POBOLJŠANJE MAPE SOLARNOG POTENCIJALA: ODBACIVANJE MERENJA NETO POTROŠNJE ENERGIJE, A PRIHVATANJE KRIVE POTRAŽNJE I LOKALNOG VREMENA

IMPROVING SOLAR POTENTIAL MAP: DITCHING NET-METERING, EMBRACING DEMAND CURVE AND LOCAL WEATHER

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Ovim istraživanjem se proširuje pristup “odozdo prema gore” kako bi se odredili troškovi ulaganja za autonomne Solar Plus sisteme. Postojeće solarne mape obično koriste šemu merenja neto potrošene energije i posmatraju električnu mrežu kao jednu džinovsku bateriju. Međutim, sa povećanom proizvodnjom solarnih proizvoda, to može da napravi dodatno opterećenje na mreži. Pored toga, da bi se dobili rezultati na nivou cele zemlje, analizirano je više vremenskih prilika (obrazaca) dobijenih iz različitih meteoroloških stanica, koji su takođe dali različite krive potražnje. Opseg ovog istraživanja je, prema tome, u velikoj meri proširen izračunavanjem svih raspoloživih meteoroloških podataka u formi tipične godine za Sloveniju, koji se sastoje od 23 tačke unosa podataka koje su ravnomerno raspoređene u celoj Sloveniji. Međutim, ove tačke se prilično razlikuju – neke stanice su postavljene u gradovima, dok se druge nalaze u malim selima ili na značajnim lokacijama (to jest, u planinskim odmaralištima ili na aerodromima). Tačke se takođe razlikuju po nadmorskoj visini (od nekoliko metara do preko 2500 m) i pokrivaju različite klimatske zone. Veći deo Slovenije se prostire u zoni sa kontinentalnom klimom (oznake Dfb i Dfb po Kepen-Gajgerovoj klasifikaciji klime) sa hladnom zimom i toplim letom, uz delove sa suptropskom klimom u primorju (oznake Cfa i Cfb). Neka planinska područja imaju klimu tundre (ET).

Ključne reči: Solar Plus; merenje neto potrošnje energije; klimatski i meteorološki podaci; kriva potražnje; troškovi ulaganja

The research expands the bottom-up approach to determine investment cost for self-sufficient Solar Plus systems. Existing solar maps usually utilize net-metering scheme and treat electricity grid as giant battery. However, with increased solar production, this might put an additional strain to the grid. In addition, to obtain national wide results, multiple weather patterns obtained from different meteorological stations were analyzed which also resulted in different demand curves.

The scope of the research was therefore largely increased by calculating all available meteorological data in form of a typical year for Slovenia, which consist of 23 data points evenly spread all over Slovenia. However, those points vary quite a bit – some stations are positioned in the cities and towns, while others are located in small villages or places of interests (i.e., mountain resorts or airports). The points also vary in altitude (from few meters to over 2500 m) and cover different climate zones. The majority of Slovenia lies in continental zone (described with Dfb and Dfb by Köppen-Geiger climate classification) with cold winters and warm summers, with some subtropical climate at the coastal areas (Cfa and Cfb). Some mountain areas have tundra climate (ET).

The presented research shows how to combine the existing data to calculate optimal Solar Plus instalment for self-sufficient buildings for each calculation point. The already validated simplified model was used for calculation of energy balance for the typical year which was later used for optimization of the results regarding costs. This includes the roof area for photovoltaic, optimal orientation of solar panels, the capacity of the battery storage and other influential parameters. The results clearly indicated the capability of each analyzed area for Solar Plus installation.

Key words: solar plus; net-metering; climate and weather data; demand curve; investment costs

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1. Introduction

The recent large increase in interest and development in photovoltaic in the recent years [1]–[3] made self-sufficient homes or even micro-grids possible, however still expensive [4]. Optimizing the solar panel angles to catch more solar energy during the winter, when the solar energy is scarce and hence abandoning net-metering scheme does produce a bit less energy overall, however the peaks are smoothed, which lower the needs for a still expensive battery yearly storage [5], [6]. Two previous works [4], [7] already addressed some of the particular issues and found out that optimizing the PV angle for self-sufficient home can lower the cost of installation for around 15 % while decreasing the total potential electricity production by 11 %. The main achievement is reduction of the needs for battery storage for almost 30 %.

However, these results do utilize just one weather pattern and are not useful for other areas. On the other hand, the existent maps for solar potential [8] or algorithms [9] does not account for described benefits of highly angled panels. This paper expands the bottom-up approach to determine investment cost and LCOE for self-sufficient Solar Plus systems that has been used in our previous researches [4], [7].

In the recent years, models of PV production are becoming more and more refined (e.g., [10], [11]), which by rule is concentrated on maximizing the overall electricity gains from PV. However, these models are less able to use different optimizing goal (e.g., self-sufficiency). Only recently a handful of academic analyses of PV instalments concentrated on other optimization goals such as minimal tariffs etc. [12], [13]. On the other hand, an extensive model for home owners (overviewed in [14]), which are quite sophisticated, and might use a lot of parameters, which can affect the ability to find an optimal solution. Therefore, a somewhat simplified approach to model the PV energy input and battery storage [4] in line with similar models (e.g., [11], [15]), which should be suitable for the purpose while accurate enough, was used.

The scope of the research was therefore increased by calculating all available meteorological data in form of a typical year for Slovenia. This consist of 23 points, which are more or less evenly spread all over the territory of Slovenia (see Fig 1). The data of these points vary quite a bit – some stations are positioned in the cities and towns, while others are located in small villages or interesting places (mountain resorts or airports). The height above the sea level of those points are from couple of meters to more than 2500 m above sea level. In addition, the points hence also cover different climate zones (the

majority of Slovenia lies in continental zone (described with Dfb and Dfb by Köppen-Geiger climate classification [16]) with cold winters and warm summers, with some subtropical climate at the coastal areas (Cfa and Cfb). Some mountain areas have tundra climate (ET).

2. Model and data

Relying on local meteorological data and especially typical model years can be a bit restrictive. As mentioned, there are only 23 locations, which seems to be on the lower side of any statistical approach without substantial assumptions. Furthermore, typical model years' data is somewhat filtered to allow cycling analysis and gaps in data are extrapolated [17]. There are several different approaches to building data for typical meteorological year, which show some differences in assumptions and also results [7]. This should be kept in mind while interpreting the results of simplified and idealistic model to not so simple and idealistic reality.

Nevertheless, this approach moves us a step closer to the final goal – to have discrete calculation of photovoltaic (PV) and Solar Plus facility calculation for each rooftop regarding the dimensions, roof geometry (azimuth and elevation), weather data etc. Figure 1 shows all meteorological stations (red dots) with data of typical meteorological year for Slovenia.

Figure 1: Places for model calculation with adequate meteorological data (typical meteorological year)

Table 1 shows additional data on used weather station including latitude, longitude and altitude, with climate zone and population of nearby towns or villages.

Data for utilized meteorological stations

Weather station	Latitude [° E]	Longitude [° N]	Altitude [m]	Climate zone	Population (aprox of 2018)
Bilje pri Novi Gorici	13.624	45.896	55	Cfa	1100
Boršt pri Gorenji vasi	14.181	46.084	530	Dfb	1100
Dobliče pri Črnomlju	15.146	45.560	157	Dfb	180
Iskrba pri Kočevju	14.850	45.646	467	Dfb	100
Koper	13.725	45.548	54	Cfa	25000
Koseze pri Ilirski Bistrici	14.243	45.570	421	Cfb	370
Kredarica	13.849	46.379	2514	ET	N/A
Krvavec	14.533	46.297	1450	Dfc	N/A
Letališče Bovec	13.549	46.329	439	Dfb	1600
Letališče ER Maribor	15.680	46.480	264	Dfb	30
Letališče JP Ljubljana	14.473	46.218	364	Dfb	1400
Letališče Lesce	14.173	46.359	515	Dfb	3000
Letališče Portorož	13.616	45.475	2	Cfa	2800
Ljubljana	14.513	46.065	299	Dfb	280000
Malkovec	15.205	45.953	420	Dfb	144
Murska Sobota	16.165	46.662	186	Dfb	20000
Novo mesto	15.168	45.804	220	Dfb	24000
Podčetrtek	15.608	46.155	219	Dfb	3200
Rateče	13.713	46.497	863	Dfb	640
Rogla	15.332	46.453	1517	Dfc	N/A
Sotinski breg na Goričkem	16.031	46.836	418	Dfb	0
Škocjan na Krasu	13.993	45.664	424	Cfb	N/A
Šmartno pri Slovenj Gradcu	15.111	46.489	444	Dfb	1260

Figure 2 shows the schematics of utilized simplified model for calculating solar power and battery usage. The system energy depends on PV and battery power outputs: (which are defined by the Sun position ω_{sun} (i.e., azimuth γ_{sun} and elevation α_{sun}), PV orientation ω_{PV} , the size and efficiency of PV panel (with incorporated efficiency of add-ons like inverter

etc.), weather, local surroundings (e.g., shading), battery capacity, state and efficiency, household consumption (loading curve), outside and desired inside temperature (for heating) etc.

The production of electric energy by photovoltaic is defined by PV panel orientation ω_{PV} and sun orientation ω_{sun} .

The latter is defined by time and weather pattern, which defines solar radiation: $sol_rad(t)$.

Figure 2: Schematics of model used for calculating the photovoltaic energy production and battery usage

Battery storage can help if production is lower than a demand, of course until storage is depleted. This also represents single point of failure in our model. Therefore, the electricity demand P_{demand} should be outweighed by sum of production $P_{production}$ and reserve from battery storage $P_{battery}(s)$ at any time:

$$\forall t; P_{production}(\omega_{sun}(t), \omega_{PV}, sol_rad(t)) + P_{battery}(s) \geq P_{demand}(t, T) \quad (1)$$

To accommodate the shading effect of neighboring vegetation and building on PV production, a window function was used [18], similar to those used in signal processing. Welch window function, which is defined by current elevation α and limited elevation α_{limit} (which is in our case set to 10°):

$$w[\alpha] = 1 - \left(\frac{\alpha - 2 \alpha_{limit}}{2 \alpha_{limit}} \right)^2 \quad (2)$$

Please note that some more sophisticated window functions such as Planck-taper could also be used, but due to high numerical demand of calculation, simpler Welch window was chosen, since low sun angle yields only small differences.

Electric energy demand $P_{demand}(t, T)$ is then a sum of general demand $P_{gen}(t)$ (e.g., lighting, home appliances), which varies over time of the day, and demand for heating $P_{heat}(T(t))$, which depends on the outside temperature (if that is lower than desired):

$$P_{demand}(t, T) = P_{gen}(t) + P_{heat}(T(t)) \quad (3)$$

Please note that thermal inertia of the house is not taken into the account. Thermal inertia has a tendency to shift the energy demand towards more PV favourable part of the day.

Temperature deficit $\Delta T^*(t)$ and specific heating demand C^* are defined by:

$$\Delta T^*(t) = \min\{T_{out}(t) - T_0, 0\} \text{ and } C^* = \frac{Q_{heat, year}}{\sum_t \Delta T^*(t)}. \quad (5)$$

The focus of this research is to define the single minimum battery level $E_{battery_min}$ over the whole year:

$$E_{battery_min} = \min\{P_{battery}(s)|_t\}. \quad (6)$$

This approach is somewhat different from other approaches, such as [19], where the overall minimum sum of energy was observed. This is due to the different fail-mechanism for self-sustainable houses or clusters defined in eq. (1). Other types of energies (e.g., solar thermal, heat storage etc.), was not considered in this part of the research. Figure 3 shows a solar potential model of Slovenia (left) and a climate model of Slovenia (right). The calculation points are also indicated.

Figure 3: A solar potential model of Slovenia (left) and a climate model of Slovenia (right).

The price data on PV and battery system was obtained from general long-time international Data survey [16]. The current prices of installed battery storage are around 325 €/kWh for small units (up to 50 kWh). The prices for PV installation up to 50 kW_{el} are around 1200 €/kW_{el}, which includes the cost of modules and installation and yields approximately 530 EUR/m².

3. Results

The minimum battery level was calculated for all 23 places in Slovenia with proper modelling data (i.e., typical meteorological year). The results can be shown as a factors of roof photovoltaic area and battery storage capacity, as shown in Figure 4 for four typical places with different climate in western part of Slovenia. The calculations are shown for Kredarica (climate ET), Letališče Bovec (Dft), Škocjan na Krasu (Cfb) and Letališče Portorož (Cfa). The map un-derlay shows climate areas and solar potential. The different colours in graph shows areas with large surplus in energy (white) or deficit (gray). Rainbow are shows more balanced area. The thick line at minimum battery level of 0 kWh is the optimal solution, where PV and battery are sufficient enough.

Figure 4: Calculations of minimum battery level for some interesting places in western part of Slovenia

It can be observed that for places in temperate climate (Škocjan na Krasu, Letališče Portorož) the needs for self-sufficient homes are small enough, however somewhat surprising are large demands for Letališče Bovec with cold climate than for Kredarica, which is highest meteorological observation point in Slovenia with an altitude of 2514 m above sea level

and Polar climate. It seems that large amount of unobscured sun makes up for the temperature deficit.

To compare all results for minimum battery level of self-sufficient houses, only the optimal solution (level of 0 kWh) could be shown,

Figure 5. The calculations are shown with colour curves and typical investment costs are indicated by dotted grey lines.

Figure 5: The optimal solution (0 kWh level) of minimum battery level as a function of roof photovoltaic area and battery storage capacity

The method can also be used to determine the effect of the place population regarding the installation costs, Figure 6. While clear match can be found in sea-side area: Koper and Letališče Portorož, have similar climate and their costs are also similar, other places do behave quite erratically, which might be another argument for improved solar potential map.

4. Conclusions

The paper explains some fundamental approaches towards improved solar potential map, which would account for Solar Plus installation. The used approached showed adequate enough to obtain installation costs for places with proper weather data (i.e. typical meteorological year). Despite expecting that results for cost of self-sufficient Solar Plus installation will follow climatological categorization, we could find some quite different results within the same climate descriptive (Köppen-Geiger climate classification). This also shows that geometric propertied (e.g. shading) and additional weather data (cloudiness) also play important role in the cost calculation.

Figure 6: Cost of self-sufficient installation in dependence of temperature deficit and type of town

Further work should enclose at least order of magnitude more calculation points with proper weather data to allow for new and improved solar potential map of Slovenia. In addition, the geometry shading should data should be properly accounted for on point-to-point bases.

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