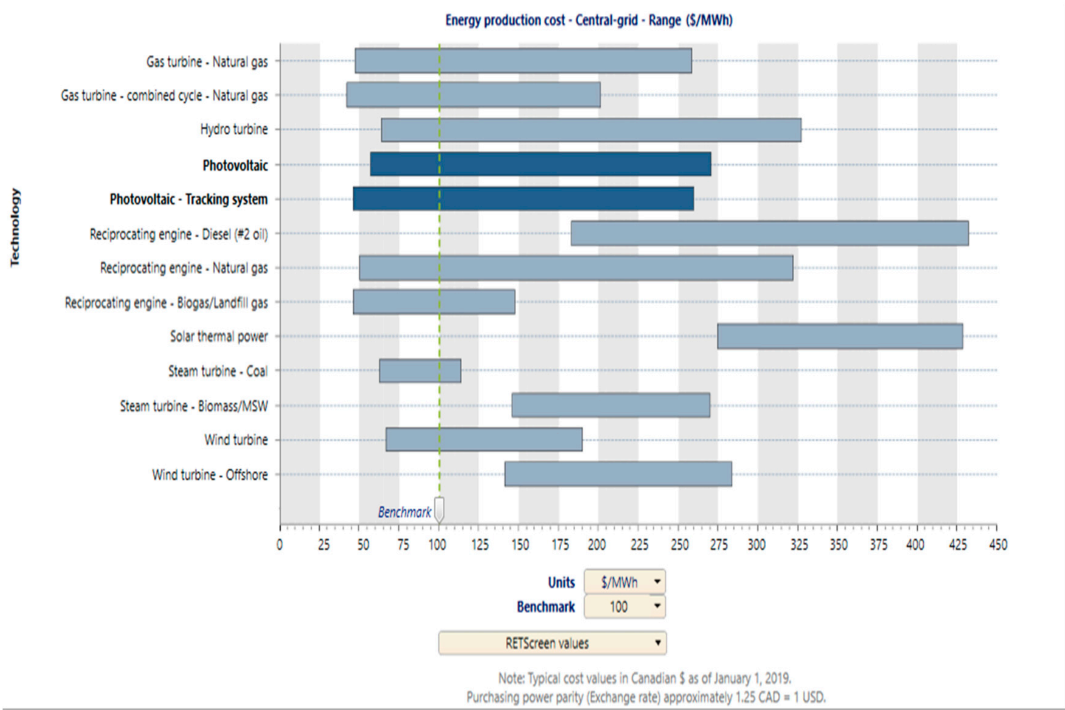

Figure 6. Benchmark setting for energy production (screenshot by author using RETScreen).

The solar cells for this photovoltaic installation are made of mono-crystalline silicon. This system performs with a higher efficiency in terms of energy production and space occupied; moreover, this type of solar cell guarantees the longest lifetime for the whole project. On the other hand, this technology is more expensive than polycrystalline solar panels, and it could be damaged in the case of dirt, shadow or snow or sometimes it might not work properly in very hot locations. In addition, during the production process, a large part of the material becomes waste, so depending on the dimension of the project it could become unsustainable even if it is a renewable energy project.

Details about tailoring the photovoltaic system are presented in Figure 7.

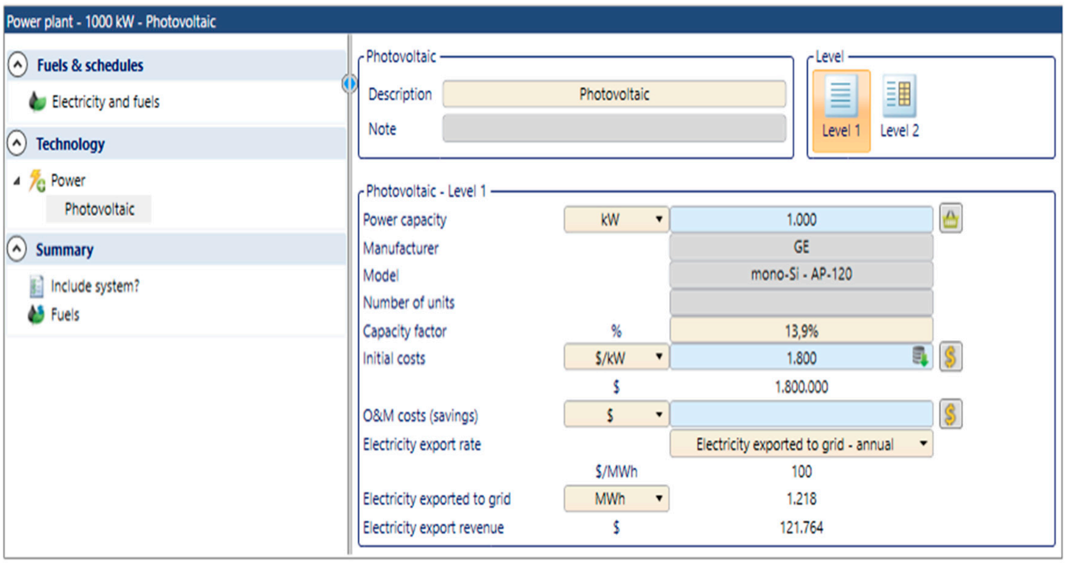

Figure 7. Tailoring the photovoltaic system (screenshot by author using RETScreen).

3. Case Study Results

3.1. Case Study 1

Results are derived from a model comparison between the baseline scenario with the proposed alternative showing the difference in GHG emissions ("Gross annual GHG emission reduction"). Transmission and distribution (T&D) losses are automatically evaluated thanks to the largely populated database embedded in the software. An equivalence is shown in Figure 8 to better understand how much emission is being reduced (almost like 3,000 cars not used).

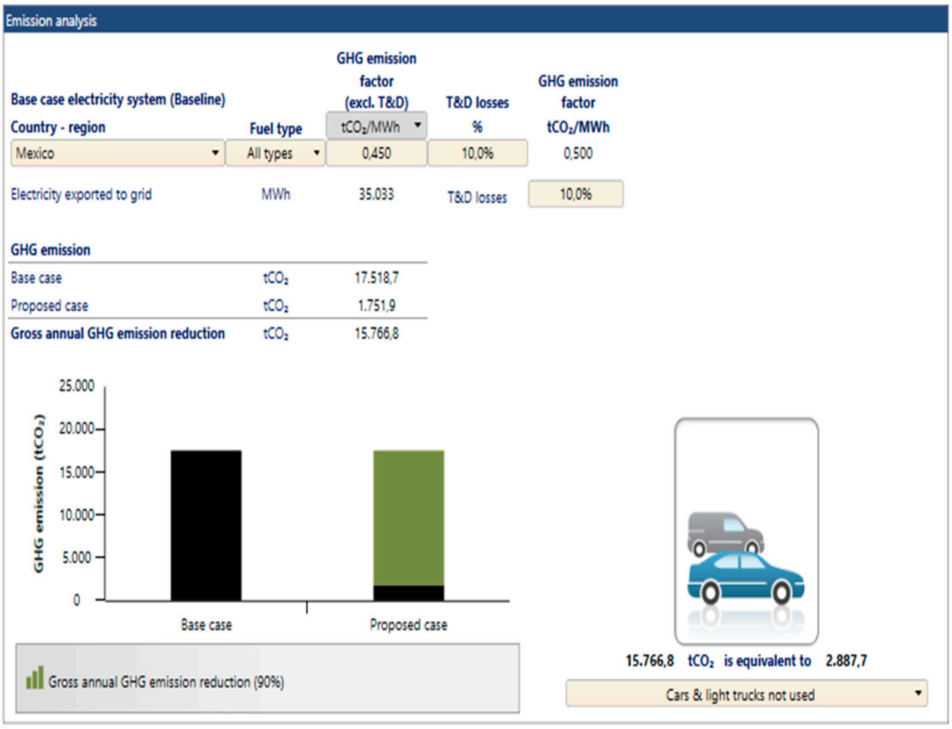

Figure 8. Emission analysis chart (screenshot by author using RETScreen).

A financial analysis is provided as a final step of this pre-feasibility study. Some parameters have been defined such as inflation rate, project lifetime, debt ratio, debt interest rate and debt duration. User-defined costs usually include O&M for the project lifetime or manpower for the installation. Incentives could be inserted, if available for the specific project.

The software gives four outcomes for evaluating financial viability:

- the pre-tax internal rate of return (IRR) on equity, in percentage, represents the true interest yield provided by the project equity through its lifetime (before applying taxes). It is calculated using the pre-tax yearly cash flows and the project duration. To simplify its meaning, it can be linked to the return on equity (ROE) or return on investment (ROI). IRR on equity of the project is used by the organisation as a comparison to the company IRR and to decide if the investment is convenient or not. For a project which requires cash injections during its lifetime, with amounts that are similar to the project annual earnings, the IRR estimate may become inaccurate.
- the pre-tax internal rate of return (IRR) on assets (%) is described as the true interest yield provided by the project assets over its lifetime (pre-tax). It can be reconnected to the return on assets (ROA) meaning.

- the simple payback (in years) formula considers the estimated initial costs, the total annual costs (excluding debt payments) and the total annual benefits and income. This indicator represents how long it takes for a certain plant to cover its initial cost. The simple payback method has the meaning of evaluating the desirability of an investment: if the time to cover the initial cost is short enough, the investment could be considered convenient. This index could be adopted to compare different projects' profitability. This indicator is of secondary importance to evaluate the risk of an investment, especially because it disregards important aspects, such as the impact of inflation during the project lifetime, but it could be useful for small companies which should prefer short-term payback projects, even though they have lower IRR with respect to other ones.
- the equity payback, which represents the duration it takes for the plant owner to cover its own initial investment (equity) out of the project cash flows generated. Equity payback takes into account the cash flow of the company from its start as well as the equity (debt level) of the business, which allows it a better time measure of the value of the project than the previous indicator (simple payback). The model uses the year number and the accumulated post-tax cash flows to measure this value.

As a result, financial feasibility is provided in Figure 9, together with the cumulative cash flow graph. Less than one year is needed to reach the equity payback.

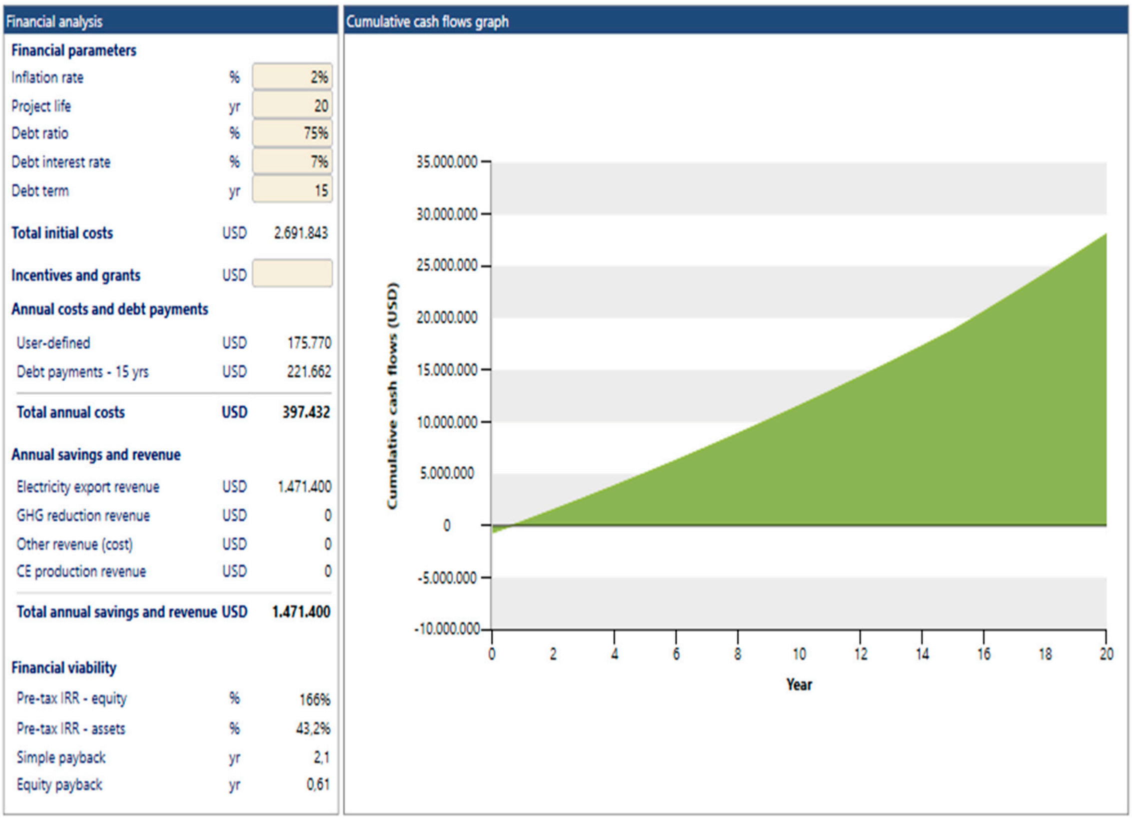

Figure 9. Financial analysis chart (screenshot by author using RETScreen).

For risk analysis, the Monte Carlo method is applied. The possible combinations of input variables range from 500 to 5,000 values of pre and after-tax IRR equity, pre and after-tax IRR assets, equity payback, net present value (NPV) or energy production cost. The risk analysis allows the user to determine whether or not the volatility of the financial metric is appropriate by looking at the range of possible results. An excessive variance would imply the need to make further effort to reduce the volatility associated with the input variables that have been identified as having the greatest impact on the financial metric.

The applicant should enter an appropriate level of risk for the financial metric under consideration. The rate of risk feedback is used to assess the confidence interval (defined by the maximum and minimum limits) within which the financial predictor is expected to fall. The level of risk reflects the possibility that the financial predictor may slip outside this confidence interval.

Limits of the confidence interval are generally determined on the basis of the median value and the risk rate and are shown as "Minimum within the confidence level" and "Maximum within the confidence level". It is recommended that the individual reach a maximum risk level of 5%–10%, which are common values for the generic risk analysis.

The histogram lays out the array of possible values for the financial metric arising from the Monte Carlo simulation. The height of each bar reflects the rate (percent) of values that drop within the scope specified by the width of each bar. The value corresponding to the center of each range is plotted on the X axis.

Looking at the distribution of the financial metric, the consumer is able to quickly determine the volatility of the variable. In some instances, there is a lack of data to accurately map the graph. In the case of equity payback reached instantaneously, the outcome is the "n/a" (not applicable) symbol, and therefore this analysis will be missing.

3.2. Case Study 2

For this case study, we will analyze two sets of results depending on the system adopted (wind turbine or photovoltaics).

For the wind turbine case, the gross annual GHG emission reduction is 93%, comparable to 55 cars (traditionally fueled) no longer used.

Financial analysis shows, in Figure 10, that equity payback for the wind turbine power plant is reached after 3.5 years of the 25 years of the project's lifetime, but it should be taken into consideration that this analysis does not involve any incentive due to the rapid evolution of regulations, that it is progressively converting the initiatives for funding clean energy generation with initiatives for help in designing sustainable systems.

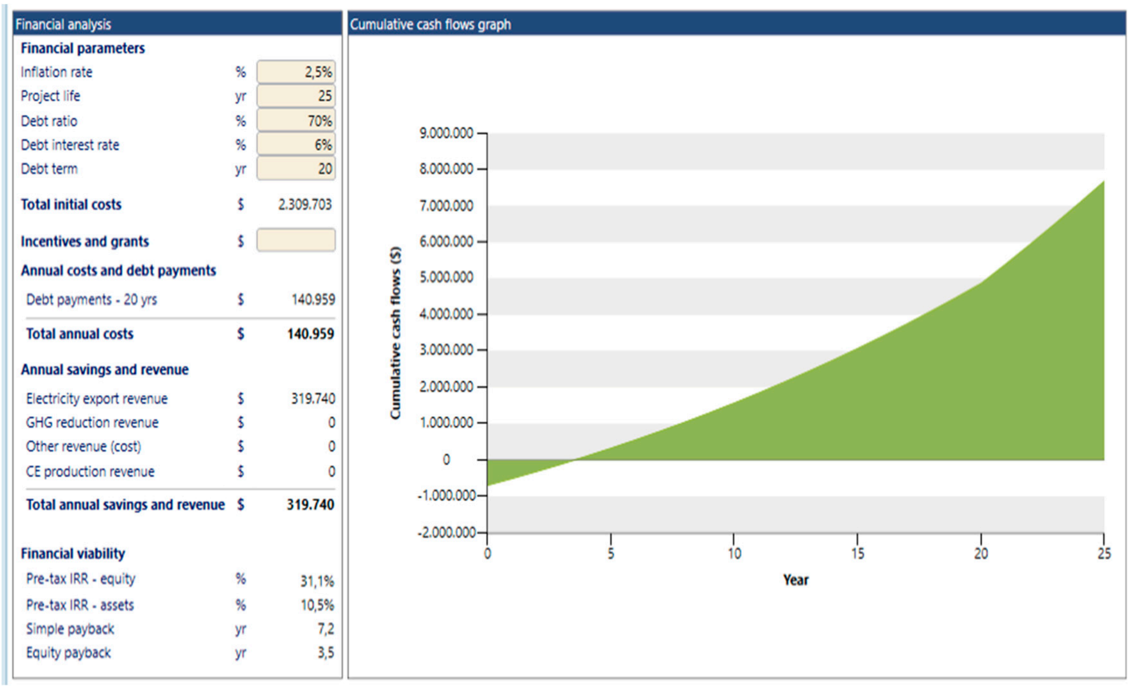

Figure 10. Financial analysis chart (screenshot by author using RETScreen).

For photovoltaic installation, the gross annual GHG emission reduction is 96%, comparable to 22 cars (traditionally fueled) no longer used. Even though the percentage is greater than the wind turbine case, we should consider that the electricity produced with photovoltaics is around one third of that produced by the other system, so effectively the CO_2 reduction is minor.

Financial analysis shows, in Figure 11, that equity payback for the photovoltaic case is reached after 16.7 years of the 25 years of project's lifetime. For incentives and grants, the same consideration made for wind turbine system has been evaluated.

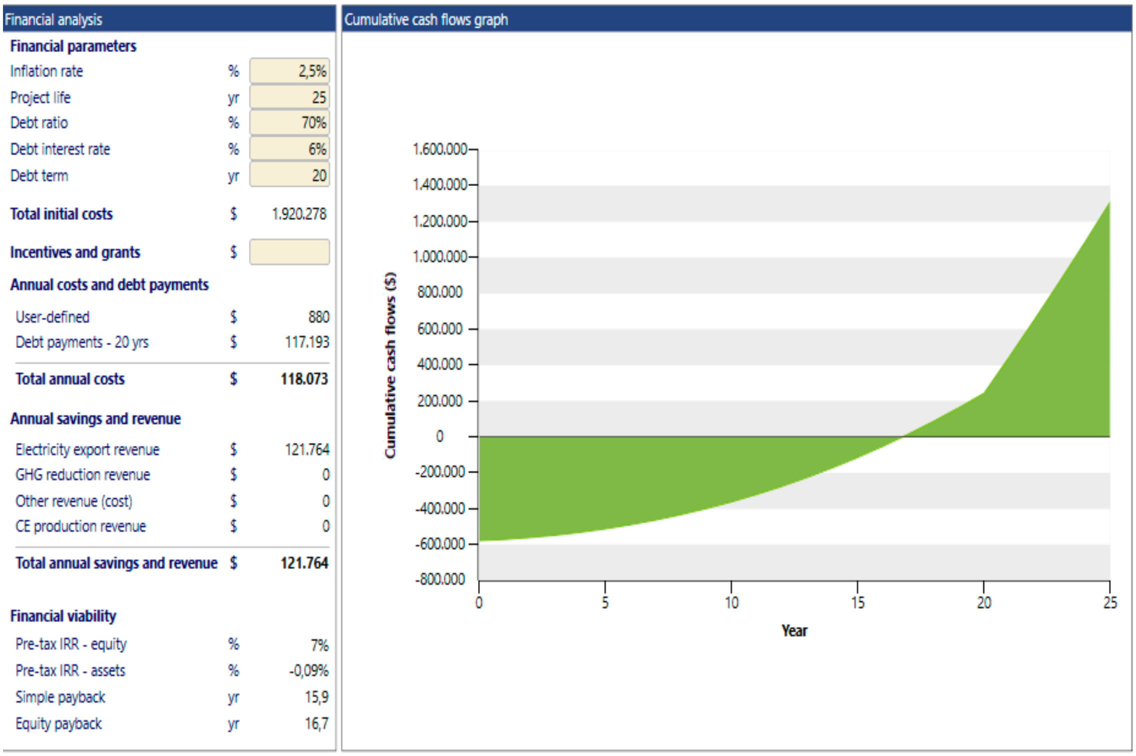

Figure 11. Financial analysis chart (screenshot by author using RETScreen).

4. Discussion

The first case study was only aimed at showing how RETScreen is powerful, even mixing different renewable technologies in one single power plant, optimizing the project on the base of the location characteristics. The second case study provided more evidence, reported in Table 9. The different outputs of the two installations (i.e., wind turbine vs. photovoltaic) are provided.

Table 9. Wind turbine vs photovoltaic in RETScreen.

	Wind Turbine	Photovoltaic
Location	TORONTO	
Capacity	1000 kW	
Project life	25 yr	
Electricity export rate	100 CA$/MWh	
Electricity	3197 MWh	1218 MWh
Gross annual GHG emission reduction	302 tCO_2	120 tCO_2
Total initial costs	2,309,703 CA$	1,920,278 CA$
Pre-tax IRR-equity	31.1%	7%
Equity payback period	3.5 yr	16.7 yr

It is possible to notice that, starting from a common baseline (same location, same power plant capacity, same project life and same evaluation for electricity export rate), that the electricity produced by the two power plants is sensibly different; in fact, the wind turbine system is much more efficient than the photovoltaics. Due to its higher efficiency in producing electricity, the correspondent gross annual emission reduction of greenhouse gases is bigger for the wind turbine with respect to the photovoltaic case. Findings emerged from our investigation can represent useful insights for policy makers. Specifically, besides looking at policy of direct regulations, other policy instruments that can indirectly support deployment of renewable energy resources in the long term should be adequately taken into account. These indirect strategies can be in the form of environmental taxes or of emission permits for energy produced by non-renewable sources, as well as the removal of subsidies given to fossil fuel generation [34]. Moreover, even though the total initial cost for the photovoltaic power plant is lower than for the wind turbine installation, it can be inferred from the financial indicators that the investment is much more convenient for the wind turbine project, which is able to cover its initial costs in a time 14% of the total lifetime; on the other side, with photovoltaics installation you will cover the costs after 70% of the project lifetime. Another aspect for policy makers to consider is looking at the financial issues that might prevent investment decisions. In this perspective, enhancing the green finance—i.e., the financing of investments that provide environmental benefits in the broader context of environmentally sustainable development [35]—may significantly contribute to guaranteeing capital flow in renewable energy sectors [36] so as to enhance the sustainability of the overall financial system [37] as well as to improve corporate planning strategies [38].

Overall, the aim of this study is not to evaluate which renewable technology is more affordable or efficient (it is very easy to find wind turbine for high-capacity systems and, on the contrary, projecting photovoltaic installation is usually aimed at small-capacity systems, such as houses), but to understand how the RETScreen software could be successfully adopted in decision-making processes in an early stage (e.g., pre-feasibility analysis), to effectively exclude inconvenient choices under determined constraints. From this perspective, a technique for optimizing a renewable energy network is developed using RETScreen software tool. It is built to maximize the size of an integrated hybrid energy system in buildings. Case studies for a single and an integrated renewable energy program may research the efficiency of the methods [39]. Another example of using RETScreen is to provide a techno-economic assessment of a certain type of renewable energy installation only after evaluating the environmental consequences of the selected energy systems through comprehensive life cycle assessment (LCA) with a more accurate tool [40]. To provide evidence for how it is valuable to move from traditional energy resources to renewable ones, another case study using RETScreen described how urban photovoltaic installations could improve sustainability in Saudi Arabia [41].

The significant number of analyses carried out with RETScreen is all thanks to the worldwide satellite missions providing data for Earth monitoring, even mapping areas where no ground-based information is available, due to territorial constraints (islands, mountains, etc.).

5. Conclusions

At the Conference of the Parties in December 2015 (Paris Agreement), 195 countries agreed to take urgent action to combat climate change by limiting global warming to well below 2 °C and pursuing efforts to limit it to 1.5 °C. The space industry, and related applications and tools, gives rise to a significant and innovative approach to clean energy generation; it is enough to think that starting from satellite missions, providing more and more accurate weather information, we are able to map every area of the globe, overcoming data limitation due to the lack of meteorological ground stations.

The novelty of this work comes from the emphasis given to one of the most innovative fields of study (i.e., space research) for finding solutions for our environment by trying to exploit already existing technologies, such as EO satellites or deep space exploration applications (them being mostly circular systems). Applying RETScreen software could be useful in the pre-feasibility phase to discriminate the type of installation that is not efficient for the selected location or not convenient in terms of IRR on equity. Results of our analysis indicate that, looking at the geographical context of our case studies, the wind turbine system is much more efficient than the photovoltaics in terms of financial indicators as well as the annual emission reduction of greenhouse gases.

There is a need to expand research based upon space exploration applications to develop capacity building and create less uncertainty for financing long-term projects to accelerate the circular economy framework. Governments and industry must increase R&D efforts to reduce costs and ensure space-based technologies' readiness for rapid deployment, while also supporting longer-term technology innovations.

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Abbreviations

CCGT	combined-cycle gas turbine
CE	circular economy
DST	decision support tool
EO	earth observation
ESA	European Space Agency
EU	European Union
GHG	greenhouse gases
HRSG	heat recovery steam generator
IRR	internal rate of return
LCOE	levelized cost of electricity
NASA	National Aeronautics and Space Administration
NPV	net present value
O&M	operation and maintenance
RETs	renewable-energy and energy-efficient technologies
ROA	return on assets
ROE	return on equity
ROI	return on investments
SDGs	sustainable development goals
T&D	transmission and distribution

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