Renewable energy technology feasibility study for a new hotel building in Amsterdam

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This article discusses the economic and environmental feasibility of applying renewable energy technology (RET) to a new hotel building in Amsterdam using the simulation software HOMER. The study shows that applying PV including a surface up to 750m² can be both economical and environmentally feasible and that achieving a Renewable Fraction (RF) of above 75% at the hotel building in Amsterdam goes along with an increasing life cycle cost (LCC). Besides PV, other renewable energy technologies as micro wind-turbine and CHP are investigated.

Keywords: hotel; renewable energy technology; wind; photo voltaic; biomass; life cycle cost; renewable fraction; optimization software, HOMER, combined heat and power.

Background

The energy consumed by hotel buildings is relatively large compared to the consumption of other commercial buildings. A typical hotel's (<100 beds) annual energy use ranges from 250 to 350 kWh/m² and for large hotels (>100 beds) it ranges from 450 to 700 kWh/m², versus a typical commercial building's energy use between 30 and 152 kWh/m² [1,2]. Another characteristic of hotel buildings is their unique energy profile. Specific characteristics of the hotel sector are 24-h operation, high degree of comfort provision, low tolerance for failure and the occurrence of two daily load peaks [3].

Generation of energy from renewable sources to cover a buildings energy demand contributes to the reduction of the environmental impact of buildings. There is a shortage of literature about hotel building case studies in Europe, while the specific hotel energy characteristics necessitate a separate assessment of RET viability studies in this sector.

Case study

The current study is a cooperation between the company Croonwolter&dros, specialist in building services, and the Technical University of Eindhoven. The design of the hotel building is awarded with a platinum LEED certificate, the highest possible award regarding sustainability. This certification is mainly merit to sustainable measures as a grey water system, green roof area, CHP running on BIO-oil and the usage of sustainable and local materials. The thermal energy demand is decreased by an adaptable façade which responds to the outdoor weather conditions by increasing the overall U-value and by the regulation of the sun admittance.

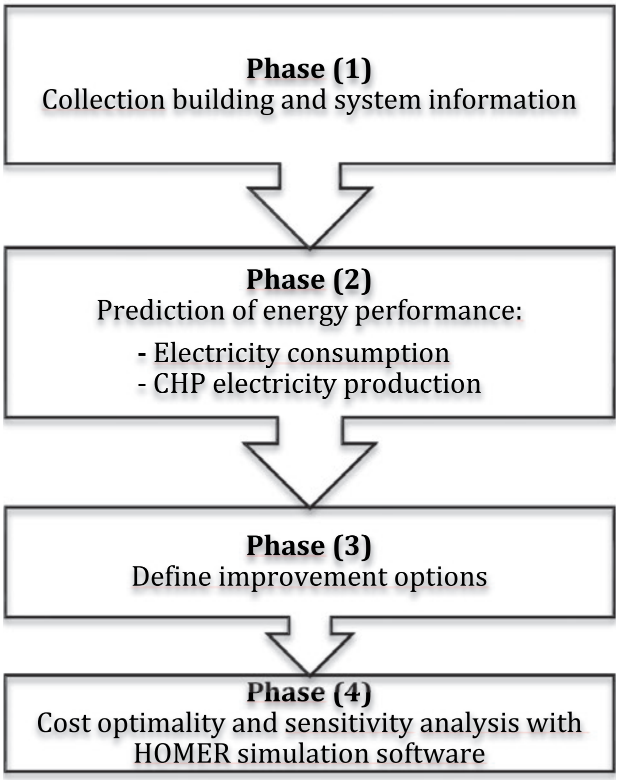

Figure 1. Applied methodology expressed in 4 research phases.

Renewable technology generation as PV and wind turbines is currently not included in the hotel's energy supply system.

The research aim is to investigate the economic and environmental feasibility of applying more renewable energy technology in the current design of the hotel.

Methodology

HOMER – Modeling software for energy supply systems was used to examine the research aims. HOMER, produced by the National Renewable Energy Laboratory, US [4] was chosen as the primary application for this study due to its extensive use in previous RET case studies [5,6] and RET validation tests [7,8]. HOMER is an optimization software package which simulates electrical energy supply system configurations, including energy from renewable sources, and scales them on the basis of LCC and technical feasibility. The proposed methodology in this research is shown in **Figure 1**, consisting of 4 research phases.

Energy system (Phase 1)

A simplified overview of the hotel's energy supply system is shown in **Figure 2**. The domestic hot water (DHW) demand is mainly supplied by a heating tracked combined heat and power (CHP) generator running on BIO-oil which makes it a renewable energy source. An electricity driven, ground source heat pump is the main source for space heating and cooling. The hotel is connected to the district heating to serve the DHW demand and space heating as a back-up for the CHP or heat pump. As a secondary output, the CHP produces electricity which directly serves the electricity demand of the hotel. The remaining electricity needed by the hotel, is in the current energy supply system provided

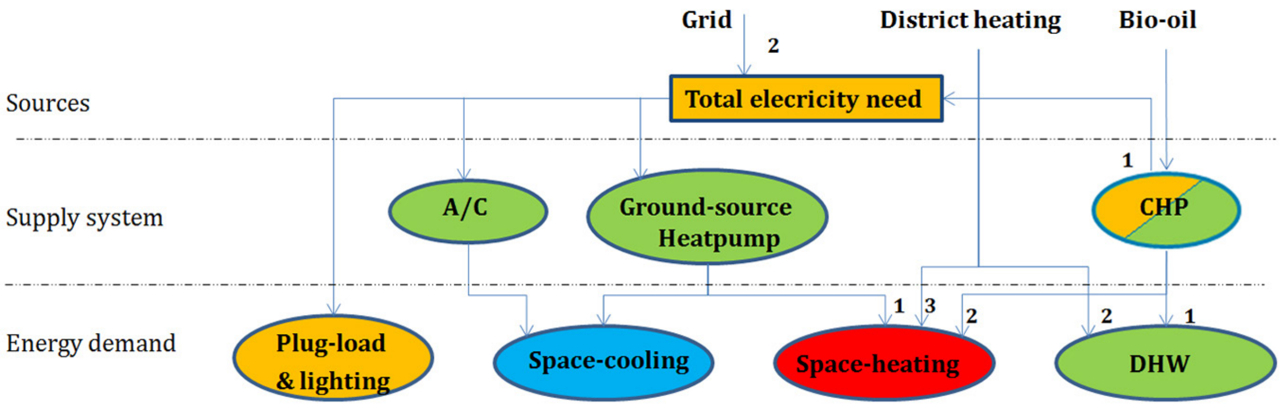

Figure 2. Simplified overview of hotel's energy supply system where the priority in consumption is addressed by numbers; the DHW demand is supplied by the CHP and is in case of excessive demand also supplied by district heating.

by the grid. In this research, a renewable solution for the resulting grid demand is investigated. Hence these main consumers, including the electricity production of the CHP; strongly influence the resulting electricity need of the grid, a prediction of all four energy demand sides of the hotel building had to be made.

Energy performance prediction (Phase 2)

A prediction of the space cooling and space heating is performed with the building performance simulation program IES VE, which produces the hourly heating and cooling demand over a year. The prediction of the plug load, lighting and the DHW demand is based on statistics of reference hotel buildings [9], taking into account the expected occupancy of hotels in Amsterdam [10]. An overview of the expected occupancy profile is shown in **Table 1**.

The hourly electricity production in a heating tracked CHP depends on the hourly demand for DHW. The ratio electricity production-heat production (r) is used to calculated the hourly electricity production of the CHP. (r) is determined as shown in equation 1:

$$r = \frac{\eta_h}{\eta_e} \qquad \text{(eq. 1)}$$

Where:
r = heating to power ratio (0.65);
η_e = annual electrical efficiency CHP;
η_h = annual heat efficiency CHP.

The impact of part load on the CHP and ground source heat pump is not taken into account. The heat pump and CHP efficiencies therefore are overestimated, leading to a decreased resulting electricity need from the grid. The results of the RET feasibility study could in reality be more optimistic, as a larger percentage of renewable electricity produced on own site could be used for own consumption, rather than be sold back to the grid or stored in batteries.

Table 1. Expected occupancy profile used for the energy performance prediction [10].

Timeframe	Occupancy
January-April	60%
May-August	100%
September-December	80%

Results energy performance prediction

The results of the annual expected electricity flows in the hotel are shown in **Table 2**. **Figure 3** shows a typical daily pattern of the electricity flows in the hotel, where the typical characteristics as 24h operation and two daily peaks in the morning and evening [3] are visible. More detailed information about the prediction and the results can be derived from the full version of the master-thesis [11].

Table 2. Predicted annual electricity flows in the hotel.

Timeframe	Occupancy
Total electricity consumption	930 [MWh/yr]
CHP electricity production	538 [MWh/yr]
Grid electricity consumption	392 [MWh/yr]

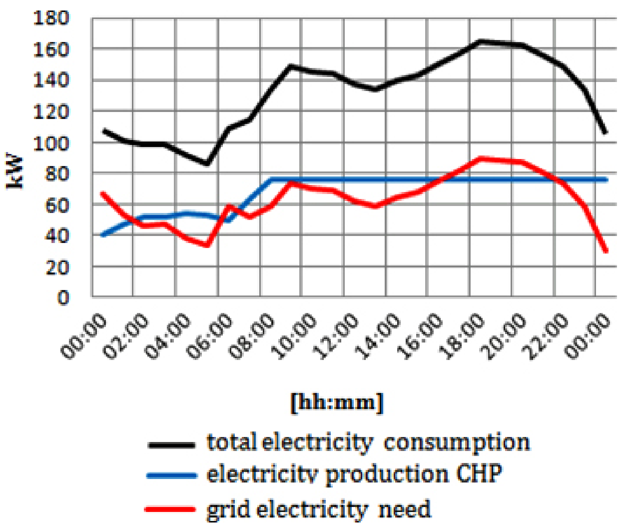

Figure 3. Expected typical daily electricity flow pattern.

Improvement options (Phase 3)

In order to decrease the simulation time and extensive data output of HOMER, a pre-selection of renewable technology for building application is made.

Considered on site renewable energy technology (RET)

Wind-turbines

The hotel is located in an urban area; hence only rooftop application wind turbines are left as a realistic option. In this research, a 5 kW rooftop wind-turbine is evaluated.

PV panels

The most common RET on site or nearby is PV. The free space at the roof of the hotel forms a potential surface of 240 m² for PV panels. As there are more options for PV panels considered in this research, the roof top PV panels will be addressed as 'roof PV'. Another potential surface for installing PV panels is the south-façade of the hotel, where the hotel from the 7th floor will be free from shading by neighbor buildings. A potential vertical PV area 530m² is taken into consideration, further addressed as *'façade PV'*. The third possibility for installing PV is found in placing PV panels at one of the neighbor buildings, addressed as 'nearby PV', in return for a monthly rent price. This increases the potential surface area for PV panels significantly.

Storage

HOMER automatically determines the most feasible storage capacity for the surplus of electricity production by renewables, or to sell the electricity back to the grid. Batteries are considered as apossible storage medium, and is automatically sized by HOMER.

HOMER input

The expected real discount rate considered in the HOMER simulations is 3.43% and is calculated by equation 2:

$$i = \frac{i' - f}{1 + f} \qquad \text{(eq.2)} \quad [4]$$

Where:
i =real discount rate;
i' = nominal discount rate (=5.5%);
f = inflation rate (=2%)[12,13].

An overview of all RET options, including sizes, evaluated in this research are shown in **Table 3**. HOMER evaluates all possible combinations of configurations of the given options.

Weather conditions

Annual weather conditions at the location of Amsterdam as wind speed and irradiation are obtained from the NASA Surface Meteorology and Solar Energy website [14].

Results and discussion

HOMER scales the RET improvement options, as is shown in **Table 3**, on the basis of Renewable Fraction (RF, percentage of consumed electricity coming from on-site RET) and Life Cycle Cost (LCC). Scatterplots show the relation between RF and dLCC (difference in Life Cycle Cost) for every possible configuration. The dLCC of the configuration without any RET improvement options (base-case) is considered to be € 0,00.

Table 3. RET improvement options.

RET options	Options on size and unit numbers	Price
Wind-turbine	0 or 1 wind-turbines	28.500€ incl. installation
Roof PV	0, 120, 240 m²	311 €/m²
Façade PV	0, 265, 530 m²	334 €/m²
Nearby PV	0, 500, 1000, 2000 m²	236 €/m²
Battery	50.000 kWh	1.000 €/unit numberb
Converter	Automatically sized by HOMER	900 €/kWb
Grid		€0,112a

[a] Considered is €100/MWh according to the commodity prices, adding a price of €11,80 of taxes/MWh and energy escalation rate of 2% [16,17].

[b] Unit price in HOMER.

Figure 4 shows the results of all combinations of the three possible variations of PV-packages, when **no roof rental cost** is considered. Groups of same sized nearby PV surface area are circled, and their size is addressed above. The groups of same sized façade PV packages can be identified by their color: black refers to 0 m² façade PV, orange refers to 265 m² façade PV and blue refers to 530 m² façade PV. Groups of same sized roof PV can be identified by the shape of the figure: a circle refers to 0 m² roof PV, a triangle refers to 120 m² roof PV and a cross refers to 240 m² roof PV. A low dLCC and a high RF is most preferable and the package with the lowest dLCC is the cost optimal. The façade PV (comparing colors) leads to an increase of both dLCC and RF. From economical point of view, it can be concluded that façade PV is not unfeasible. The roof PV (comparing shape) results, especially in the lower PV surface areas, in a decreased dLCC and an increased RF, which makes these packages both economically and environmentally feasible. The nearby PV packages cannot be analysed due to the absence of roof rental cost.

Figure 5 shows all possible RET improvement options, including the possibility of a rooftop wind-turbine. Black dots refer to a configuration without a wind-turbine and blue dots to configurations with wind-turbine. In the situation of the base-case, adding a wind-turbine to the to the current energy supply system leads to an expected contribution of € 10.435 in LCC and 2.7% in renewable fraction. The contribution of the wind turbine to the LCC has in every PV package

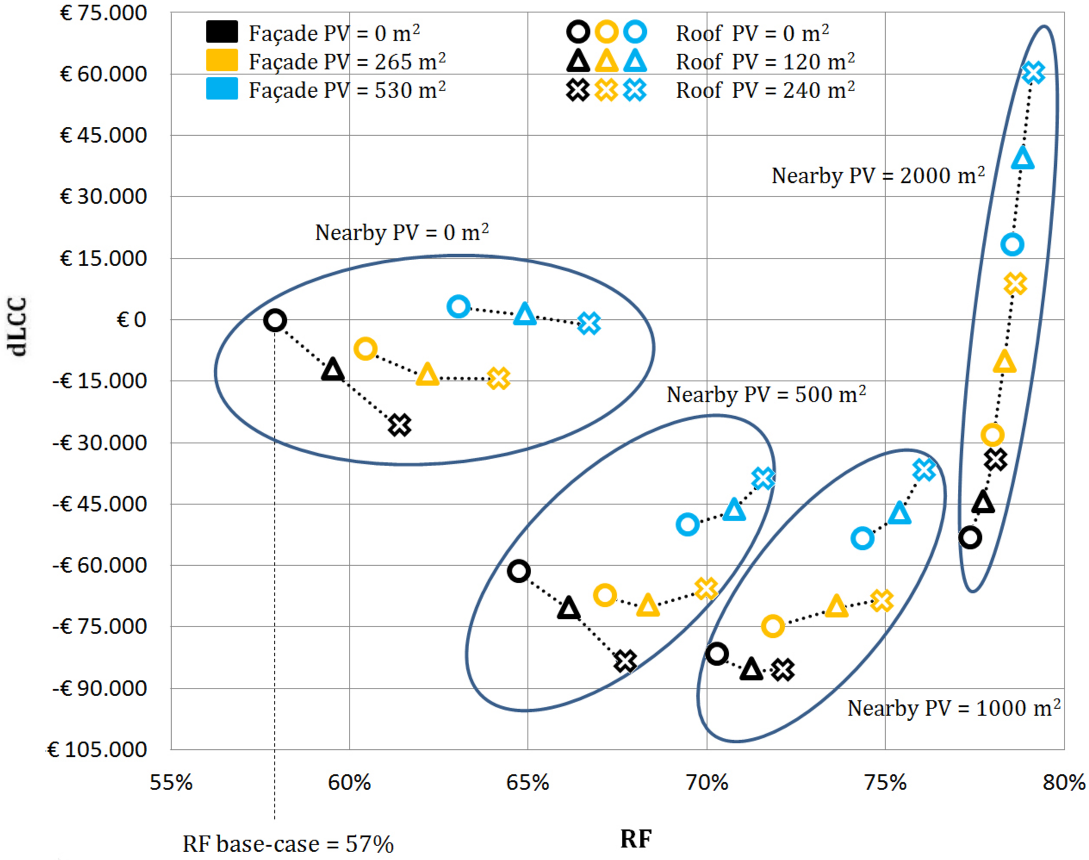

Figure 4. Scatter plot for all PV-packages for without roof rental cost.

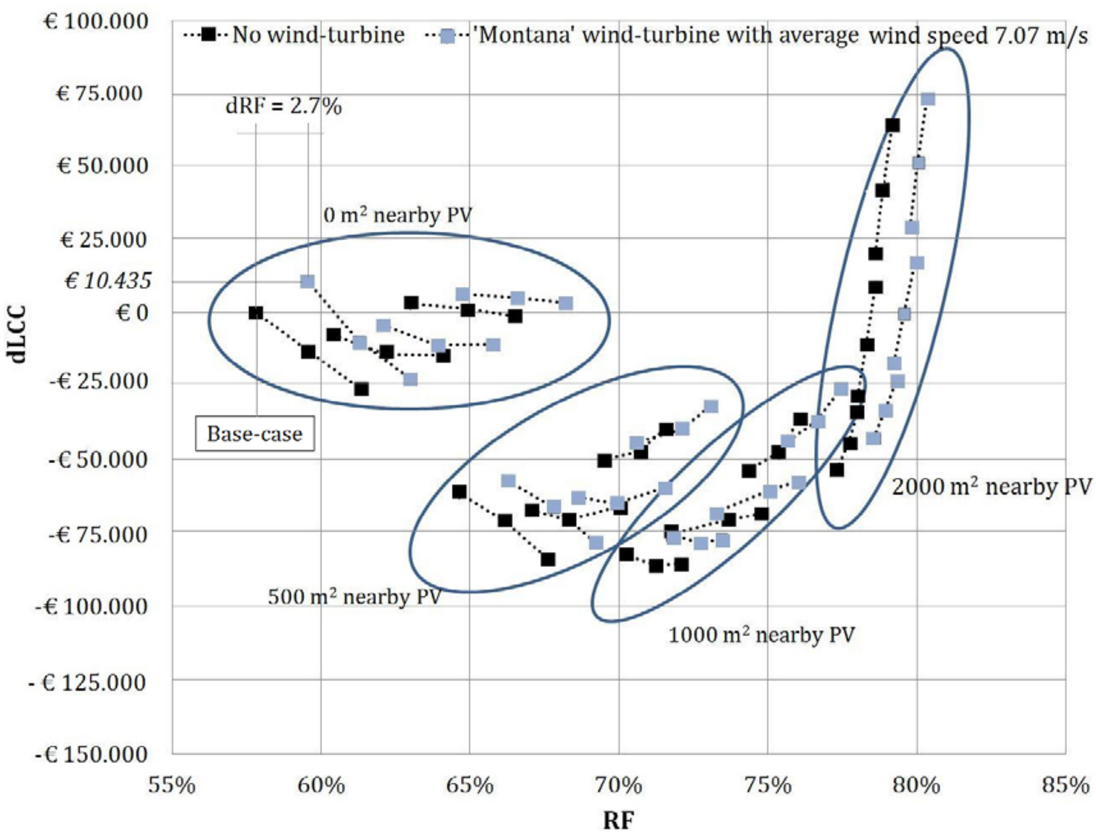

Figure 5. Scatter plot of all PV packages with and without wind turbine and without roof rental cost.

approximately the same magnitude, which makes it under the current circumstances economically unfeasible to add a rooftop wind-turbine at the hotel and just small increase of RF in return.

Figure 6 includes all PV packages as shown in **Figure 4**, but includes roof rental cost of 5 €/m² in the nearby PV option, the PV installed on a neighbour building. The groups of packages with nearby PV increased in dLCC and significantly changed the expected economical performance. Achieving a RF of above 75% with PV panels appears to be difficult and goes along with a rapid growing dLCC. Out of **Figure 6**, 5 optimal packages are selected:

1: Cost optimal in case of no nearby PV;
2: Cost optimal in case of nearby PV only;
3: Overall cost optimal solution; Cost optimal solution in case all considered renewable energy packages are taken into account.
4: Preferable solution; higher RF (+12.8%);
5: Preferable solution; higher RF (+14.9%);

The optimal packages 4 and 5 expect smaller profit compared to the cost optimal solution, however show a larger increase of RF, which could be important to meet potentially increasing LEED requirements in the future.

Conclusions

The study shows that applying the current design of the energy system of the hotel in Amsterdam can be further improved by applying PV on the façade, roof and on the roof of a neighbor building. The cost optimality analysis results in five optimal packages and are shown in **Figure 6**. Optimal package 3 with 500 m² nearby PV and 240 m² roof PV is the cost optimal solution, leading to a difference in LCC of -€ 41.452 and contributes for 10.5% to the RF.

Installing PV panels on the rooftop of the hotel appears to be profitable. However, the small available surface area leads to a maximum increase of RF of 4,5%. Renting a roof top of a neighbor building could be used for a more significant increase of the RF and is in case roof rental costs of 5 €/m² even profitable until ±1000 m². Achieving a RF of above 75% requires a large PV area, and goes along with an increasing LCC.

The installation of a rooftop wind-turbine is not profitable and only leads to a small increase in RF, as shown in **Figure 5.** ■

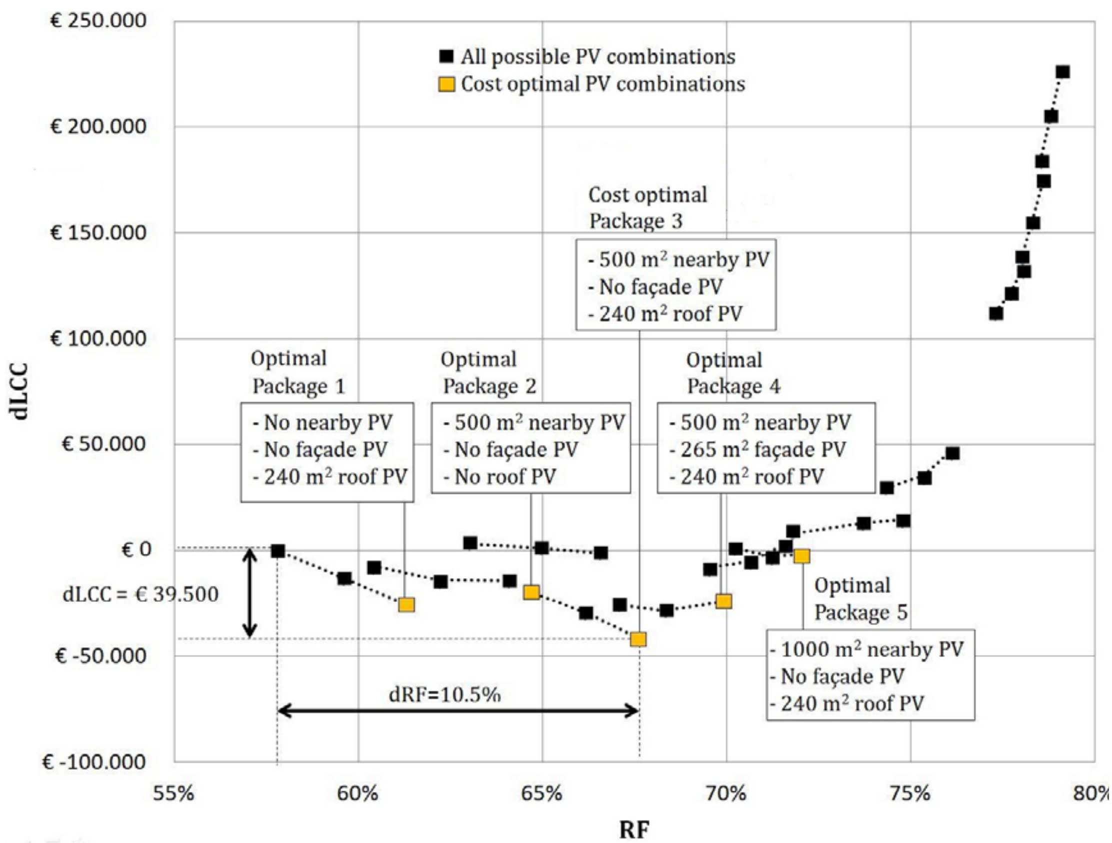

Figure 6. Scatter plot of all PV packages including 5 €/m² roof rental cost for nearby PV and the 5 optimal PV packages.

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