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IMPLEMENTING PHOTOVOLTAICS ON CARIBBEAN ISLANDS VIA NET-BILLING FOR THE EXAMPLE OF ST VINCENT – AN ECONOMICAL APPROACH FOR INDEPENDENT PRODUCERS, UTILITIES AND GOVERNMENTS

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ABSTRACT: Photovoltaic (PV) will play a major role in the global Energiewende. Especially on Caribbean islands it is the most promising power generation technology based on high solar radiation, easy scaling and expensive conventional diesel power generation. Even though PV is economically competitive on almost all Caribbean islands, it has only been significantly installed on islands with regulatory frameworks such as feed-in tariffs or net metering schemes. Within this work the benefits of net-billing schemes (feed-in tariff below the retail price) are analyzed for the Caribbean along the example of St Vincent. The analysis shows that this framework offers a huge economic and ecological potential extending St Vincent’s power generation with PV. By choosing the optimized net-billing tariff private investors, the utility, consumer and the entire economy of St Vincent can profit.

Keywords: developing countries, policy instruments, feed-in tariff

1 MOTIVATION

The Caribbean area has a great potential for renewable power generation especially by photovoltaic power plants (PV) (Fig. 1,[1]). In addition to the high overall solar radiation its timely resolution over the year is very favorable: it shows almost no seasonal differences and the peak around noon matches very well with the air conditioning driven load profile of Caribbean islands, which peaks on weekdays as well around noon (Fig. 2).

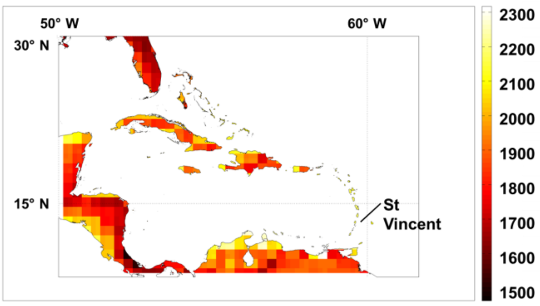

Figure 1: Solar Map Caribbean Area, Global horizontal radiation in kWh/m²*year, shows the excellent solar power potential, especially on the eastern Caribbean Islands such as St Vincent [1].

Despite these excellent natural resource conditions and expensive local diesel power generation, only few PV systems are installed in this region at the moment [2]. To attract private investments and to start the implementation of PV from the bottom, net-billing, which means a feed-in tariff below the retail price [3], is a promising market model to overcome the current barriers of implementation [4]. Such a secure regulatory framework removes the lack of financing by attracting investors [5], [6].

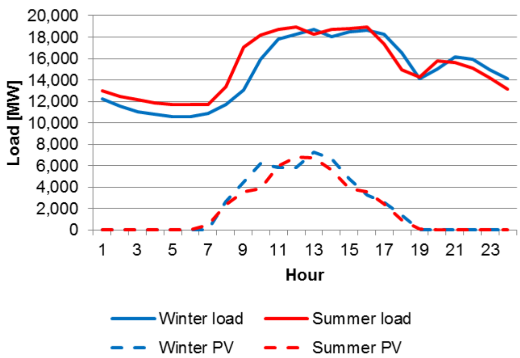

Figure 2: Load and PV power generation profile for St Vincent in 2010, The load profiles for an average summer and winter day in the year 2010 are shown, in addition the potential PV production by 10 MW installed PV for the same days. The shape of the curves reveals the advantage of the daily PV power generation without seasonal differences [7], [8].

The purpose of this work is to testify the advantages of net-billing for PV along the example of the island state St Vincent and the Grenadines (SVG). The local utility St Vincent Electricity Ltd. (VINLEC) is seeking to increase the share of renewable energies. Within this strategy net-billing for PV plays an important role. The government is strongly supportive as fuel costs are the main price driver for electricity and 8 % of the country’s imports (2.3 % of the GDP) are spent for diesel for power generation (Fig. 3, [9], [10]). An economical price for generated PV electricity is determined in this work for the following different stakeholders: independent power producers, utilities and governments.

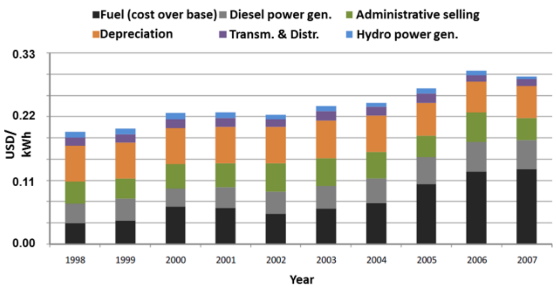

Figure 3: Cost of electricity generation by type of expenditure 1998-2007 (in USD) shows the development of electricity costs on SVG by different categories. Fuel costs are becoming significantly more and more important [10].

2 APPROACH

Different scales of installed PV capacity are studied to determine the impacts on the electricity grid and the requested spinning and storage capacity for each scale. The assessment of the PV penetration scenarios is performed with a spreadsheet based simulation tool. During the simulation the power flow of different renewable integration scenarios can be calculated according to the current setup and operation approach of the transmission system operator, VINLEC [11–13].The hourly PV yield for the different scenarios over one year is calculated with the help of the simulation tool HOMER Energy [14].

Derived from these simulations, the levelized costs of electricity (LCOE) of PV are calculated according to Eqs. 1, 2, 3, 4 [15].

Equation 1

$$Gen_{el} = \sum_{i=1}^{n} AnnualGen_n * (1 - DF)^{(n-1)}$$

Equation 2

$$NPC = \sum_{i=1}^{n,p} \frac{Capex_n * Eq_{ratio} * crf_{eq} + Capex_p * (1 - Eq\_ratio) * crf_{loan} + Opex_n}{(1+i)^{(n-1)}}$$

Equation 3

$$crf_{eq} = \frac{i_{eq} * (1+i_{eq})^n}{(1+i_{eq})^n - 1} ; crf_{loan} = \frac{i_{loan} * (1+i_{loan})^p}{(1+i_{loan})^p - 1}$$

Equation 4

$$LCOE = \frac{Gen_{el}}{NPC}$$

Explanation of equations 1, 2, 3, 4:

Gen_{el}: Overall generated electricity; $AnnualGen_n$: Generated electricity per year, depending on the annual solar radiation; DF: Derating factor; n: Project lifetime; NPC: Net present costs; $Capex_{n/p}$: Capital expenditures PV; Eq_ratio: Ratio of equity to total capital;
$Opex_n$: Annual operation and maintenance expenditures PV; i: Inflation rate; n: Project lifetime; p: Life of loan;
crf_{eq}: Capital recovery factor for equity; i_{eq}: Equity yield rate; n: Project lifetime;
crf_{loan}: Capital recovery factor for loan; i_{loan}: Loan yield rate; p: Life of loan;
LCOE: Levelized cost of electricity

The revenues of the net-billing tariff are calculated according to Eq. 5.

Equation 5

$$Rev_{Net-bill} = \sum_{i=1}^{n} \frac{Gen_{el_n} * NB_n}{(1-i)^{(n-1)}}$$

Explanation of equation 5:

$Rev_{Net-bill}$: Overall revenues of fed-in electricity; Gen_{el_n}: Generated electricity per year; NB_n: Net-billing tariff in USD per kWh; i: inflation rate; n: Project lifetime;

Based on the projected oil price development, current retail prices and costs of technology, the net-billing tariffs are determined. At the end of the economic simulation the value of PV for the utility, the private investors and the entire economy on SVG is shown.

3 SCIENTIFIC INNOVATION AND RELEVANCE

Current research supports feed-in tariffs in opposite to quota models to push the implementation of renewable energies [16], [17]. While in most countries of the world the feed-in tariffs for PV are higher than the fossil power generation costs or even higher than the retail prices, we look at very competitive solar power generation costs in the Caribbean [18], [19]. Thus it is reasonable to analyze net-billing as implementation model under the Caribbean conditions. This instrument is already implemented on some islands [20], but the challenge of determining a fair PV tariff, which satisfies all stakeholders, still exists.

Especially the smaller Caribbean islands are lacking capacities and experts to target this challenge. Even though programs such as e.g. CREDP support the implementation of renewable energy policies [21], the policy makers are still in need of external consultancy. This scientific work tries to increase the understanding of the calculation of the net-billing tariff. In addition it will lead to more transparency of the power generation sector and its regulation as all stakeholders are able to calculate their own tariff according to their technological and economic assumptions.

The methodology, calculation and its main results are presented along the example of SVG. In addition a PV policy suggestion is made for this island. SVG has been chosen based on its current policy development process, which targets to implement a net-billing scheme soon [10].

3 RESULTS

The technological simulations are based on the data of the current energy supply system of SVG (37 MW diesel power, 6.5 MW hydro power, 19 MW peak load). They resulted in 3 scenarios, low, middle and high penetration of PV (Tab. 1), defined by the additional system requirements for the different range of installed PV capacity. For each scenario a certain PV capacity has been chosen out of the listed capacity range for further calculations. Shares of peak load and PV penetration for each capacity have been calculated by HOMER Energy and are listed in Tab. 1. Even at the high penetration scenario, only 1 % of the generated PV capacity is excess energy, which underlines the perfect match of load profile and solar power generation.

The costs of the additional spinning reserve are derived from the higher fuel consumption at part load compared to full load and add up to two USDct/kWh[1] per generated kWh PV electricity. Battery storage technologies, such as NaS batteries, are required for high PV shares for two reasons: first, the genset is not able to balance the power anymore at peak PV generation and second, excess energy can be stored. Current costs of NaS batteries are about 0.12 USD/kWh per cycle [22]. These specific storage costs are distributed among all the generated PV power. As only one quarter of the PV generation has to be stored in the high PV scenario, the distributed storage costs are 0.03 USD/kWh for each kWh PV power. In addition, less spinning reserve is required as batteries serve in combination with intelligent inverters as power balancing unit [23]. This leads to overall storage and spinning reserve costs of 0.04 USD/kWh.

With these technological simulations and cost calculations, the PV generation costs and profits and net-billing tariffs are determined for 2, 10 and 20 MW_p PV. At these scenarios the levelized costs of electricity for PV (LCOE) result to 17.2, 16.1 and 14.3 USDct/kWh under the assumptions, which are mentioned in Tab. 2.

The net-billing tariffs are derived from the fuel surcharge minus bonus payments (system requirement costs plus one USDct profit) to the utility. Current retail prices are at 0.32 USD/kWh on SVG, with 0.196 USD/kWh fixed rate and 0.124 USD/kWh fuel surcharge [24]. For the calculation, a constant growth of 6 % of the fuel surcharge is expected according to the historic crude oil price development, which leads to an increased fuel surcharge of almost 0.40 USD/kWh in 20 years. Based on this growth path an equivalent average net-billing tariff is derived with similar net present earnings: 22.5 USDct/kWh for low, 20.3 USDct/kWh for middle and 18.4 USDct/kWh for high penetration (Tab. 2). Assuming these tariffs, an investor would be indifferent in choosing the oil price coupled tariff with 6 % growth per year or the aforementioned fixed tariff for 20 years.

Based on these calculations, the profits for the different stakeholders of solar power generation are shown. The internal rate of return for solar power producers is between 21 % and 23 % for the fuel surcharged coupled net-billing tariff. Under the conservative assumptions of lifetime of 20 years and loan payback time of 10 years, the investment can be considered as very secure. In addition the political and economic conditions on most of the Caribbean islands are quite favorable [25], therefore an expected IRR between 21 % and 23 % at relatively low risks represents a very attractive investment for private investors or independent power producers.

The utility can earn secure profits of one USDct/kWh PV by allowing the net-billing system, instead of covering its fuel costs by the fuel surcharge. The cumulated annual bonus earnings are shown in the last column of Tab. 2. In addition the utility could also generate PV power to reduce own costs and the fuel surcharge for customers, but the end-customers have still to pay the fixed rate, which is creating the main income for the utility. This shows that switching from diesel to solar power generation can also generate profits for the local utility, if the fuel surcharge system is adjusted to renewable resources accounting as “renewable fuel”.

Eventually the utility could decrease the fixed rate and therefore lower the increasing retail prices based on its reduced operation and maintenance costs of the conventional power plants. This is based on the idea that economic profits for the entire economy of SVG can be divided at different shares among the different stakeholder groups of the power generation sector.

About 25,000 tons of diesel are burned in the power plants of SVG per year. As all diesel has to be imported, this causes a huge economic loss for SVG being about 2.3 % of local gross domestic product (GDP). The import savings by installing PV are shown in Fig. 4 and Tab. 3. Depending on the scenario, the break-even point is reached after 8 to 9 years and beyond this, SVG avoids import expenditures from average 2 to 20 Million USD per year being about 0.3 to 3 % of local GDP. In addition GHG emissions from 2,500 to 25,000 tons are avoided per year. Beside the positive ecological effect this can create additional income for SVG by participating in an international carbon trading scheme.

[1] 20 % higher fuel consumption at part load increases fuel surcharge by appr. 0.02 USD (0.124 USD * 20 %)

5 CONCLUSION

The calculations have shown that net-billing scheme for PV on SVG is a win-win-win situation, as the producer, the utility and the consumer profit. Setting up the proper regulatory framework can attract a lot of private investments. Instead of spending money for imported fuel local enterprises and economy can prosper and create sustainable jobs on SVG.

Due to similar conditions on other Caribbean islands, they should be eager to implement PV via net-billing systems. Even a very high penetration with PV is technologically and economically feasible due to advanced storage technologies. PV will be a main driver in combination with wind, hydro and geothermal energy for Caribbean islands towards a sustainable and clean energy supply system.

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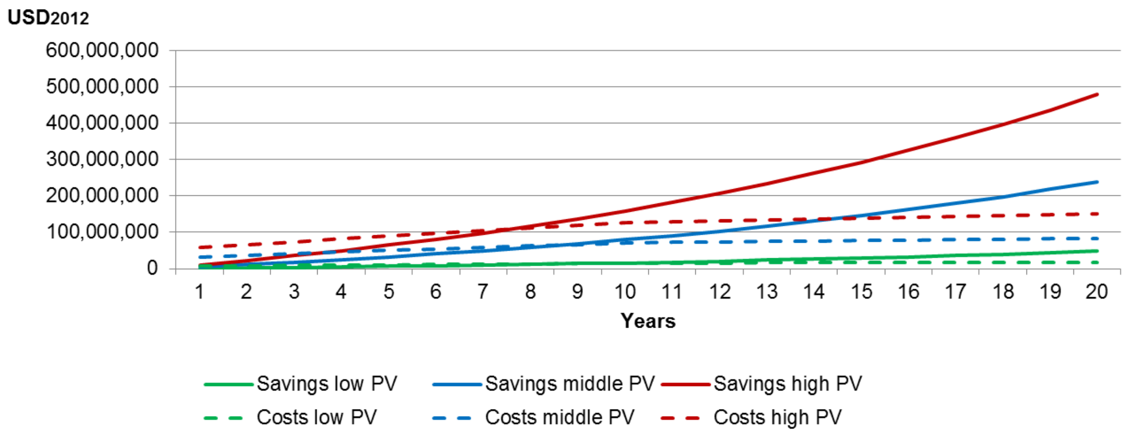

Figure 4: Cumulated savings and costs for SVG for each PV scenario, in USD_{2012}, green is the low capacity (2 MW_p) scenario, with lowest initial and overall costs, but also least savings; blue shows the middle capacity (10 MW_p) scenario with higher costs (PV costs and 0.02 USD/kWh spinning reserve costs) and higher savings; red as high capacity (20 MW_p) scenario includes PV and storage costs (0.04 USD/kWh per cycle). All scenarios have an almost similar break-even point, but the overall earnings increase dramatically with higher capacities

Table 1: Different PV implementation scenarios for SVG, Scenario names (column 1). Range of installed capacity (column 2). Additional system requirements to stabilize the frequency and to ensure the quality of the power supply system (column 3). Capital expenditures (Capex) for the year 2012 according to scale effects on SVG (column 4). Assumed capacity for economic calculation (column 5). Penetration of PV for capacities of column 5 (column 6).

Scenario	**PV capacity range**	**Additional system requirements**	**Capex**	**PV capacity for calculation**	**Share of peak load**	**Penetration**
Low	up to 5.6 MW_p	none	3,000 USD/kW_p	2 MW_p	10 %	4 %
Middle	5.6 to 16.8 MW_p	more spinning reserve	2,800 USD/kW_p	10 MW_p	53 %	18 %
High	higher than 16.8 MW_p	more spinning reserve and storage	2,500 USD/kW_p	20 MW_p	105 %	35 %

Table 2: Levelized cost of electricity (LCOE), other costs and tariffs for SVG, Scenario names (column 1). PV LCOE at IRR of 15 % (column 2). Costs for spinning reserve and storage (column 3). Average tariff calculated by fuel surcharge minus additional costs and utility bonus (column 4). Internal rate of return (IRR) for PV investors at the average tariff (column 5). Bonus payments (one USDct/kWh) to utility (column 6).

Scenario	**PV LCOE**	**Additional system requirement costs**	**Average tariff**	**IRR**	**PV-bonus utility per year**
Low	0.172 USD/kWh	none	0.225 USD/kWh	23 %	40,000 USD
Middle	0.161 USD/kWh	0.02 USD/kWh	0.203 USD/kWh	21 %	190,000 USD
High	0.143 USD/kWh	0.04 USD/kWh	0.184 USD/kWh	22 %	380,000 USD

Input: Irradiation: 1,800 kWh/m²/yr; Degradation factor: 0.5 %/year; Operational expenditures (Opex): 1.0 % of initial Capex per year; weighted average cost of capital (WACC): 8.0 % (return on equity (IRR): 15.0 %, cost for debt: 6.0 %, ratio equity to debt: 20:80); inflation: 1.5 %/year; lifetime: 20 years; loan lifetime: 10 years

Table 3: Fuel savings and profits for SVG, Scenario names (column 1). Saved fuels by PV power generation (column 2). Reduced diesel expenditures for an average diesel price of 2.02 USD/liter for the next 20 years (start price 1.1 USD/liter, 6 % annual escalation) (column 3). Initial Capex (column 4). Break-even point for investment (Fig.3) (column 5). Avoided CO_2-emissions by PV power generation (1 liter burned diesel = 2.65 $kgCO_2$) (column 6).

Scenario	**Fuel savings per year**	**Average avoided fuel costs per year**	**Initial Capex**	**Break-even point after**	**Avoided CO_2-emissions per year**
Low	950,000 liters	1.9 Million USD	6 Million USD	9 years	2,500 tons
Middle	4,800,000 liters	9.5 Million USD	28 Million USD	9 years	12,450 tons
High	9,500,000 liters	19.0 Million USD	50 Million USD	8 years	24,900 tons