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Potential Assessment for supplying Infrastructural Facilities in the City of Savannah by Photovoltaic Power Systems with respect to Economical Aspects

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PREFACE/ACKNOWLEDGEMENTS

This master thesis resulted from a cooperation between the *University of Applied Sciences Upper Austria,* the *City Government of Savannah* and the *Georgia Institute of Technology* and was financially supported by the *Austrian Marshall Plan Foundation*.

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Finally, I want to thank Dr. Robert Höller for the support with the necessary expert knowledge and the supervision of my project and thesis.

SWORN DECLARATION

I hereby declare, in lieu of an oath, that I prepared the present work independently and without help from third parties, that I did not use sources other than the ones referenced, and that I indicated passages adopted from said sources as such.

This thesis was not submitted in identical or similar form to another examination board and was not published.

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Andreas Wimmer

Wels, August 2015

KURZFASSUNG

Der Zweck dieser Forschungsarbeit ist die Untersuchung und Analyse des Potentials für die elektrische Versorgung von infrastrukturellen Einrichtungen der Stadtverwaltung von Savannah, Georgia, mittels Energie welche durch Photovoltaik-Anlagen erzeugt wird. Besonderes Augenmerk wird dabei auf die Evaluierung von Wirtschaftlichkeitskennzahlen gelegt, um die lokalen Autoritäten in ihren Entscheidungsprozessen bezüglich zukünftiger Investitionen zu unterstützen.

Um dies zu erreichen wird ein Software Programm entwickelt, welches die schnelle und unkomplizierte Analyse einer Vielzahl von Projekten innerhalb der Stadtgrenzen ermöglicht. Dies beinhaltet die Auswertung einer großen Menge von Input- Parametern, wie Energieverträge, Steuern, Systemparameter der Photovoltaik-Anlage und Finanzierungsmethoden sowie mögliche Förderungen. Das Programm verarbeitet diese dann intern um die zu erwartenden Amortisationszeiten und internen Zinsfüße sowie die spezifischen Energiekosten und verhinderte Mengen an CO_2 - Emissionen zu berechnen. Des Weiteren wird die Entwicklung des Cashflows in einem Graph dargestellt, um die visuelle Präsentation der Ergebnisse zu ermöglichen.

Insgesamt werden 12 verschieden Projekte unter Verwendung dieser Methode analysiert und die Ergebnisse in dieser Arbeit diskutiert. Es können mehrere Gebäude identifiziert werden, welche sehr gute Bedingungen für die Implementierung von Photovoltaik-Anlagen bieten, zum Teil mit Amortisationszeiten von weniger als 10 Jahren. Es werden jedoch auch mehrere Gebäude ausgemacht, welche keinerlei Möglichkeiten für eine wirtschaftlich Betreibbarkeit von Photovoltaik-Anlagen bieten. Die Gründe für diese unterschiedlichen Ergebnisse werden dabei erhoben und in Folge für jedes Projekt eine spezifische Bewertung durchgeführt.

ABSTRACT

The purpose of this thesis is the assessment and analysis of the potential for supplying infrastructural facilities owned or operated by the city government of Savannah, Georgia, with electricity generated by solar photovoltaic systems. The focus is set on evaluating economical key figures to assist the local authorities in their decision making process concerning their investment strategies.

Therefore, a software program is developed, enabling the fast and uncomplicated analyses of a wide range of projects that are located within the city borders. This includes the evaluation of a comprehensive amount of input parameters, like utility contracts, taxations, photovoltaic system parameters and different financing methods as well as possible incentives. The tool processes these factors internally to compute the expectable payback times and interest rates, as well as the levelized cost of electricity and the amount of prevented carbon dioxide emissions. Further, the cash flow development is displayed in a graph to allow the visual presentation of the results.

A total of 12 different projects are analyzed with this method and the findings are discussed in the thesis. Several buildings are found to provide very good options for the implementation of photovoltaic systems, with discounted payback times of less than 10 years. Others are identified not to allow any economical implementations at all. The reasons for these varying results are investigated and a specific evaluation is done for each project.

CONTENTS

Preface/Acknowledgements .... **II**

Kurzfassung .... **IV**

Abstract .... **V**

1 Introduction **1**

1.1 Method 2

1.2 Objective 3

2 Electricity market in Georgia **4**

2.1 Electricity rates and energy sources 4

2.2 Feed in tariffs 7

2.3 Incentives for PV systems 8

2.3.1 Federal programs 8

2.3.1.1 Solar investment tax credit 8

2.3.1.2 Renewable energy certificate 8

2.3.1.3 Residential energy conservation subsidy exclusion 9

2.3.1.4 Clean Renewable Energy Bonds 10

2.3.1.5 Qualified Energy Conservation Bonds 10

2.3.2 State programs 11

2.3.3 Performance based programs 11

2.3.3.1 'Georgia Power' – Small & Medium Scale Advanced Solar Initiative 11

2.3.3.2 'Georgia Power' - Solar Buyback Program 12

2.3.3.3 'TVA' - Renewable Standard Offer Program + Solar Solution Incentive 12

2.3.3.4 'TVA' - Green Power Providers 13

2.3.4 Rebate programs 13

2.3.4.1 Utility rebate programs 13

2.3.4.2 Georgia green loans Save & Sustain program 14

2.3.5 Market situation in Georgia 14

2.3.6 Comparison with incentives in Austria 15

2.3.6.1 Investment incentive for PV - systems in private sector, agriculture and forestry 15

2.3.6.2 Investment incentive for PV - systems on public buildings 16

2.3.6.3 Nationwide tariff incentive for PV - systems on buildings 16

2.3.6.4 System prizes & avoided costs in Austria ... 16
2.3.6.5 Summary of incentive situation in Austria ... 18
2.3.7 Summary for the city of Savannah ... 19

3 Meteorological data - Savannah, GA ... 20
3.1 Local climate conditions ... 20
3.2 Meteorological data sources ... 20
3.2.1 Meteonorm ... 20
3.2.2 NASA-SSE ... 21
3.2.3 U.S. TMY 2/3 ... 21
3.2.4 RETScreen ... 21
3.3 Irradiation data – Comparison ... 22
3.4 Temperature data – Comparison ... 23
3.5 Wind data – Comparison ... 24
3.6 Relative humidity – Comparison ... 25
3.7 Meteorological data – Conclusion ... 25

4 Photovoltaic technologies ... 26
4.1 Crystalline silicon - modules ... 26
4.2 CdTe ... 27
4.3 CIGS ... 27
4.4 CPV ... 28
4.5 Technology comparison ... 29
4.5.1 Conversion efficiency ... 29
4.5.2 Temperature coefficients ... 30
4.5.3 Degradation ... 30

5 Economical analysis – Tool ... 31
5.1 General ... 31
5.1.1 Input parameters ... 32
5.1.2 General information ... 32
5.1.3 System data ... 34
5.1.4 Financing ... 37
5.1.5 Output parameters ... 39
5.2 Calculation methods ... 41

5.2.1 Generator yield calculation 41
5.2.1.1 Direct irradiance on module plane 42
5.2.1.2 Diffuse irradiance on module plane 44
5.2.1.3 Reflected irradiance on module plane 45
5.2.1.4 Total irradiance on module plane 45
5.2.1.5 Module temperature 45
5.2.1.6 Total generator yield before validation 46
5.2.2 Yield modification 46
5.2.3 Losses 50
5.2.4 Consumer types 52
5.2.4.1 NREL - load profiles 53
5.2.4.2 Short time fluctuations 54
5.2.5 Energy Balance 56
5.2.6 Electricity purchase contracts 57
5.2.7 Scenarios 59
5.2.8 Cash flow 60
5.2.9 levelized costs of electricity 61
5.2.10 modified internal rate of return 62

6 Economic analyses 63

6.1 Infrastructural facilities of the City of Savannah 63
6.2 State Street Garage 65
6.3 City Hall 73
6.4 Civic Center 76
6.5 I&D Water Supply 78
6.6 Other office buildings 80
6.7 Savannah Gardens 83
6.8 Residential building 85

7 Summary / conclusion 86

8 List of abbreviations 88

9 List of figures 89

10 List of tables 91

11 List of equations 92

12 References 95
13 Appendix A 99
14 Appendix B 101
15 Appendix C 104

1 INTRODUCTION

The City of Savannah has taken steps towards becoming a more sustainable city by committing itself to reduce the energy consumption of its facilities by 15 % until 2020. Due to this commitment of the city government entire areas within the City of Savannah are revitalized by improving the energy-efficiency of existing buildings and by erecting new resource- and energy-efficient infrastructures.

In this context an international cooperation between the Georgia Tech Savannah, a satellite campus of the Atlanta-based Georgia Institute of Technology, and the University of Applied Sciences Upper Austria has been established. In combination with support trough a scholarship, provided by the “Marshall Plan Foundation”, this offers students of the master’s degree program “Eco-Energy Engineering” the possibility to work on research projects for their master thesis in the field of sustainable building services in Savannah. This work is a result of this cooperation.

While examining possibilities for cutting down energy demands in Savannah, it is almost inevitable to utilize renewable energy technologies. Probably the most important of them regarding urban areas is the utilization of photovoltaic (PV) power. With approximately 1,675 kWh/(m^2*yr) of annual global horizontal solar irradiation the area of Savannah has a very high potential for applying this technology. Moreover, due to the warm and humid climate there is a high popularity of air-conditioning systems. This leads to a high demand of electricity during daytime, which coincides with the availability of solar radiation. Therefore, a potential for high self-consumption of the PV provided electricity is expected.

The goal of this thesis is to evaluate and assess the potential of supplying infrastructural facilities of Savannah with electricity generated in PV power systems and thus reducing the demand for electric energy generated out of fossil resources and preventing carbon dioxide emissions. In this context it is of particular interest what level of economic feasibility would be achievable with such a system. Therefore, the development of a software program for calculating these economics would help persons in charge to come to decisions about where and how the implementation of PV is economically reasonable by analyzing the expectable amounts of generated electricity, the type of use of the examined facilities, the costs of energy as well as possible governmental subsidies in the area of Savannah.

1.1 METHOD

To allow a recommendation about where the generation of electricity with PV power systems is ecological and economical reasonable, a comprehensive analysis tool is developed in the spreadsheet program “Microsoft Excel 2010”. The first step for this project is a detailed analysis of the financial, meteorological and regulatory boundary conditions in Savannah, GA, as well as of the state of the art of PV technologies. This is done in the first three main chapters of this thesis.

The next step is the evaluation of the energy consumptions of potential projects. These are for example office buildings, water treatment facilities or residential buildings. The later is chosen to be included in this study, despite it is not an infrastructural facility. However, the city government of Savannah also tries to promote private installations of PV systems and supports them with information campaigns.

These different consumers are analyzed and their energy demands simulated to allow the detection of potentials for implementing PV power systems. For a detailed and reliable assessment it is necessary to have full knowledge of the continuous energy demands during the whole year to allow an evaluation of the possible self-consumption of the generated electric energy. Data about system peak loads, consumer behavior and continuity of energy demands are either provided by the city administration or simulated with data that is based on local weather measurements.

Based on this, the designing of suitable PV systems can be done. It is attempted to optimize the correlations of energy demand and energy yield with aim to a highest possible self-consumption rate. There is a range of different approaches available to meet this requirement, thus a method is developed to evaluate appropriate system dimensions and an optimized orientation of PV modules.

While the reduction of the overall energy and resource demands of the different facilities and buildings is one objective, also architectonic issues are considered in the evaluation, i.e. the systems are designed with consideration of their impact on the building’s appearance. Furthermore, the possible government incentives and their effect on the profitability of different systems are analyzed in detail and a comparison with the subsidy system in Austria is done.

1.2 OBJECTIVE

The overall goal of this research is to provide a practical overview about PV implementations in different infrastructural facilities that are economically realizable under given local circumstances.

Further, a spreadsheet program should be created, enabling a user-friendly calculation of expectable levelized costs of electricity, simple- and discounted- payback times, the internal rates of return as well as the predicted amount of saved energy, and the reduced carbon emissions. Therefore, the program has to be specifically adapted to the climatic and regulatory situation of the City of Savannah.

This research is not only intended to allow the city council of Savannah to make decisions about where the building of PV power systems is reasonable considering its profitability, but also investors in general who consider building PV systems in the region of Savannah.

2 ELECTRICITY MARKET IN GEORGIA

The vast majority of PV power plants built today is connected to the grid to allow the sale of generated electric energy. This is due to the fact that PV power production often doesn't coincide with the demand for electricity and therefore the power would possibly get lost if it was not sold to an electric utility company. The rates PV system owners get for their sold electricity differs very strong depending on the utility company, the form of contract and possible incentives. This chapter will analyze the related economic boundary conditions in the USA and will go into further detail for the state of Georgia.

2.1 ELECTRICITY RATES AND ENERGY SOURCES

A widely used form for operating a PV system is to use the energy yield to decrease the amount of electricity that has to be imported from the grid. Therefore the costs that would come along with an energy unit bought from a utility company are avoided, including taxes and other fees that depend on the amount of consumed energy. As a result, the knowledge of electricity rates and the assumptions concerning their future developments are crucial for an economic analysis.

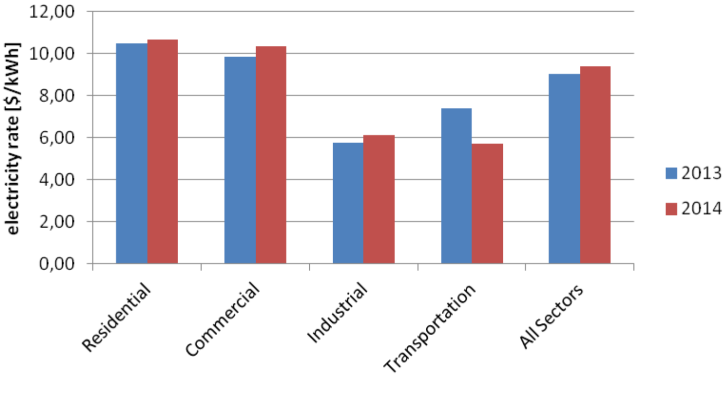

Figure 1: Electricity rates in Georgia, 2014 **[U.S. EIA, 2014b]**

Figure 1 shows the average electricity price in Georgia for different customers and their development from 2013 to 2014. It can be observed that with the only exception of the transportation sector the electricity rates increased within this time period at an average rate of 1.6 % in the residential sector and 5 - 6.5 % for commercial and industrial customers. For residential consumers the average purchase rate was

0.1065 $/kWh and for commercial customers it was 0.1037 $/kWh in 2014. This is a very low rate compared to most European countries and also compared to other states in the US, as it can be seen in the comparison of *Figure 2*.

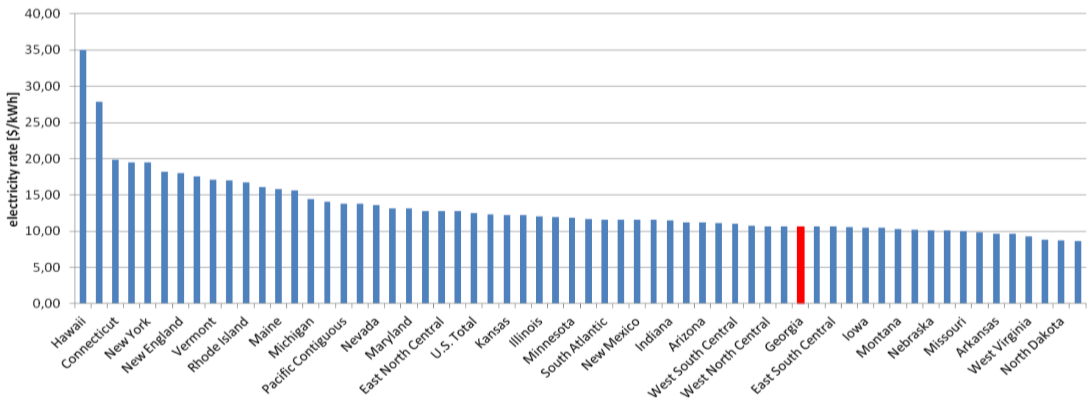

Figure 2: Average residential electricity rates by states **[U.S. EIA, 2014b]**

Figure 3 shows the electric power generation for Georgia in 2012, subdivided by the different energy sources used. It can be shown that this market is clearly dominated by fossil and nuclear technologies, which were responsible for more than 95 % of net electricity production in 2012. Solar electricity was only responsible for 0.0024 % of total production [U.S. EIA, 2014b].

This is also assumed to be the main reason for the observed low electricity rates. Furthermore, the high amount of coal and fossil power plants require a constant base load, what could be one reason for the structure of the available electricity service tariffs, which promote the consumption of electricity in off-peak periods in almost all cases, sometimes with electricity prices below 0.05 $/kWh [Georgia Power, 2014a].

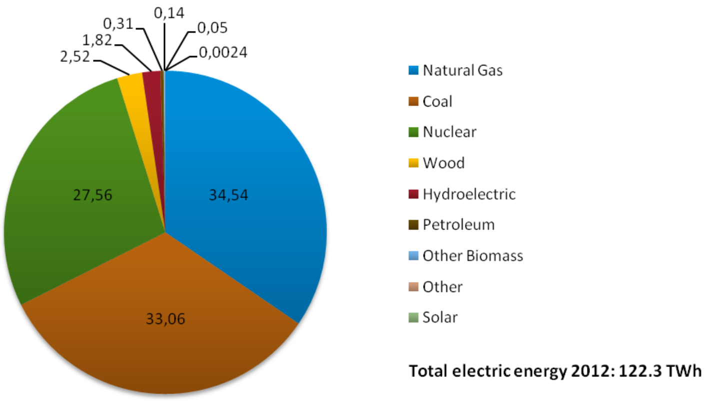

Figure 3: Electricity production by energy source - Georgia **[U.S. EIA, 2014b]**

A more detailed analysis of relevant energy purchase contracts that are available in the region of Savannah, GA, will be done in Chapter 5.2.6.

Figure 4 shows the historic development of electricity production in Georgia. It can be clearly seen that there was a recent strong shift from coal towards gas-fired electric power plants.

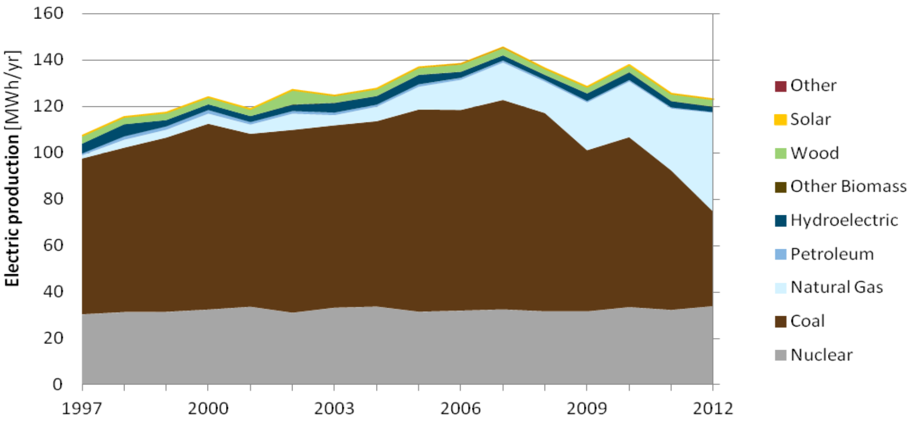

Figure 4: Historic electric energy production by source – Georgia **[U.S. EIA, 2014a]**

This is interpreted to be the main cause for the development of the specific carbon dioxide emissions that can be seen in *Figure 5*. These were reduced from 1,462 lbs/MWh in 2007 to a value of 1,062 lbs/MWh in the year 2012, which equals a reduction of 27 % within a relative short time frame of 5 years. However, since the city government of Savannah is currently working on a greenhouse-gas inventory of its infrastructural facilities, it is chosen to use the same data source for emissions as they do, since this work is also intended to be used by its departments.

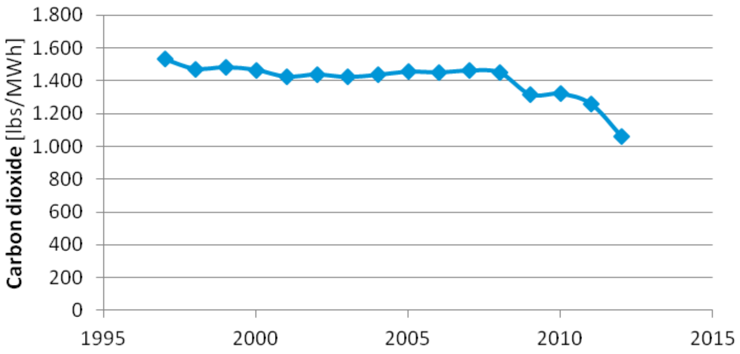

***Figure 5: Electricity - carbon dioxide emissions – Georgia* [U.S. EIA, 2014a]**

The difference of this emission data used by the city government is that they also take into account the carbon-dioxide equivalent of other greenhouse gases like released methane. These data are provided by the U.S. Environmental Protection Agency (EPA) and are intended specifically for the use in greenhouse gas inventories. However, the disadvantage is that the most recent data available is from 2010. Therefore, the recent reduction of carbon dioxide emissions is not yet included. The value used for calculations within this thesis concerning the CO2e-emissions in Georgia is therefore 1,354.09 lbs/MWh [U.S. EPA, 2014].

2.2 FEED IN TARIFFS

As described before, PV generated electricity that cannot be directly used by the owner is very likely to get sold to a utility. The only exceptions to this are so called island systems, which can operate without a connection to the grid, but are in need of either a storage system or a backup electricity generator. For all other systems a contract has to be obtained, which determines the rates that are paid for the amount of electricity sold. Appropriate to the low electricity rates and without any kind of special program this rate is 0.04375 $/kWh for the region Savannah in 2015 [Cook, 2015].

2.3 INCENTIVES FOR PV SYSTEMS

Despite the immense drop in PV system costs that has been achieved in the last years, they are on the edge of being competitive to commercial power production without any type of incentive. Therefore, the government of the United States as well as most utilities provide different types of programs which aim to encourage people and companies as well as state- and federal- governmental institutions to invest in PV power systems. Summaries of the different possible incentives available in the state of Georgia as well as some important regulations are described within the following Sections.

2.3.1 FEDERAL PROGRAMS

The primary measures the federal government of the Unites States takes to support the growth of the PV energy sector are described below. The description is limited to programs only that are also relevant in the state of Georgia.

2.3.1.1 SOLAR INVESTMENT TAX CREDIT

The probably most important incentive is the so called “Solar Investment Energy Tax Credit” (ITC). It enables the applicant to get back 30 % of qualified expenditures for a PV system mounted on a residential, commercial or industrial property. Therefore the amount of taxes that has to be paid by the system owner will be reduced by 30 % of the PV system's costs. If the credit exceeds the amount of taxes that has to be paid the rest still remains saved for the next year. This incentive is valid for systems that are placed in service until December, 31th 2016. After this date the credit’s percentage is planned to be reduced to an amount of 10 % [DSIRE, 2014].

This incentive is not applicable for systems owned or operated by governmental institutions. Therefore, the city government of Savannah cannot use it for improving the economics of its PV projects.

2.3.1.2 RENEWABLE ENERGY CERTIFICATE

The “Renewable Energy Certificates” (RECs) are certificates for “green” energy and are traded separately from the generated electrical energy. For example, these certificates can be bought by utilities to increase their renewable energy portfolio or to sell them to customers who wish to buy electricity out of renewable energy sources. In 33 of the 50 U.S. states utilities are required by the government to introduce a certain renewable energy portfolio. This lead to the creation of a market to trade these certificates. The price of RECs traded in such a market vary in the dimension of 0.001 – 0.025 $/REC and depend on the mixture of renewable energy sources, time of purchase and marketer.

Additionally there is a nationwide voluntary market for purchasing certificates to claim the usage of renewable energy, which targets primarily big companies and governmental agencies. Since there is no 'Renewable Portfolio Standard' in the state of Georgia it is only possible to try selling RECs on a voluntary market and typically only the most cost-effective renewable resources can be sold. In Figure 6 the development of REC prices is shown. Due to less demand within a voluntary market the resulting prices are below the level of a market that is affected by portfolio standards [U.S. EERE, 2014].

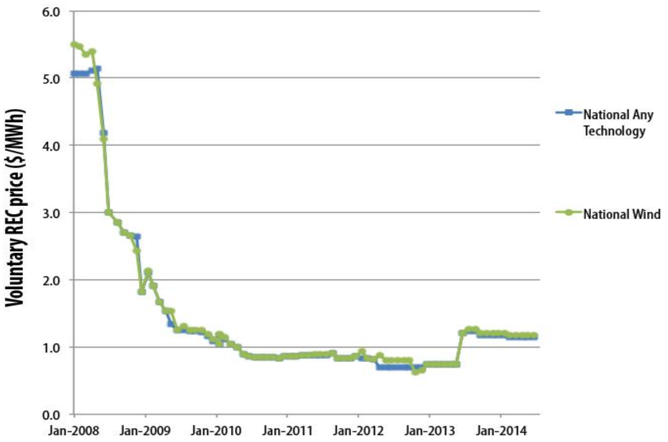

Figure 6: REC retail price development **[U.S. EERE, 2014]**

2.3.1.3 RESIDENTIAL ENERGY CONSERVATION SUBSIDY EXCLUSION

The federal government decided in Section 136 of the U.S. Code that subsidies for energy conversion measures, including PV, provided by public utilities to residential customers are non-taxable. Therefore utilities can offer incentives for renewable energy applications tax-free. However, if in addition federal tax credits are obtained, the investment basis for these credits has to be reduced by the amount of the utility subsidies [DSIRE, 2014].

2.3.1.4 CLEAN RENEWABLE ENERGY BONDS

The “Internal Revenue Service” agency (IRS) announced in 2015 the availability of close to $1.4 billion for the purpose of “Clean Renewable Energy Bonds” (CREBs). These enable an applying entity to purchase a traditional bond and to receive federal tax credits in amount of a portion of the bond interest rate, resulting in a lower effective interest rate that has to be paid back. The borrower remains responsible for repaying the principal on the bond.

This incentive is available to entities in the public sector like states, cities or territories as well as to electric cooperatives. Participants must first apply to the IRS for a CREBs allocation, and then issue the bonds within a specific time period. The applicable tax credit rate is set daily by the U.S. Treasury Department and is further treated as taxable income. However, because of new regulations this published rate has to be reduced to 70% when applied for CREBs [DSIRE, 2014].

2.3.1.5 QUALIFIED ENERGY CONSERVATION BONDS

The “Qualified Energy Conservation Bonds” (QECB) with a total volume of $3.2 billion are available to state, local and tribal governments for financing certain types of energy projects. They are similar to the CREBs described above, with the difference that they are not subject to a U.S. Department of Treasury application- and approval process. Instead the bond volume is allocated to each state based on its percentage of the U.S. population. Another difference is that the bond issuer may choose to receive a direct payment from the Department of Treasury in form of a refundable tax credit and equivalent to the amount of the non-refundable tax credits that would otherwise be paid to the bondholder.

The definition of “qualified energy conservation projects” for CREBs and QECBs is fairly broad, containing all sorts of energy efficiency measures, renewable energy projects as well as various research and development applications. However, PV systems are definitely a part of it [DSIRE, 2014].

2.3.2 STATE PROGRAMS

In the state of Georgia there are no explicit state incentives or loan programs available for PV systems. However, the state requires electric utilities to offer bi-directional or single- directional metering to customers who want to sell their generated electricity. This regulation is applicable for systems with up to 10 kW$_P$ in peak power for residential applications and up to 100 kW$_P$ for commercial applications and only as long as the aggregate capacity of PV, fuel cells and wind turbines combined does not exceed 0.2 % of a utility's system peak demand from the previous year. Further Georgia is one of five U.S. states that banned 3rd party ownerships and leasing arrangements for PV systems in the past, but it is currently discussing to end this ban [DSIRE, 2014].

2.3.3 PERFORMANCE BASED PROGRAMS

Some electric utility companies in the state of Georgia offer incentives that promote a high productivity of the subsidized PV-systems. These are described within this chapter.

2.3.3.1 'GEORGIA POWER' – SMALL & MEDIUM SCALE ADVANCED SOLAR INITIATIVE

In 2013 the utility company “Georgia Power” started the program 'Small and medium scale advanced solar initiative (GPASI) to support PV systems in form of a subsidized feed-in tariff with the goal of obtaining a peak power capacity of 735 MW$_P$ by 2016. This program is available for all sectors and the applicant agrees to sell 100 % of the energy yield to “Georgia Power”. In 2014 the offered rates were either 0.13 $/kWh for 20 years and systems up to 1 MW$_P$ or an increasing feed-in tariff that starts with 0.087 $/kWh in 2014 and grows annually to an amount of 0.174 $/kWh in 2034 for systems with a peak capacity between 100 kW$_P$ and 1 MW$_P$. The applicant was required to pay a non-refundable application fee of 5 $/kW$_P$ for systems with more than 10 kW$_P$. Further, the metering is charged with 4.5 $/month for single-phase metering and 11.2 $/month for multi-phase metering. The Renewable Energy Certificates (RECs) stay with the owner. Due to the high number of applications a lottery is used to decide who will be provided with this incentive. The numbers for 2015 are still to be decided, but are assumed to be between 0.089 and 0.114 $/kWh, depending on the length of the contract period [Echols, 2015].

2.3.3.2 'GEORGIA POWER' - SOLAR BUYBACK PROGRAM

Another incentive offered by “Georgia Power” is a feed-in tariff of 0.17 $/kWh, guaranteed for a contract period of 5 years and for systems up to 25 kW$_P$ with single phase-, and up to 100 kW$_P$ with multiphase- grid connection. The contract is available to residential, commercial and industrial customers and includes that 100 % of the generated power is sold to “Georgia Power” along with the RECs. This program is currently full (Jun. 2015) and is financed by a voluntary program that offers Georgia Power customers to purchase green energy with an extra charge of $5 for 100 kWh of electric energy that is generated by a mix of renewables (min. 50 % solar). Similar to the GPASI program the metering is charged with 4.5/11.2 $/kWh for single/multi-phase metering [DSIRE, 2014].

2.3.3.3 'TVA' - RENEWABLE STANDARD OFFER PROGRAM + SOLAR SOLUTION INCENTIVE

The utility company “Tennessee Valley Authority” offers in extensions to its “Renewable Standard Offer Program” (RSO) the so called “Solar Solution Incentive” (SSI) in its serviced counties in the north of Georgia. The incentive is applicable for PV systems between 50 kW$_P$ and 20 MW$_P$. The application fee is $1000 + 1 $/kW$_P$ for systems smaller than 1 MW$_P$ and $5000 above. The offered feed-in tariff amounts 0.029 + 0.04 $/kWh in low demand periods and 0.051 + 0.04 $/kWh in high demand periods and is specified to increase by 5 % each year. In addition to the electric energy the RECs are transferred to TVA. The extra amount of 0.04 $/kWh is part of the SSI and is valid for the first 10 years of contract. The total contract period is 20 years. The current program started on January 2nd, 2015. While the large scale capacity (>200 kW$_P$) is already full, there are still capacities available for projects with 50 - 100 kW$_P$ as well as in the service areas of some local partner power companies [DSIRE, 2014].

2.3.3.4 'TVA' - GREEN POWER PROVIDERS

Similar to Georgia Power the utility TVA offers also an incentive for residential, commercial and governmental customers that is financed with voluntary payments other customers make by purchasing electricity generated out of renewable energy sources. These offered energy blocks are $4 for 150 kWh out of sources like wind, solar or biomass. The incentive provides a $1000 grant upon installation and further a premium payment of 0.02 $/kWh (2015) additionally to the retail electricity rate for the first 10 years of contract. Total contract period is 20 years. The contract requests the customer to sell 100 % of the energy yield as well as the RECs to TVA. System sizes have to be between 0.5 - 50 kW_P. Further, for systems greater than 10 kW_P there is a load requirement that the system will not produce more than 100 % of the energy usage of a customer.

2.3.4 REBATE PROGRAMS

Other available forms of subsidies for PV systems offered by some electric utilities as well as by a non-profit agency are described in this chapter. However, it has to be mentioned that if rebate programs are applied together with the “Solar Investment Energy Tax Credit” (Chapter 2.3.1.1), the later has to be reduced by the amount of the granted rebate due to the “Residential energy conservation subsidy exclusion” (Chapter 2.3.1.3). Therefore it has only an additional benefit to the end user if his tax liability would be too low for the tax credit or if a possible credit would be exceeded by a rebate.

2.3.4.1 UTILITY REBATE PROGRAMS

The utilities “Greystone Power EMC”, “Central Georgia EMC” and “Jackson EMC” each offer similar grant payments of 450 $/kW_P$ for installing residential PV systems with a peak power of up to 10 kW_P with some small differences in their policies. These are for example an application fee of $100 that has to be paid with the first two utilities or that the second utility also requires the transfer of all RECs to them [DSIRE, 2014].

2.3.4.2 GEORGIA GREEN LOANS SAVE & SUSTAIN PROGRAM

The non-profit microlending agency 'Georgia Green Loans' offers low-interest loans for funding energy efficiency measures as well as renewable energy businesses and they would cover most of the costs for commercial energy audits through a selected group of energy auditing partners. The loan has to range between \$500 and \$35,000 and the maximum term for this loan is five years. It is available to commercial and agricultural applicants [DSIRE, 2014].

2.3.5 MARKET SITUATION IN GEORGIA

Analogous to the worldwide cost development of PV systems the costs for the installation of a grid connected PV product in the USA decreased continuously over the last years. *Figure 7* shows the development of average U.S. system prizes for residential (5 kW_P), commercial (202 kW_P) and utility (175 MW_P) scale PV-systems.

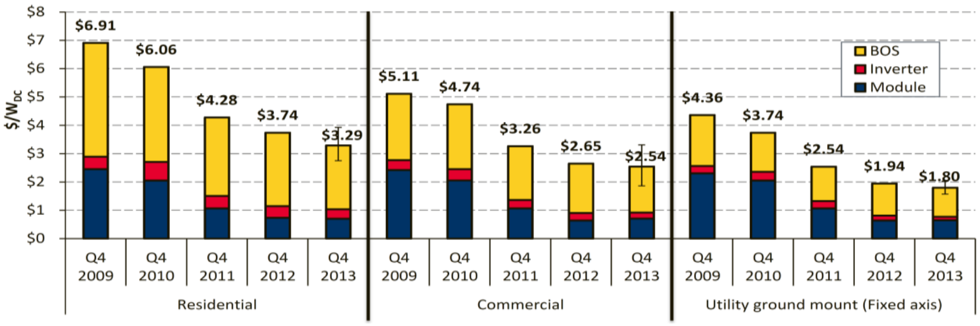

***Figure 7: PV system cost development – USA* [U.S. DOE, 2014]**

It can be seen that with end of 2013 the average price for a residential system was 3.29 $\$/W_P$ and for commercial ones 2.54 $\$/W_P$. The observable trend of an average price reduction of 16 – 19 % also continued throughout the year 2014. This can be shown by comparing these prices with an offer of the Atlanta - based company “Hannah Solar LLC”, which was presented in quartile 1 of the year 2015 in context of the program “Solarize Tybee”. This program tried to achieve low system prizes for PV systems through a collective bidding process and was supported by the U.S. Department of Energy. Originally, it was intended that this offer would be only valid for customers on Tybee island, which is about 15 miles east of Savannah, but then its availability was extended to whole Chatham County, including the city of Savannah.

Their pricing scheme ranged between 2 to 3 $/W_P$, depending on the final number of kW$_P$ that would be installed with this program. However, the lower end of these range would have only been possible with a very high customer demand, which was not achieved. The final price for residential systems purchased through this program was 2.8 $/W$_P$, what represents a price 15 % lower than what is shown in *Figure 7* for the end of 2013.

2.3.6 COMPARISON WITH INCENTIVES IN AUSTRIA

To allow a more objective evaluation of this incentive structure in the state of Georgia a comparison with the subsidy model in Austria is done within this chapter.

As described in the previous chapters, the main incentive in the USA for private or commercial PV systems is the federal “Solar Investment Energy Tax Credit”, which represents basically an investment incentive. In addition to this, some utilities provide subsidized feed-in tariffs to promote PV systems. In Austria, there are similar programs available, which are listed as follows:

2.3.6.1 INVESTMENT INCENTIVE FOR PV - SYSTEMS IN PRIVATE SECTOR, AGRICULTURE AND FORESTRY

With a budget of $19 million[1] for PV systems in the private sector and $4.5 million for use in agriculture and forestry, this nationwide incentive is the biggest program in Austria. It comes in form of a direct onetime payment after the installation was finished and the system started to operate.

For greenfield-sites or roof-parallel mounting methods this incentive amounts 308.5 $/kW$_P$ and for roof-integrated mounting methods 420.8 $/kW$_P$. However, a maximum amount of 40% of the qualified expenditures can be supported.

For residential systems there is a limit in its supported peak power of 5 kW$_P$. Within agriculture and forestry the system has to be built with a size between 5 and 30 kW$_P$. Further, all systems have to be connected to the grid [PV Austria, 2015].

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[1] Euro – Dollar exchange rate $1 = 1.124 € [June 15th 2015, www.finanzen.net]

2.3.6.2 INVESTMENT INCENTIVE FOR PV - SYSTEMS ON PUBLIC BUILDINGS

The nationwide investment incentive for public buildings comes with slightly higher rates than for the private sector. The amounts paid for systems are 420.8 $/kW_P$ for greenfield sited or roof-parallel systems and 533 $/kW_P$ for roof- integrated applications. The system sizes have to be between 5 and 150 kW_P and again there is cap with 40% of qualified expenditures. Further, this incentive is only available in so- called “Climate model regions”, which comprise 104 municipalities in Austria [PV Austria, 2015].

2.3.6.3 NATIONWIDE TARIFF INCENTIVE FOR PV - SYSTEMS ON BUILDINGS

While the incentives above are only available as onetime payments at the beginning of a PV system’s lifetime, there is another incentive offered which aims for bigger sized systems. This nationwide tariff- incentive is applicable for systems with a peak-power between 5 and 200 kW_P and provides a feed-in tariff of 0.1297 $/kWh for a time span of 13 years. Additionally, also a direct onetime payment after bringing the system into service is done in the amount of 224.4 $/kW_P$ or to a maximum of 30% of the qualified expenditures. Compared to other incentives there is only a much lower budget of $8.97 million available. Therefore, and due to the good economic viability of this program, the demand for this incentive is usually higher than the budget allows. As a result the contracts are granted on a first come – first serve basis [PV Austria, 2015].

2.3.6.4 SYSTEM PRIZES & AVOIDED COSTS IN AUSTRIA

Since the majority of Austrian incentives come in form of an exact dollar-amount, whereas they come in the American system in form of percentages of investment costs, it is necessary to have knowledge about typical system costs in Austria to allow a comparison.

Table 1 shows residential system prizes from three different Austrian installing companies. The system prizes are for roof-parallel mountings on tile roofs and all offers were solicited in June 2015.

Table 1: Investment costs - residential systems, Austria

Company	**System size** [kW$_P$]	**System price** [$]	**Specific costs** [$/kW$_P$]
Nikko Photovoltaik GmbH	5.0	11,802	2,360
MSP Solarpower GmbH	5.0	9,948	1,990
Raymann Kraft der Sonne "Photovoltaikanlagen" GmbH	5.1	12,240	2,400
Average:			**2,250**

This shows an average price for residential systems of 2,250 $/kW$_P$, which is about 24 % cheaper than a comparable system erected in Georgia, USA. *Table 2* lists the percentages that possible Austrian incentives would cover of this average system prize.

Table 2: Incentive comparison

Type of incentive	**Incentive amount** [$]	**Percent of investment cost** [%]	**Final total system prize** [$]
Investment incentive, private, AT	308.5	13.7	2,250.0 – 308.5 = **1,941.5**
Investment incentive, public, AT	420.8	18.7	2,250.0 – 420.8 = **1,829.2**
Tariff incentive, AT	224.4	10.0	2,250.0 – 224.4 = **2,025.6**
Federal tax credit, USA	-	30.0	2,800.0 - 30.0 % = **1,960.0**

It can be seen that the rate for small private systems in Austria is lower than the available U.S. federal tax credit with its 30 %, but when the initial prize difference is also taken into account, the final total prize is very similar. The rates for public systems provide better options for a customer, but cannot be compared to an U.S. American system, since there is no investment incentive available for public entities in Georgia.

Another aspect that has to be considered when comparing incentives for systems with bi-directional metering is the avoided cost of electricity. These costs have an essential impact on the economics of PV and are therefore a key factor in legitimating the extent of an incentive. *Table 3* shows the electricity rates of three (residential) standard tariffs in Austria.

Table 3: Facility selection - part 1

Utility	**Tariff**	**Avoided costs** (incl. USt.) [$/kWh]	**Feed-in Tariff** (excl. USt.) [$/kWh]	**Source**
EVN	Optima - Garant	0.1646	0.0607	[EVN, 2015]
Wien Energie	Optima	0.1928	0.0741	[Wien Energie, 2015]
Verbund	H2Ö - Komplett	0.1798	0.0641	[Verbund, 2015]

It can be seen that the avoided electricity cost is with an average of 0.179 $/kWh about 68 % higher than the average rate of 0.1065 $/kWh for residential customers in Georgia and the resulting average feed-in tariff of 0.0663 $/kWh is about 51 % higher. On the contrary, systems in Georgia benefit from a higher annual irradiation, which causes about 30 % more in production. Further, the average annual electricity consumption of households in Georgia is with 13,055 kWh/yr [U.S. EIA, 2013] much higher than the average annual consumption in Austria with 4,187 kWh/yr [Statistik Austria, 2012]. Therefore, with the same system size a higher self-consumption is very likely, improving the overall economics and making a general comparison very difficult.

The investment grant for the tariff incentive offers the lowest amount, but additionally provides a feed-in tariff that even exceeds the current average electricity rates in Georgia. Taking into account that this rate is ensured for a time of 13 years without the risk of a self-consumption rate that could be lower than expected, this rate provides the highest economical security for investments.

2.3.6.5 SUMMARY OF INCENTIVE SITUATION IN AUSTRIA

In conclusion, it can be shown that with a granted incentive the upfront system costs are very similar for small residential applications in Austria and in the USA. For higher system sizes or commercial systems the situation in Austria is potentially better subsidized, but the availability of an incentive is very limited. The incentives for governmental applicants cannot be compared without a more extensive evaluation, since they have a completely different structure. A general declaration of which country provides better economical possibilities for bi-directional metering cannot be made within this short evaluation due to the fact that electricity market situation, consumer-behavior as well as solar irradiation potentials are substantially different in these two countries.

2.3.7 SUMMARY FOR THE CITY OF SAVANNAH

The main objective of this thesis is the evaluation of potential PV system applications that are economically feasible and which can be used to reduce the city government's electricity consumption. Therefore, the focus is set on bi-directional metering to reduce the energy usage of connected buildings and facilities directly. With such a system the generated excessive amount of electricity has to be sold to the local utility "Georgia Power", which has monopoly position, for a rate of 0.04375 $/kWh. Electricity consumed within the analyzed object itself results in cost savings in amount of the avoided electricity purchase costs, which depend on the type of contract. "Georgia Power" would offer a total number of 42 often substantially different purchase contracts, but this thesis only covers contracts that are actually applied with city government facilities. Further, with all system designs it has to be considered that "Georgia Power" limits the system sizes to 10 kW_P for residential and 100 kW_P for commercial systems.

Incentives that can be applied with the systems analyzed in this thesis are the "Solar Investment Tax Credit" (ITC) for commercial and residential applications as well as the bond incentives "Qualified Energy Conservation Bonds" (QECB) and "Clean Renewable Energy Bonds" (CREB) for governmental ownerships. The "Georgia Power – Solar Buyback program" as well as the "Georgia Power – Small & Medium Scale Advanced Solar Initiative" are not considered for appliance, since they are only applicable with single-directional metering what is not seen as an objective of the analyzed projects.

3 METEOROLOGICAL DATA - SAVANNAH, GA

This chapter describes meteorological data for Savannah, Georgia, which are considered as relevant for PV systems. To ensure an unbiased evaluation it is decided to take four different data sources into account.

3.1 LOCAL CLIMATE CONDITIONS

Savannah is located on the Atlantic coast of Georgia, close to the state boarder to South Carolina and with the geographical coordinates 32° 3′ N, 81° 6′ W.

It has a humid, subtropical climate with peak temperatures between June and September and an annual average temperature of ~19.1°C. The annual precipitation is with an average of ~1250 mm very high and comes in form of frequent year-round rainfalls. About 2,842 hours of sunshine promise a high annual irradiation [Climatemps, 2015]. The average wind speed throughout the year is 3 m/s, but significant weather extremes like hurricanes are possible.

3.2 METEOROLOGICAL DATA SOURCES

To allow a better understanding of the data used a short description of the different sources and their methods of measurement is given in the following.

3.2.1 METEONORM

The Swiss company *Meteotest* offers a database called *Meteonorm*, which includes data of 8,325 meteorological stations all over the world. Of these stations about 1,500 provide measurements for irradiance. For temperature, humidity and wind speed the data are available either as average from 1961 to 1990 or from 2000 to 2009. For solar irradiance the time frames are 1981 to 1990 as well as 1991 to 2010.

Since the actual sites of interest are typically not at the same location as the meteorological stations, *Meteonorm* interpolates the meteorological data between the two or three closest sites of measurement and supplements the created data with surface data from five geostationary satellites [Meteonorm, 2015].

Given that it is one of the most extensive data sources, several PV simulation software programs like *PVSyst* or *PV*Sol* use *Meteonorm* as a basis for their calculations.

3.2.2 NASA-SSE

NASA-SSE, describes NASA’s program for “Surface Meteorology and Solar Energy”. It offers monthly satellite data, which are published online and are freely accessible. The accuracy is with a resolution of 1° latitude times 1° longitude comparatively low[2], but worldwide data are available. The data were measured over a time span of 22 years from 1983 to 2005 and contain measurements of solar irradiation, temperature, humidity and wind speed [NASA-SSE, 2015].

3.2.3 U.S. TMY 2/3

The “National Solar Radiation Data Base”, provided by the "National Renewable Energy Laboratory” (NREL) contains data for “typical meteorological years” (TMY) of version 2 and 3. There are 239 measured sites available for TMY2, which are based on average data from the time of 1961 to 1990. The newer TMY3 data however contains 1,020 locations measured between 1991 and 2005. Because of the younger and more accurate data of TMY3 NREL recommends their use instead of TMY2. The data are free available on the website of NREL and come in form of comma-separated-value – files (.csv) [NREL, 2015].

3.2.4 RETSCREEN

The free downloadable software database *RETScreen*, provided by “Natural Resources Canada“, consists of ground measurement- and NASA satellite- data and is available for locations all over the world. The time resolution is with monthly averages relatively low. Further, the only irradiation data available is for global horizontal irradiation (GHI). Besides that, data for relative humidity, air- & earth- temperature and wind speed are also available, which are all considered relevant for PV systems. The period of measurement of these data ranges from 1961 to 1990 [RETScreen, 2014].

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[2] 1° latitude equals ~ 68 miles, 1°longitude decreases from ~68 miles at the equator to 0 miles at the poles

3.3 IRRADIATION DATA – COMPARISON

Table 4 shows the monthly global horizontal irradiation for the City of Savannah from the different sources described as well as the average GHI. With an annual global horizontal irradiation of 1,666.8 kWh/m² a very good potential for high energy yields is given. Further, it can be shown that the deviations of average irradiations between the sources are relatively low, with a maximum of -1.9 % with the data provided by the *NASA-SSE* database.

Table 4: Horizontal Irradiation data - monthly and from different sources

Database:	**Meteonorm** [kWh/m²]	**NASA-SSE** [kWh/m²]	**US TMY3** [kWh/m²]	**RETScreen** [kWh/m²]	**Average** [kWh/m²]
January	80.5	85.6	80.5	85.9	83.1
February	93.4	95.8	93.5	99.4	95.5
March	141.0	138.3	141.1	144.8	141.3
April	182.4	169.8	182,4	174.9	177.4
May	199.5	189.4	199.6	192.5	195.2
June	179.8	176.4	179.9	188.1	181.0
July	193.7	181.4	193.7	187.6	189.1
August	172.0	162.4	172.0	170.2	169.2
September	129.4	136.5	129.4	141.3	134.2
October	128.0	124.0	128.1	126.2	126.6
November	95.5	93.6	95.4	92.7	94.3
December	79.1	81.8	79.1	80.0	90.0
Total:	**1,674.2**	**1,634.9**	**1,674.7**	**1,683.4**	**1,666.8**
Difference to average:	**+0.4 %**	**-1.9 %**	**+0.5 %**	**+1.0 %**	**-**

When analyzing Figure 8 in greater detail it can be seen that on a monthly basis these data vary a little more. However, the data of *Meteonorm* and the US TMY3 are highly in agreement. The reason to this is likely that there are a total of 3 meteorological stations in the immediate surrounding region of Savannah, namely the Savannah State College, the Hunter Army Airfield and the Savannah International Airport, which are all used by both sources. Contrary to this the *NASA-SSE* uses relatively coarse satellite data, what may be the reason for the deviation. For the data provided by *RETScreen* the deviation may be ascribable to rounding errors, due to the data given in monthly averages of daily irradiation.

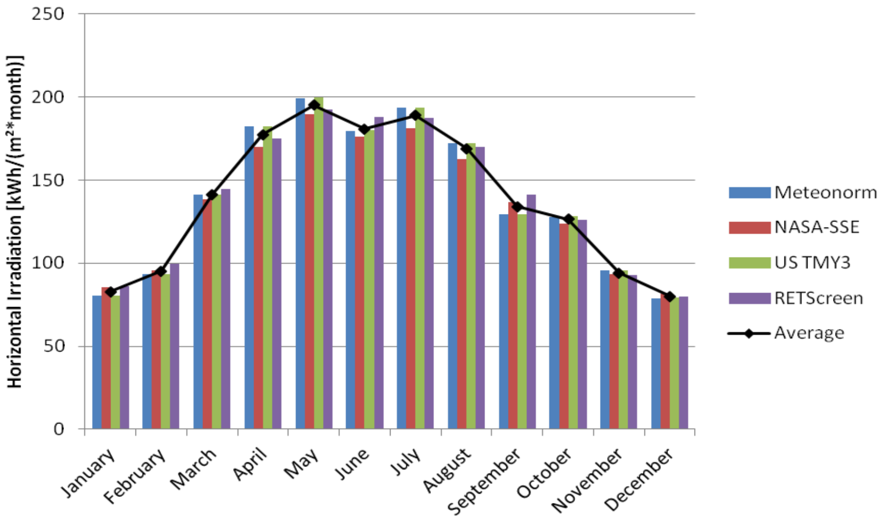

Figure 8: Monthly horizontal irradiation data

3.4 TEMPERATURE DATA – COMPARISON

A comparison in *Figure 9* of the monthly average temperature data between the sources shows a high conformity, but for calculating a prediction for a PV generator yield these monthly average temperature data are not sufficient. The reason to this is that they include temperatures during nighttime, which are not relevant for PV energy generation. Further, the temperatures occurring during noon are more relevant than temperatures at morning or in the evening, since their effect on production is proportional to the irradiance. Therefore, hourly data are necessary for simulating the likely production of energy, which is possible with *Meteonorm*- as well as with *US TMY2/3*- data.

For the purpose of analyzing temperature extremes *Figure 9* includes hourly maximum and minimum temperatures for each month. With this knowledge it can be seen that temperatures below -10 °C are very unlikely to occur, what can be used for the dimensioning of module string lengths, since they depend on the maximum voltage that can occur in a module, what happens with lowest temperatures.

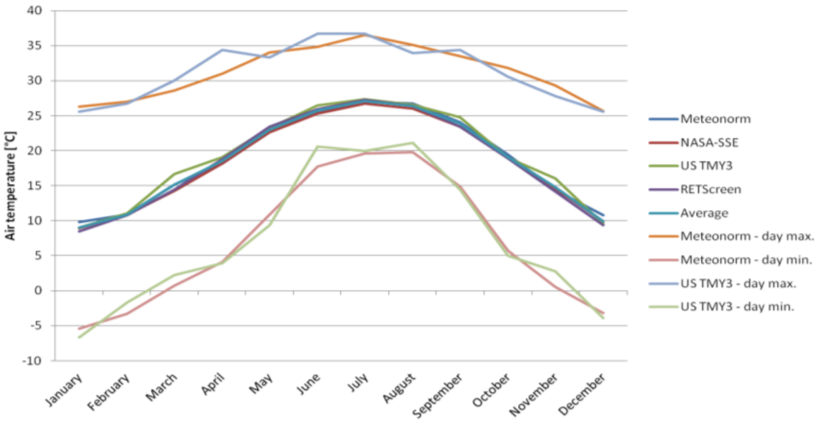

Figure 9: Monthly average air temperature and min-/ max- temperatures

3.5 WIND DATA – COMPARISON

Figure 10 shows the monthly average wind speeds from 4 different sources, as well as the monthly maxima from the source *Metenorm* and *US TMY3*. The higher wind speeds measured by *NASA-SSE* can be related due to the height of measurement. With 50 m above ground this measurement takes place much higher than with the other sources, which measure in a height of 10 m. Therefore the average values are calculated by using these other sources only. The result is an annual average wind speed of 3 m/s.

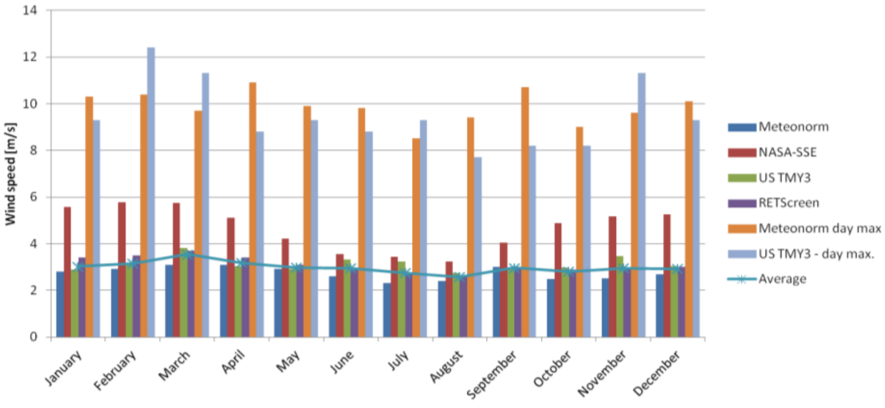

Figure 10: Monthly average and monthly maximum wind-speeds

It has to be mentioned that the shown maxima are not to be used for dimensioning the mounting system of PV applications in this region. The reason is that Savannah is located in a possible impact region of hurricanes. Therefore, the structure should be built to withstand these weather extremes, where wind speeds of up to 120 miles/h (54 m/s) or greater can occur [BTG, 2002].

3.6 RELATIVE HUMIDITY – COMPARISON

The monthly average data for relative humidity is shown in *Figure 11*. It can be clearly seen that especially in the time from June to September a high relative humidity rate is very likely. In connection with the temperature peak from June to August shown in *Figure 9* this increases the risk of the occurrence of potential induced degradation (PID), which is recommended to consider when deciding on a module product.

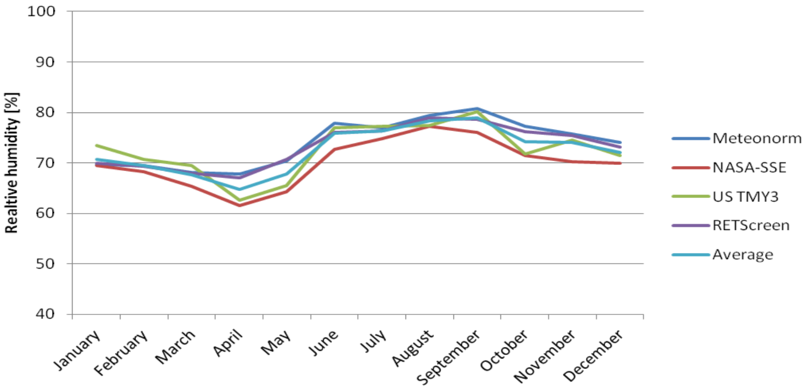

Figure 11: Monthly average relative humidity

3.7 METEOROLOGICAL DATA – CONCLUSION

It is shown that all data agree with the high potential of solar irradiation that is available in the region of Savannah. Further, the occurrence of regular rainfalls provide good conditions for self-cleaning effects of modules. Disadvantageous could be the year round relatively high ambient temperatures in combination with a high humidity, since they contribute to high module temperatures and as result in reduced module efficiencies. However, the advantage of a high irradiation exceeds this efficiency losses by far and very good annual results for energy yields are possible.

It is decided to use the database of Meteonorm as source for all calculations done in this thesis. The reason is that its data comes in hourly time intervals what is seen as necessary for the analyses. Another reason is that this database is also used by the PV simulation software that is used for verifying the calculated results, what helps to minimize sources of error.

4 PHOTOVOLTAIC TECHNOLOGIES

In this chapter a short summary of available PV technologies is performed, including their major differences and the impacts these could have on the economics of PV systems.

4.1 CRYSTALLINE SILICON - MODULES

The vast majority of PV systems today is equipped either with mono- or multi-crystalline module technology due to their reliability and well known operating behaviors. As shown in *Table 5* the current efficiency records with these types are 25 % for mono-crystalline- and 20.76 % for multi-crystalline- cells under laboratory conditions. The highest achieved efficiencies for complete modules are 21.5 % for mono- and 19.4 % for multi- crystalline types in respect to the total module area. It is important to point out that in most applications the efficiency is less important than the resulting system price per Watt, since these highest efficiency modules are usually way more expensive than modules with moderate efficiencies. Therefore the latter often achieve better overall economic results. Some typical efficiencies are pointed out in *Table 5*.

Table 5: Silicon type efficiencies

Type	$\eta_{\text{max, cell}}$	Source	$\eta_{\text{max, module}}$	Source	η_{usual}	Source
Mono-Si	25 %	**[NREL, 2014]**	21.5 %	**[Shahan, 2014]**	20- 16 %	**[Maehlum, 2013]**
Multi-Si	20.76 %	**[Trina Solar, 2014]**	20.76 %	**[Trina Solar, 2014]**	17.8- 14 %	**[Maehlum, 2013]**
Mono-Si + aSI	25.6 %	**[NREL, 2014]**	19.4 %	**[Maehlum, 2013]**	19.4- 17 %	**[Maehlum, 2013]**

Additionally to the conventional silicon-type solar cells there is another approach, which combines mono-crystalline silicon structures with amorphous silicon layers. This increases the highest achievable efficiencies to a value of 25.6 % in a cell dimension and further lowers the losses due to high cell temperatures through a better temperature coefficient. Modules equipped with this technology are available with efficiencies of up to 19.4 %. In addition, some of these module designs allow irradiation from both front and back side, what can lead to higher energy yields throughout the year when installed above a reflecting surface.

4.2 CdTe

Compared to silicon-type PV the technology of cadmium-telluride solar cells is less spread. This is probably due to lower achieved maximum efficiencies, less understood lifetime behavior and concerns about the use of the potentially toxic element cadmium. However, recently strong increases in efficiency and reliability were announced. With module efficiencies around 15 % the competitiveness with conventional module technologies is already given. Further this technology shows advantages under humid and hot climate conditions due to a better spectral response with diffuse light and a low temperature coefficient (< -0.3 %/°C), which increases the overall energy yield throughout a year compared to silicon modules [First Solar, 2015].

4.3 CIGS

The technology of CIGS is also still a niche product, but similar to CdTe-modules constant progresses in efficiency and manufacturing processes are shown. Again concerns about toxicity of a used element (selenium) and a predicted but also disputed possibility in a shortage of the element indium slows the development of this technology. Nevertheless, the efficiencies are already competitive and a low temperature coefficient promotes use in hot climate regions.

Table 6: Thin-film type efficiencies

Type	**$\eta_{max, cell}$**	**Source**	**$\eta_{max, module}$**	**Source**	**η_{usual}**	**Source**
CdTe	21.5	**[NREL, 2014]**	17 %	**[First Solar, 2015]**	14.5- 10 %	**[Maehlum, 2013]**
CIGS	21.7	**[NREL, 2014]**	16.6 %[3]	**[Wesoff, 2014]**	15.2- 12%	**[Maehlum, 2013]**

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[3] Efficiency based on aperture area

4.4 CPV

Concentrating PV systems (CPV) are still in a very early stage of development. Usually they require at least a one-axis or better a two-axis tracking system. Since they can only convert direct irradiance they are recommended for regions with a high DNI[4] above the mark of 1,800 kWh/(m²*yr) [Höller, Advanced Photovoltaics - Part 7 - CPV, 2014b]. One advantage of these systems is that due to the concentration of irradiance less cell area is required and therefore more expensive solar cell constructions could be used economically. Further this high irradiance density leads to an increasing cell voltage and in consequence to a higher achievable cell efficiency.

Figure 12 shows the direct- and diffuse- solar irradiation on a horizontal surface as well as the direct normal irradiation for a typical meteorological year and several cities in the state of Georgia [Meteonorm, 2015]. It can be observed that there is a high share of diffuse irradiation, what decreases the applicability of concentrating systems. The resulting DNI of 1,500 - 1,600 kWh/(m²*yr) is below the annual global horizontal radiation and also below the described minimum of 1,800 kWh/(m²*yr). Therefore, the application of CPV-systems is not recommended with the current state of development.

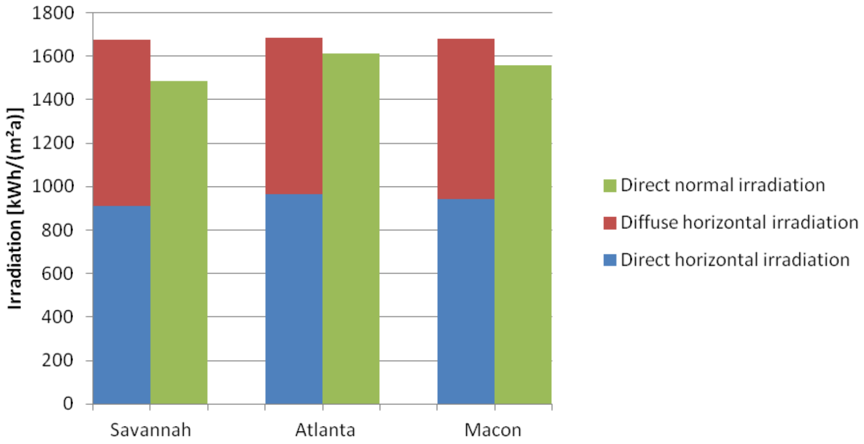

Figure 12: Irradiation data - Georgia **[Meteonorm, 2015]**

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[4] DNI - Direct normal irradiation

4.5 TECHNOLOGY COMPARISON

In this chapter some consequences of the most important differences in module characteristics are observed.

4.5.1 CONVERSION EFFICIENCY

The above described efficiency factors are often used to rate module qualities. This is appropriate if there is only limited space for module installation available and the maximum possible electricity generation is the main goal. If the available space is not a major issue it is often more recommendable to purchase lower efficiency modules, since their relative price per power is often considerably lower. Nevertheless, it has always be to kept in mind that a larger module area also leads to higher demand of mounting systems. Therefore an optimum between module efficiency, available area and costs has to be evaluated separately for each application. *Figure 13* shows an example of necessary space that comes along with different module efficiencies to achieve a power of 1 kW_P(5).

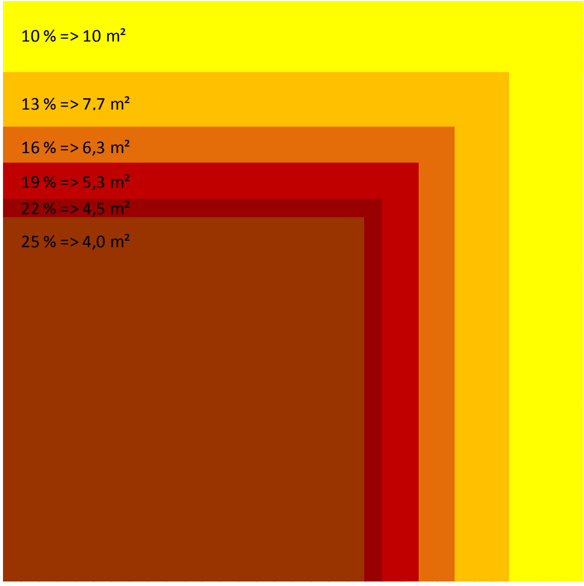

Figure 13: Required total area

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(5) Assumption of Standard Testing Conditions (STC): 1000W/m²; 25°C module temp.; AM 1,5

4.5.2 TEMPERATURE COEFFICIENTS

Table 7 shows a number of typical temperature coefficients for PV modules. It can be found that multi-crystalline as well as conventional mono-crystalline PV - cells suffer under a higher temperature coefficient than high-efficiency mono-crystalline or thin-film solar cells. Since the operating temperature of PV modules can be easily 60 °C or more, a difference of 0.1 %/K would result in a 3.5 % increase of energy losses [Mertens, 2013].

Table 7: Temperature efficiency coefficients

Type	**$\Delta\eta_{\text{max, cell}}$**	**Example Module**
Mono-Si	-0.3 %/K	Sunpower X21-345
	-0.41 %/K	JA Solar JAM6-60-280
Multi-Si	-0.41 %/K	Trina Solar TSM-250 PDG5
	-0.405 %/K	Kioto KPV 260 PE poly
Mono-Si + aSi	-0.29 %/K	Panasonic VBHH250AE01
	-0.27 %/K	Triex U305 Watt
CdTe	-0.29 %/K	First Solar Series 4
	-0.25 %/K	GE Energy GE-CdTe83
CIGS	-0.30 %/K	TSMC Solar TS-165C2
	-0.36 %/K	Manz M-ges101E092

4.5.3 DEGRADATION

The different module technologies can also show different behaviors in their degradation. While most modules show the same or similar guaranteed values for the development of their nominal power output over time, the technology of CdTe-modules has an important difference. With this technology a significant initial degradation of the modules within the beginning of its operating lifetime has to be expected. An example for this would be a degradation of 3 % within the first year [PVSyst SA, 2015].

5 ECONOMICAL ANALYSIS – TOOL

The calculation of economical key figures for PV systems in Savannah depends on a number of factors that are difficult to estimate in a simple analysis. An example is the highly fluctuating cost of electricity purchased from the grid which can be influenced by the time of use, the height of the demand, the amount of total energy consumption, or a combination of these. Another point is the possible self-consumption which depends on the timing of production and consumption. Therefore, a tool is programmed that allows to take all relevant factors into account by simulating all parameters on an hourly basis. This is done in the spreadsheet-program “Microsoft Excel 2010”, in combination with the programming tool “Microsoft Visual Basic”.

5.1 GENERAL

The method for an economic analysis of PV systems is defined in this chapter. The goal of the analysis should be to allow the determination of payback times or maximum investment costs, expectable levelized costs of electricity, internal rates of return as well as the approximate amount of saved energy and the prevented carbon emissions. In general the user surface of the spreadsheet program is divided into a start–page, three input - pages and a printable report - page. It is possible to save or load up to 12 projects within one excel-file, what is controllable from the start - page. Further, there are a total of eight more worksheets that are used for different calculations, but which are hidden to the end-user. *Table 8* provides an overview of all worksheets.

Table 8: Program worksheets – overview

Visible worksheets	Name	Hidden worksheets	Name
1	Home	6	Yield calculation
2	General information	7	Energy balance
3	System data	8	Cash flow
4	Financing	9	Contracts
5	Report	10	Weather data
		11	Load profiles
		12	Scenarios
		13	Save-Load

5.1.1 INPUT PARAMETERS

The economics of PV systems depend on a comprehensive amount of input parameters which are important to allow a realistic analysis. Therefore, these necessary parameters will be defined in the following, sorted by the worksheets where they have to be entered.

5.1.2 GENERAL INFORMATION

This worksheet requires the input of the title of the project, specifications concerning the utility contract (for energy purchase), the consumer's energy usage and the electricity sale contract. *Figure 14* summarizes the necessary input data concerning the utility contract and shows the possible options that are available.

Utility contract

Type of consumer →	Type of contract
- Residential:	- Standard Service - Nights & Weekend - Plug - in Electric Vehicle - Residential Demand
- Small Business:	- General Service - Power & Light - Small
- Medium Business:	- Power & Light - Medium
- Large Business:	- Power & Light - Large - Multiple Load Management
- Governmental / Institutional:	- School Service - School Load Management - Traffic Control Metered

Grid connection level

- Secondary distribution customer (default)
- Primary distribution customer
- Transmission customer

Municipality

- Inside city limits
- Outside city limits

Sales tax

- In percent of electricity bill (usually 7 %)

Energy usage

- Monthly energy usage
- Optional: Monthly billing / peak demand (depending on contract)

Figure 14: General information – Utility contract - inputs

The possible contracts that are shown are only a selection of a total of 42 different energy purchase contracts that are offered by Georgia Power. This selection is made respectively to the contracts that are used by city operated facilities, plus the major residential options. A list of all contracts of Georgia Power is attached in Appendix A.

The input for the grid connection level describes the voltage level of the grid that a facility is connected to. In most cases it will be the secondary distribution grid with a voltage level of 120 / 240 V, but also connections to the primary distribution grid occur in some cases when there are customers with very high usage. The level of this grid connection affect several fees that are invoiced with the electricity purchase bill.

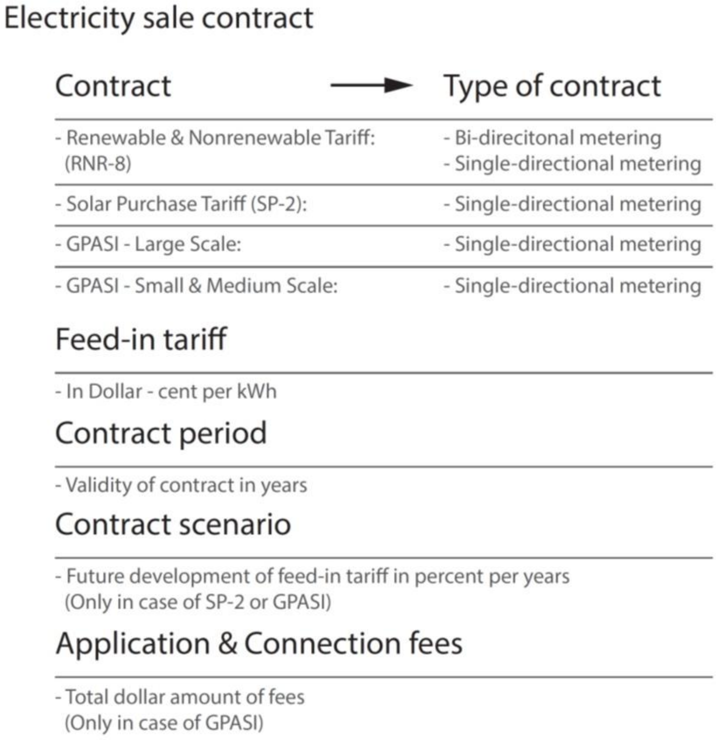
The location inside or outside city limits as well as the height of the sales taxes also affect some fees of the electricity bill. The city government is exempted from paying the latter, but is still affected by the location of its facilities.

With the definition of the energy usage of the past year, and in case of some contracts also the so called “Billing demand”, the current total costs for electricity as well as the average specific costs are computed tool-internally.

The second contract type that has to be defined is for the sale of electricity generated by the PV system. The possible options are shown in *Figure 15*. The most important tariff in context with city operated facilities is the “Renewable & Nonrenewable Tariff RNR-8”, which is the only contract that enables self-consumption of the energy yield. In case of using the tariffs “SP-2” or “GPASI” it is further necessary to enter the time of validity of the contracts.

Since at the time this thesis was written the final tariffs for the GPASI - contracts were not yet announced, it is ensured that all necessary parameters can be entered when they are known, like possible application & interconnection fees as well as a development scenario and height of the feed-in tariff.

Depending on the type of contract chosen, the charge for metering is automatically set, which amounts 2.82 $/month for bi-directional metering, 4.5 $/month for single-directional metering in combination with single-phase feed-in and 11.2 $/month for single-directional metering with a multi-phase grid connection.



Electricity sale contract

Contract	Type of contract
- Renewable & Nonrenewable Tariff: (RNR-8)	- Bi-direcitonal metering - Single-directional metering
- Solar Purchase Tariff (SP-2):	- Single-directional metering
- GPASI - Large Scale:	- Single-directional metering
- GPASI - Small & Medium Scale:	- Single-directional metering

Feed-in tariff

- In Dollar - cent per kWh

Contract period

- Validity of contract in years

Contract scenario

- Future development of feed-in tariff in percent per years (Only in case of SP-2 or GPASI)

Application & Connection fees

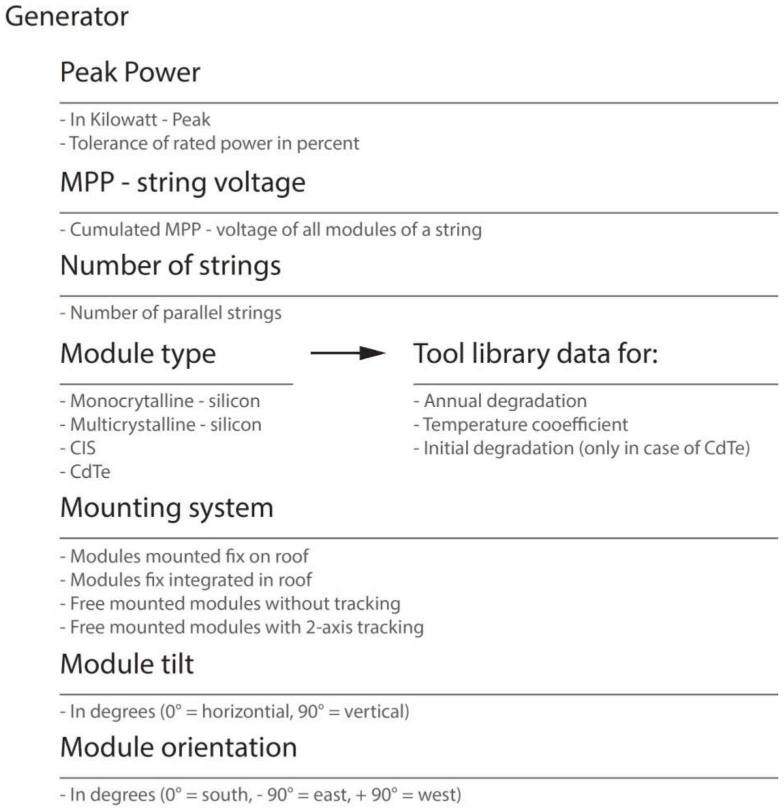
- Total dollar amount of fees (Only in case of GPASI)

Figure 15: General information – Electricity sale contract - inputs

5.1.3 SYSTEM DATA

The tool is programmed to either calculate tool-internally an estimation for the electric energy generation or to read in data provided by an external simulation software. In the latter case the data can either come with an hourly time interval, what makes further definition of generator and system data redundant, or in daily, monthly or annual intervals. In these cases the data for generator and system has to be entered thoroughly, since the tool then interpolates hourly values by combining its internal simulation with the results of the external data.

If data entries are necessary, the parameters shown in *Figure 16* and *Figure 17* have to be defined. The specific needs for these inputs are explained in context with the calculation methods in Chapter 5.2.1 on page 41.



Generator

Peak Power

- In Kilowatt - Peak
- Tolerance of rated power in percent

MPP - string voltage

- Cumulated MPP - voltage of all modules of a string

Number of strings

- Number of parallel strings

Module type

- Monocrytalline - silicon
- Multicrystalline - silicon
- CIS
- CdTe

Tool library data for:

- Annual degradation
- Temperature cooefficient
- Initial degradation (only in case of CdTe)

Mounting system

- Modules mounted fix on roof
- Modules fix integrated in roof
- Free mounted modules without tracking
- Free mounted modules with 2-axis tracking

Module tilt

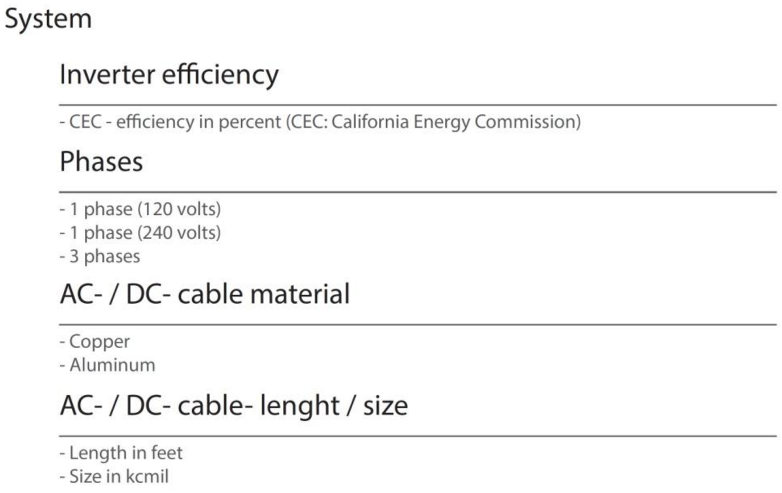
- In degrees (0° = horizontial, 90° = vertical)

Module orientation

- In degrees (0° = south, - 90° = east, + 90° = west)

Figure 16: System data – Generator – inputs

The CEC-efficiency of an inverter describes an average efficiency that is weighted in respect to the inverter’s part-load efficiencies in combination with an estimated share of the occurrence of this particular part load.



System

Inverter efficiency

- CEC - efficiency in percent (CEC: California Energy Commission)

Phases

- 1 phase (120 volts)
- 1 phase (240 volts)
- 3 phases

AC- / DC- cable material

- Copper
- Aluminum

AC- / DC- cable- lenght / size

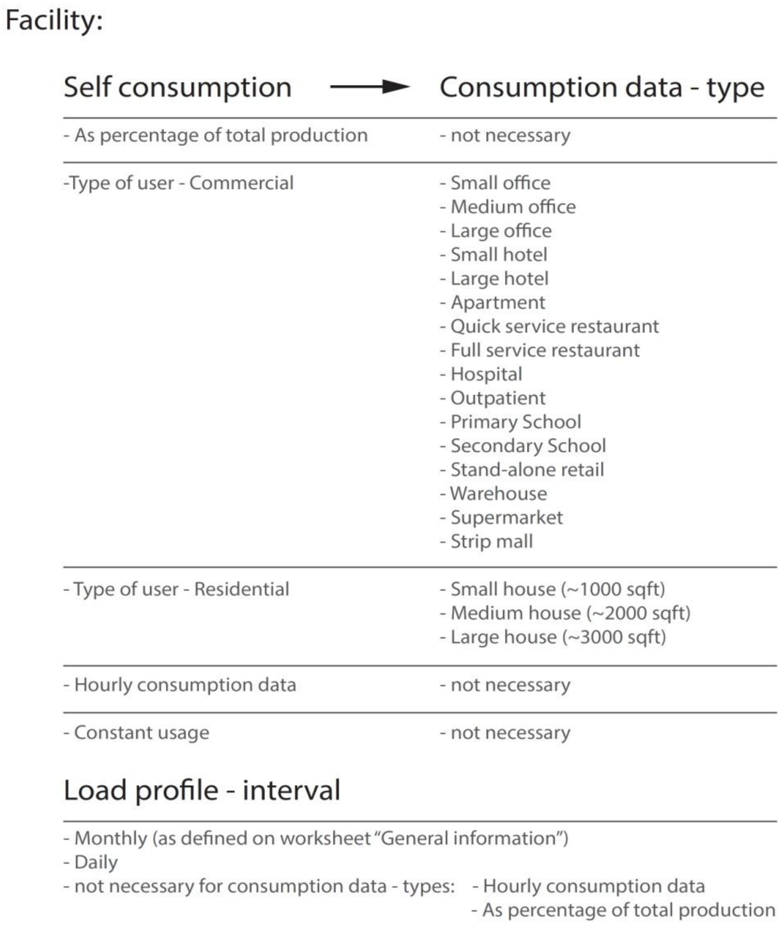
- Length in feet
- Size in kcmil

Figure 17: System data - System – inputs

In case the PV system should be operated with bi-directional metering it is obligatory to define the type of consumer, since it has crucial impact on the achievable amount of self-consumption.

Therefore, the tool provides example load data for 19 different consumer types. These are based on load profiles specified for the region of Savannah using TMY3 weather data from local meteorological stations, and which are provided by the National Renewable Energy Laboratory on their open energy data platform “Open Energy Info” [OpenEI, 2013].

Further possibilities are the input of hourly consumption data if available or the definition of a constant usage. In case of a lack of any information it is also possible to estimate the self consumption as percentage of the total production.



Facility:

Self consumption →	Consumption data - type
- As percentage of total production	- not necessary
-Type of user - Commercial	- Small office - Medium office - Large office - Small hotel - Large hotel - Apartment - Quick service restaurant - Full service restaurant - Hospital - Outpatient - Primary School - Secondary School - Stand-alone retail - Warehouse - Supermarket - Strip mall
- Type of user - Residential	- Small house (~1000 sqft) - Medium house (~2000 sqft) - Large house (~3000 sqft)
- Hourly consumption data	- not necessary
- Constant usage	- not necessary

Load profile - interval

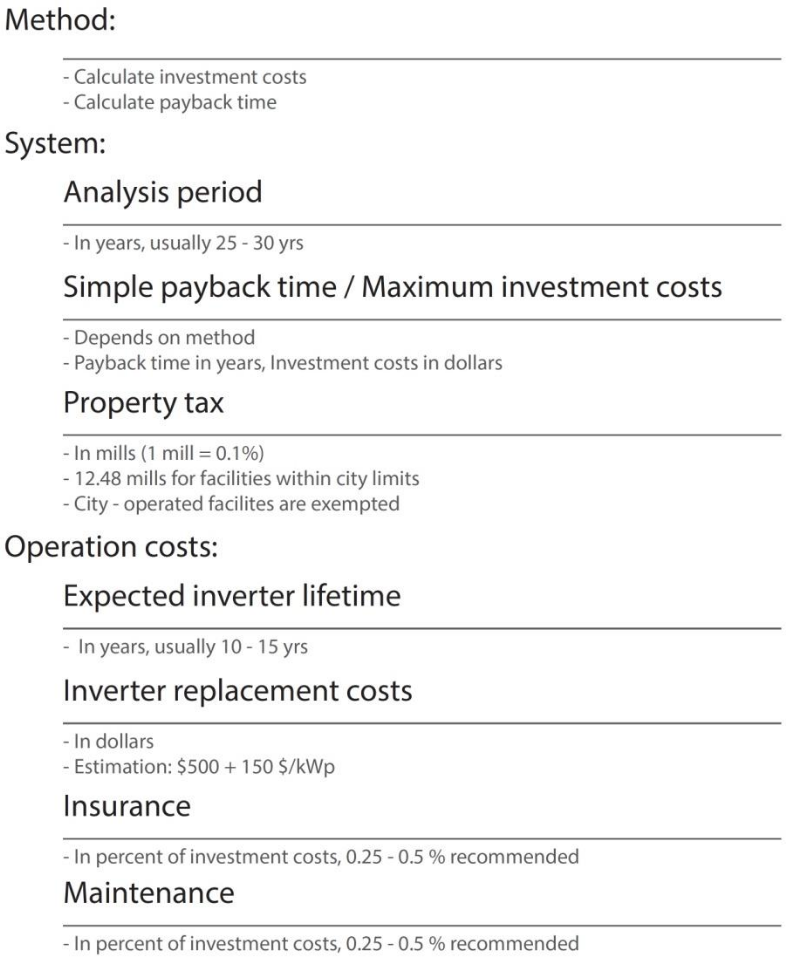
- Monthly (as defined on worksheet “General information”)
- Daily
- not necessary for consumption data - types: - Hourly consumption data
  - As percentage of total production

Figure 18: System data - Facility – inputs

5.1.4 FINANCING

Finally it is important to define the financial parameters, including the possible incentives that were described in Chapter 2. In general, the tool is programmed to allow either the definition of investment costs and then as a result the calculation of payback times or vice versa. This has to be defined within the worksheet “Financing”.

Another relevant input that is requested is concerning the property tax rate. This rate is a tax on private property that has to be paid on an annual basis. For properties located in Chatham County, Georgia, this rate is 12.48 mills, what is calculated against the assessed value, which is typically 40 % of the market value [City of Savannah, 2015]. However, city-operated facilities are exempted of this taxation.



Method:

- Calculate investment costs
- Calculate payback time

System:

Analysis period

- In years, usually 25 - 30 yrs

Simple payback time / Maximum investment costs

- Depends on method
- Payback time in years, Investment costs in dollars

Property tax

- In mills (1 mill = 0.1%)
- 12.48 mills for facilities within city limits
- City - operated facilites are exempted

Operation costs:

Expected inverter lifetime

- In years, usually 10 - 15 yrs

Inverter replacement costs

- In dollars
- Estimation: $500 + 150 $/kWp

Insurance

- In percent of investment costs, 0.25 - 0.5 % recommended

Maintenance

- In percent of investment costs, 0.25 - 0.5 % recommended

Figure 19: Financing- Method and System – inputs

The inverter replacement costs can be set as dollar-value, which is due at each end of an inverter lifetime. The estimated costs are a very rough recommendation, based on average inverter costs of different sizes that were researched online (March, 2015).

The costs for insurance and maintenance have to be entered as percentage of the total investment costs. A technical report about insurance rates by Bethany Speer et.al. and published by NREL suggests that this rate should be set between 0.25 % and 0.5 %, but depending on the occurrence of weather extremes [Speer et.al., 2010]. The operation and maintenance costs are recommended to be set between 0.5 % and 1 % of investment costs, as it is described in a “Best Practices” – Report by Keating et.al., published by NREL [Keating et.al., 2015].

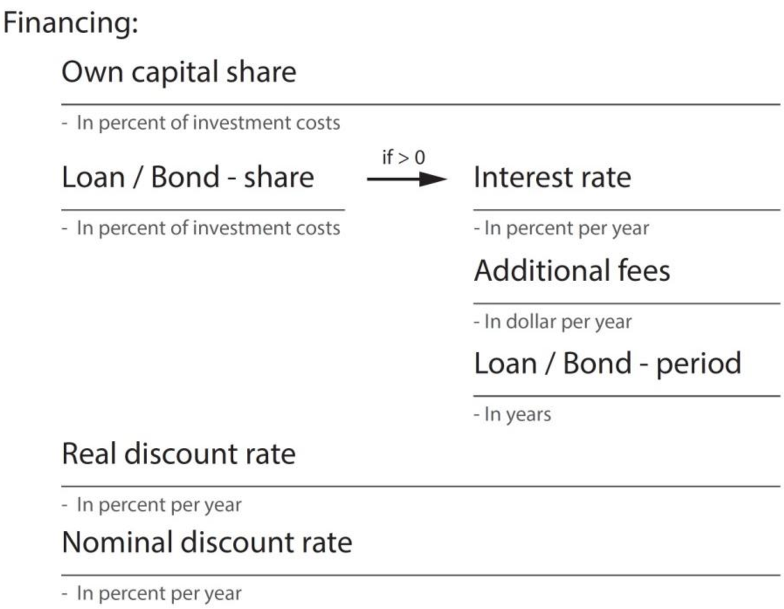


Figure 20: Financing- Financing – inputs

As listed in *Figure 20* it can be chosen between own-capital or loan-/bond- financing by setting their share of the total investment costs in percent.

Highly crucial factors that have to be set are real- and nominal discount rates. These have a major impact on predicted future cost developments, as well as on the appraisement if an investment can be considered as economical or not.

If it is intended to apply for incentives, they have to be set within this worksheet. Of special interest for governmental investments are here the possibilities of bond incentives, which would reduce bond interest rates to a minimum.

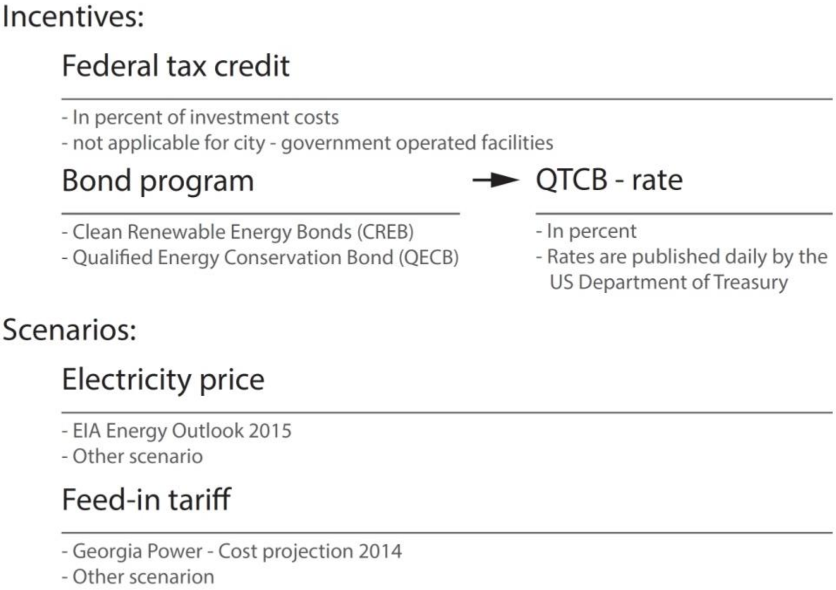
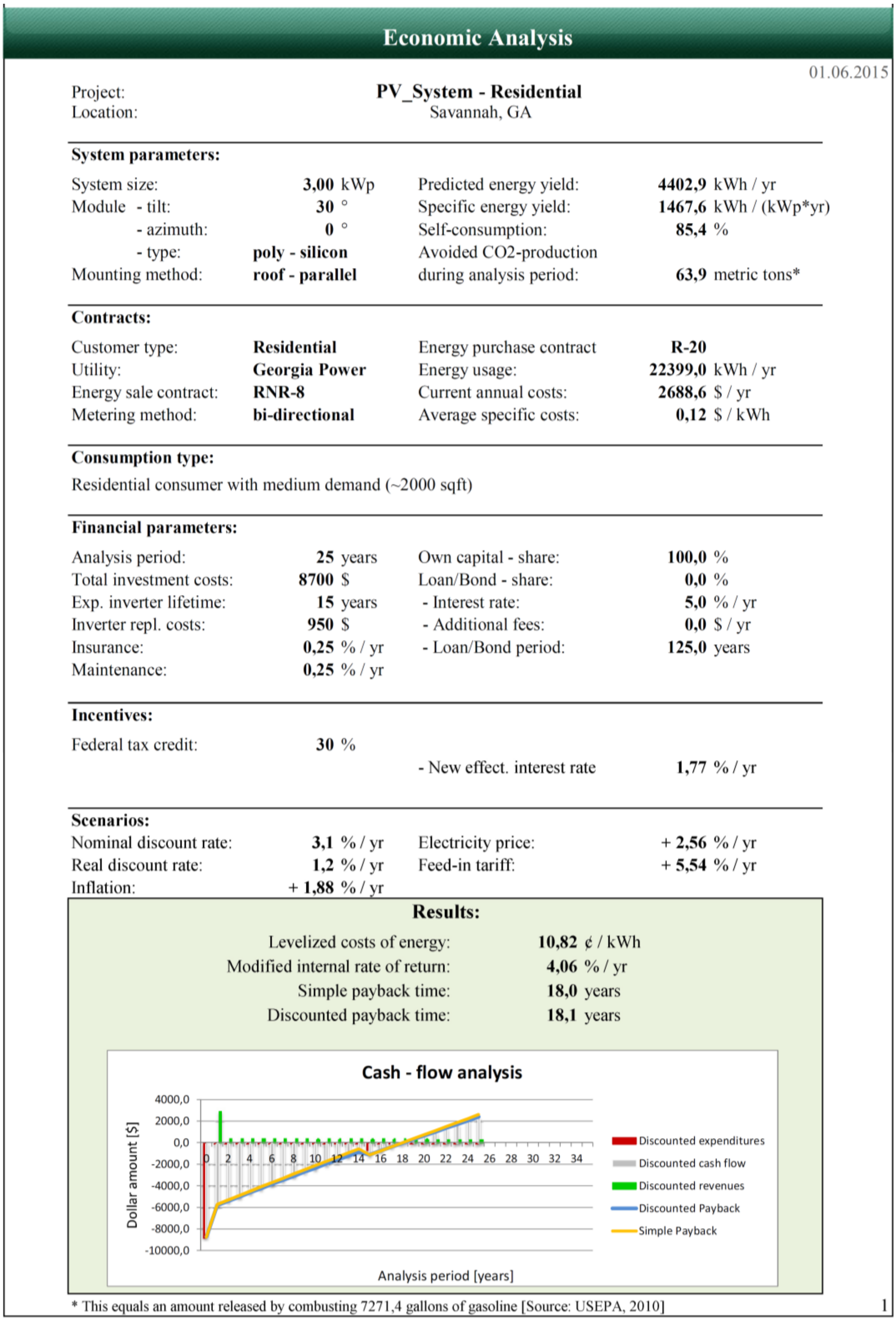


Figure 21: Financing- Incentive and Scenario – inputs

Finally, it is important to define cost scenarios for electricity rates as well as for the development of feed-in tariffs. Since it is very complex to estimate reliable predictions, it is referred to external studies. These are described in Chapter 5.2.7 on page 59.

5.1.5 OUTPUT PARAMETERS

The result of the calculations within the tool are collectively shown on a report page, together with a selection of input parameters that are considered to be key figures of an economic analysis. An example report for a residential system is shown in *Figure 22*.



Economic Analysis

01.06.2015

Project:	**PV_System - Residential**
Location:	Savannah, GA

System parameters:

System size:	**3,00** kWp	Predicted energy yield:	**4402,9** kWh / yr
Module - tilt:	**30** °	Specific energy yield:	**1467,6** kWh / (kWp*yr)
- azimuth:	**0** °	Self-consumption:	**85,4** %
- type:	**poly - silicon**	Avoided CO2-production	
Mounting method:	**roof - parallel**	during analysis period:	**63,9** metric tons*

Contracts:

Customer type:	**Residential**	Energy purchase contract	**R-20**
Utility:	**Georgia Power**	Energy usage:	**22399,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**2688,6** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,12** $ / kWh

Consumption type:

Residential consumer with medium demand (~2000 sqft)

Financial parameters:

Analysis period:	**25** years	Own capital - share:	**100,0** %
Total investment costs:	**8700** $	Loan/Bond - share:	**0,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**5,0** % / yr
Inverter repl. costs:	**950** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**125,0** years
Maintenance:	**0,25** % / yr		

Incentives:

Federal tax credit:	**30** %		
		- New effect. interest rate	**1,77** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	**+ 2,56** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	**+ 5,54** % / yr
Inflation:	**+ 1,88** % / yr		

Results:

Levelized costs of energy:	**10,82** ¢ / kWh
Modified internal rate of return:	**4,06** % / yr
Simple payback time:	**18,0** years
Discounted payback time:	**18,1** years

Cash - flow analysis

* This equals an amount released by combusting 7271,4 gallons of gasoline [Source: USEPA, 2010]

1

Figure 22: Final tool report

This report represents the calculation method for given investment costs, where the result is the time of financial amortization for simple and discounted scenarios. It is also possible to define a desired payback time as basis for the calculations, in which case the maximum total- as well as specific- costs are listed in the result box instead of amortization periods.

5.2 CALCULATION METHODS

To enable the economic analysis the inputs described above have to be processed tool-internally. The methods used for these calculations are described in detail as follows.

5.2.1 GENERATOR YIELD CALCULATION

A crucial part of the economic analysis is the evaluation of energy yield. As described before it is important to have knowledge about this production in time intervals that are as short as possible, since the timing with the facility's electricity usage defines the possible self consumption. Further, the purchase rates for electricity can vary a lot depending on the time of use, what underlines the requirement for short time intervals. On the other hand a too short interval would lead to a very high amount of data and as result in long calculation times. Therefore it is chosen to run the calculations with hourly intervals, since this is sufficient for the reasons described above, good quality data are available with this period lengths and the calculation time stays in a reasonable dimension.

In general, the tool is programmed to allow both a manual input of the generator yield as well as a tool-internal yield calculation. In case the method of reading in hourly data from a second source is not chosen, it is necessary to compute a prediction of the hourly system output. This tool-internal prediction can then be verified with either daily, monthly or annual predictions from another simulation tool or used directly. In case a method of verification is chosen, the tool scales the calculated hourly data in a way that it matches the input data.

The first step of calculating the energy yield is to compute the irradiance on the module surface. It is decided to use the same source for weather data as the software program

“PVSyst 6.3.5”. The reason to this is that a method is developed within this thesis to verify the results of the tool internal calculations through a comparison with results of the named simulation software. Therefore, it is necessary to use the same basis data for the calculations to minimize sources of error.

The following data for the region of the city of Savannah are transferred to the economic analysis tool in hourly time intervals:

- Sun azimuth, α_S [°]
- Sun elevation, γ_S [°]
- Global horizontal irradiance, $E_{G,hor}$ or GHI [W/m²]
- Diffuse horizontal irradiance, $E_{diff,hor}$ [W/m²]
- Direct horizontal irradiance, $E_{dir,hor}$ [W/m²]
- Ambient temperature, T_{amb} [°C]

The total irradiance on the module surface is a result of the sum of three different types of irradiance, that have to be calculated separately:

5.2.1.1 DIRECT IRRADIANCE ON MODULE PLANE

The direct irradiance is defined as the irradiance that comes directly from the sun. Its intensity can be calculated with knowledge of either the current direct normal- or direct horizontal irradiance and its incident angle on the module surface. The latter is a result of the sun elevation and the sun azimuth in combination with the module tilt and orientation. Since the tool allows the calculation of both fixed mounting methods and two-axis tracking systems there are two different formulas used.

- Fixed mounting method:

The incident angle with a fixed mounting method can be calculated for each time interval as a result of the sun incident angle and the modules' orientation and tilt.

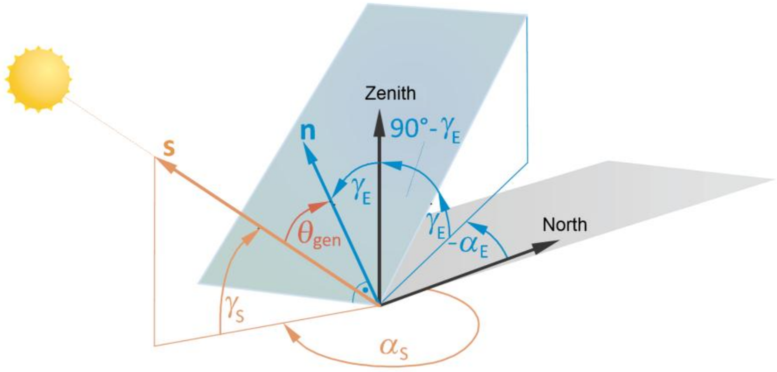


Figure 23: Incident angle on fixed surface **[Quaschning, 2006]**

This is done by calculating the vectors of sun irradiance and module plane with the following formulas described by [Quaschning, 2006].

Sun vector:

$$\vec{\boldsymbol{s}} = \begin{pmatrix} \cos \boldsymbol{\alpha_S} * \cos \boldsymbol{\gamma_S} \\ -\sin \boldsymbol{\alpha_S} * \cos \boldsymbol{\gamma_S} \\ \sin \boldsymbol{\gamma_S} \end{pmatrix} \qquad [5.1]$$

Module plane vector:

$$\vec{\boldsymbol{n}} = \begin{pmatrix} -\cos \boldsymbol{\alpha_E} * \sin \boldsymbol{\gamma_E} \\ \sin \boldsymbol{\alpha_E} * \sin \boldsymbol{\gamma_E} \\ \cos \boldsymbol{\gamma_E} \end{pmatrix} \qquad [5.2]$$

Figure 23 shows the definitions of the necessary angles. It can be seen that the azimuth angles of sun and module planes are defined with north being zero degrees and clockwise being positive.

The incident angle θ_{gen} is the result of an arccosine and a scalar product of these vectors, which is shown in equation 5.3.

$$\boldsymbol{\theta_{gen} = \arccos(\vec{s} * \vec{n})}$$
[5.3]

To enable the calculation within the spreadsheet-program “Microsoft Excel 2010” it is necessary to solve this matrix. Equation 5.4 shows the resulting formula.

$$\theta_{gen} = \arccos(-\cos\alpha_S * \cos\gamma_S * \cos\alpha_E * \sin\gamma_E - \\ -\sin\alpha_S * \cos\gamma_S * \sin\alpha_E * \sin\gamma_E + \sin\gamma_S * \cos\gamma_E) \qquad [5.4]$$

Finally, with this incident angle it is possible to calculate the direct irradiance on the module surface, described by equation 5.5. The maximum-function in this equation ensures that only irradiation with an incidence angle smaller than 90° counts towards the energy balance, since an angle greater than this would describe irradiation that is coming towards the backside of the module

$$E_{dir,gen} = E_{dir,hor} * \left\{max\left\{0, \frac{\cos\theta_{gen}}{\sin\gamma_S}\right\}\right\} \qquad [5.5]$$

- Two-axis tracking system:

  The direct irradiance on a PV system equipped with two-axis tracking is also calculated by using equation 5.5, but with the difference that the incident angle θ_{gen} is set to zero.

5.2.1.2 DIFFUSE IRRADIANCE ON MODULE PLANE

The diffuse irradiance represents light that is reflected or emitted by another source at the sky that is not the sun, for example clouds. Since the tool-internal simulation is rather intended to provide a simple prediction of the generator yield than a fully sophisticated simulation and to limit the input data that is necessary for each simulation, it is chosen to use a simple isotropic approach. This model assumes an uniform irradiance from all sky directions. Therefore, with knowledge of the horizontal diffuse irradiance and the module tilt it is possible to calculate the diffuse irradiance on the module surface by using equation 5.6.

$$E_{diff,gen} = E_{diff,hor} * \frac{1}{2} * (1 + \cos\gamma_E) \tag{5.6}$$

In case of a two axis tracking system the module tilt is changing respectively to the current sun incident angle. Therefore the angle is defined as shown in equation 5.7.

$$\gamma_E = 90° - \gamma_S \tag{5.7}$$

5.2.1.3 REFLECTED IRRADIANCE ON MODULE PLANE

The third part of the total irradiance is ground reflection. It is defined by the ability of the surrounding objects to reflect light towards the modules, called albedo (A). This albedo depends on the surface type of the generator's environment and is given as a fraction of 1. To simplify the usage of the tool it is decided to define A = 0.2 [-], what is commonly seen as standard for unknown surfaces. The formula for the reflected irradiance is shown in equation 5.8 [Höller, 2014a].

$$E_{refl,gen} = E_{G,hor} * A * \frac{1}{2}(1 - \cos\gamma_E) \tag{5.8}$$

5.2.1.4 TOTAL IRRADIANCE ON MODULE PLANE

The total irradiance on the module plane is defined in equation 5.9 as the sum of direct-, diffuse- and reflected irradiance.

$$E_{G,gen} = E_{dir,gen} + E_{diff,gen} + E_{refl,gen} \tag{5.9}$$

5.2.1.5 MODULE TEMPERATURE

The next important parameter is the temperature of the PV modules under operating conditions, since it has a crucial impact on the generators efficiency. It is computed by using the same method as the software program "PVSyst 6.3.5", again to minimize possible sources of error previously to the validation process.

$$U * (T_{module} - T_{amb}) = \alpha * E_{G,gen} * (1 - \eta_{module}) \tag{5.10}$$

This model uses a heat transfer coefficient for the heat losses, that is defined equivalent to the settings in PVSyst and in dependency of the mounting method.

- Free mounted modules: U = 29 [W/(m²*K)]
- Fix mounted modules with air duct behind: U = 20 [W/(m²*K)]
- Fix integrated modules with insulated backside: U = 15 [W/(m²*K)]

Further, the absorption coefficient is assumed with $\alpha = 0.9$ [-] and the module efficiency η_{module} is set with 0.14 [-].

5.2.1.6 TOTAL GENERATOR YIELD BEFORE VALIDATION

The generator power can be computed by combining formula 5.11 and 5.12, where E_{STC} is 1000 W/m² and T_{STC} is 25 °C. The temperature coefficient $\Delta\eta_{Pmpp}$ depends on the module technology, further described in Chapter 4.5.2.

$$P_{Peak} = E_{STC} * A_{gen} * \eta_{gen} \qquad [5.11]$$

$$\begin{aligned} P_{Gen} &= E_{G,gen} * A_{gen} * \eta_{gen} * \left(1 - \Delta\eta_{Pmpp} * (T_{module} - T_{STC})\right) \\ &= E_{G,gen} * \frac{P_{Peak}}{E_{STC}} * \left(1 - \Delta\eta_{Pmpp} * (T_{module} - T_{STC})\right) \qquad [5.12] \end{aligned}$$

Since all calculations are done on an hourly basis, the value of the calculated power [W] is equal to the generator energy yield per hour [Wh].

5.2.2 YIELD MODIFICATION

The described calculation process is a simplified method. Therefore, the results cannot be used directly for further analyses, as they do not match to results simulated in a more sophisticated calculation program as PVSyst. To meet this problem a simple modification process is developed to achieve more accurate results while maintaining the simplicity of the calculation process.

The programmed tool is intended to allow the simulation of Silicon-, CdTe- and CIS-module technologies. As described in Chapter 4 these technologies can show different operating behaviors, especially under low- and diffuse light conditions, for example due to different spectral response characteristics. Therefore, a separate modification is performed for each of these technologies.

To begin with the modification simulations of identical example systems are done both tool-internally and in PVSyst for all 3 technologies. These calculations are performed for the orientations south, east and west, as well as for the module tilts 0°, 30°, 60° and 90°. The resulting predictions for the hourly generator yields of these simulations are then transferred to a spreadsheet. Since the data from PVSyst already includes all losses of the DC-section of a PV-system, these have to be subtracted from the tool internal calculations too. The methods for this are described in Chapter 5.2.3. Then a comparison is done by sorting these hourly data in dependency of the global horizontal irradiation and displaying their relative error (equation 5.13) in a graph. An example is shown in *Figure 24*, where the blue data points represent these errors. A complete illustration of all analyzed orientations and module tilts is attached in Appendix B.

$$e_{relative} = \frac{E_{PVSyst}}{E_{tool}} \tag{5.13}$$

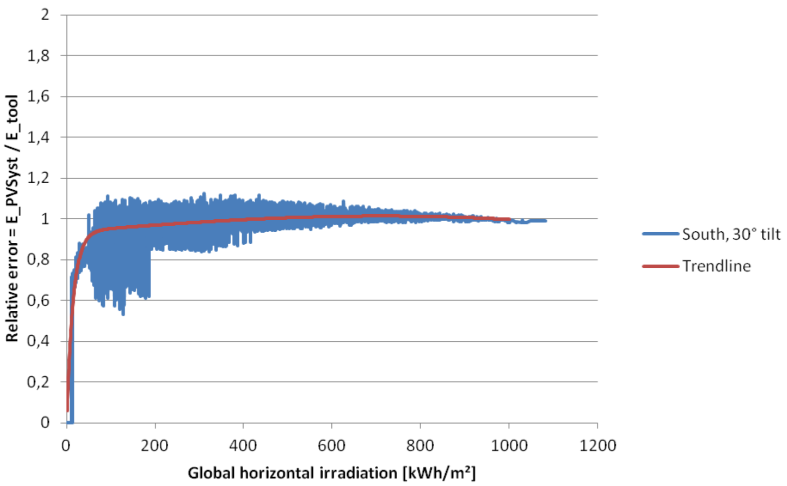


Figure 24: Relative error - silicon module to south, 30° tilt

Despite the noise of the data it can be obtained that there is clearly a trend of an increasing error under low light conditions, showing an overestimation by the programmed tool.

Further, in total the tool-internal predictions exceed the predictions simulated in PVSyst. Therefore, a trendline is introduced to compensate for this error, shown in *Figure 24* in red.

This trendline is put together out of three elements, shown in equation 5.14. The first part represents a fast growing term that slows down when approaching the value of “K”, while the speed for approaching this value “K” is defined by the constant “a”. This term is also used for step response programming in control engineering. The second term is a sinus-function, used for introducing a bend to the trendline. The last term represents a simple slope.

$$f(GHI) = K * \left(1 - e^{\left(\frac{-GHI}{a}\right)}\right) + b * \sin\left(\frac{GHI}{c}\right) - d * GHI \qquad [5.14]$$

With this function it is possible to modify the tool internal calculations by adjusting the variables “K”, “a”, “b”, “c”, and “d” to reduce the relative error. This is done for all 3 technologies and for all module tilts and orientations in a way that the trendline follows the course of the error and that the annual prediction of both programs match exactly.

As result the variables “K” and “d” are different for each orientation, whereas the variables “a” to “c” only differ between the different module technologies. Therefore, formulas are developed to adjust “K” and “d” in dependency of the module tilt and orientation.

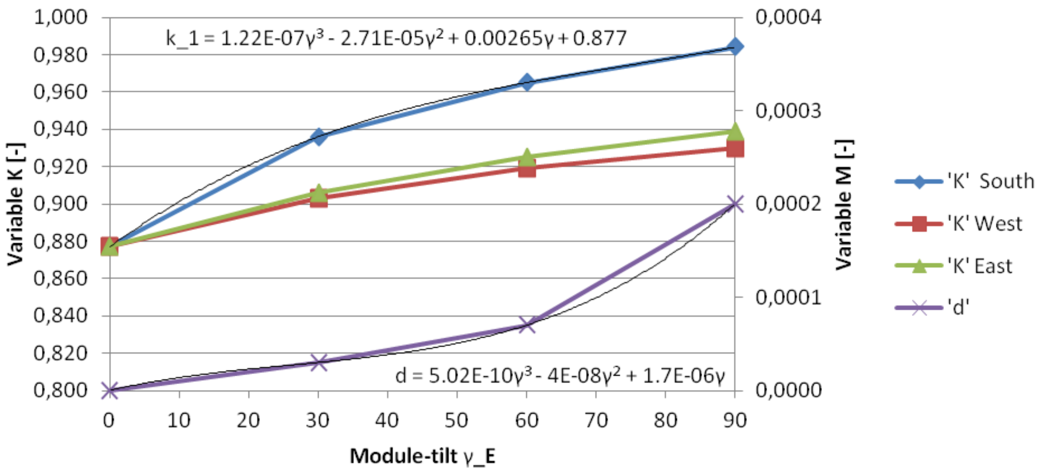


Figure 25: Variables "K" & "d" with respect to module tilt

Figure 25 shows both variables “K” and “d” with respect to the module tilt and for all orientations for silicon module technologies. It can be seen that only “K” depends on the orientation as well as on module tilt. Therefore, it is decided to split it into two sub-variables “k_1” and “k_2”, where “K” is the sum of them. By introducing trend lines of 3rd order into *Figure 25* the equations for “k_1” and “d” are defined.

$$k_1(\gamma_E) = e * {\gamma_E}^3 + f * {\gamma_E}^2 + g * \gamma_E + h \qquad [5.15]$$

$$d(\gamma_E) = l * {\gamma_E}^3 + m * {\gamma_E}^2 + n * \gamma_E \qquad [5.16]$$

Finally, the dependency on the module orientation is defined with a formula for k_2, which is developed by setting the data points for k_1 as reference points and then introducing a trendline of second order. This trendline is further modified by a term in dependency of γ_E, since the deviation of K grows with increasing module tilt. This is shown in *Figure 26* as well as in equation 5.17, again for silicon module technologies.

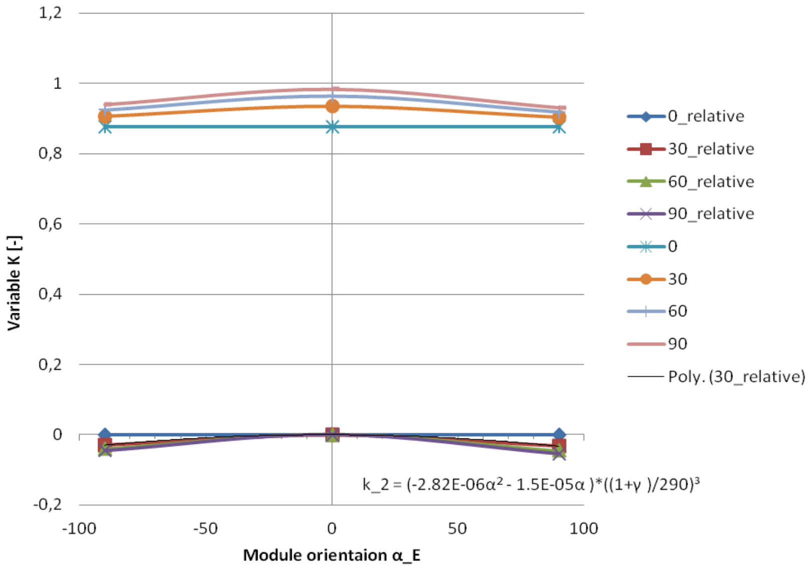


Figure 26: Variable "K" with respect to module orientation

$$k_2(\alpha_E) = (m * {\alpha_E}^2 + n * \alpha_E) * (\frac{1+\gamma_E}{k})^3 \qquad [5.17]$$

With this modification process it is possible to calculate generator yield predictions tool-internally that are similar in their results to predictions of the much more sophisticated simulation software PVSyst. Especially the annual generator yield is tried to be modified to match with great accuracy, since it has great impact on the final financial analysis.

5.2.3 LOSSES

This chapter describes the sources of energy losses that are included in the tool-internal calculation process. Losses that are not covered within this chapter are compensated with the described modification process of Chapter 5.2.2.

- Power tolerance:

  When purchasing PV modules, they always come with a tolerance of their nominal power. Typical values are ±3 % for silicon modules and ±5 % for thin-film technologies. In the calculation process of this tool it is decided to use the power that represents the lower quarter of this tolerance band. This decision is made with reference to PVSyst, since they use the same method with the explanation that manufacturers hardly sell products that are better than promised.

  In consequence this means that a module with ±3 % power tolerance is assumed to have a power that is reduced by a negative tolerance of -1.5 %.

- Mismatch losses:

  Additionally to the nominal power tolerance there is a loss that occurs due to a mismatch of current productions of modules connected in a row. This is due to the characteristics of modules in series, since their circuit current is limited to the lowest production of a single module. The assumption is made that these losses reduce the string power by 1 %, which matches the assumption made by PVSyst.

- Soiling losses:

  Another effect that reduces the harvestable energy is the soiling of modules. In principle, the circumstances in the region of Savannah promise good self-cleaning effects due to a regular rain, but on the other hand this region shows also a strong occurrence of pollen over a long period in spring. Therefore, it is decided to include 3 % annual soiling losses like it is proposed as default value in PVSyst.

- DC- cable losses:

The ohmic losses of the DC-circuit are calculated as result of string voltage, amount of parallel strings and cable dimensions and in dependency of the generated power of each time interval. Further, it is possible to choose either copper or aluminum as cable material, since they can both be used with PV applications. The applied equations 5.19 and 5.18 are described in the book “Planning & Installing Photovoltaic Systems” [DGS, 2008].

$$R_{cable} = \rho_{\mathrm{cable}} * \frac{\mathrm{l}_{\mathrm{single\ length}}}{\mathrm{A}_{\mathrm{cable}}} \quad [5.18]$$

$$P_{loss-DC} = R * I^2 = 2 * R_{cable} * n_{string} * \left(\frac{P_{gen}}{n_{string} * U_{string}}\right)^2 \quad [5.19]$$

- Inverter losses:

The energy losses that occur in the inverter with the transformation of DC- to AC-power are included by using a factor for inverter efficiency. Since the real efficiency of inverters vary in dependency of current power and voltage it is not recommended to use its nominal efficiency. Instead it is decided to use a weighted efficiency, called “CEC-efficiency”, defined by the California Energy Commission. This efficiency should represent the annual average efficiency of an inverter and is usually stated in the datasheet.

- AC- cable losses:

For the calculation of AC- cable losses it is necessary to differ between single- and multi – phase grid connections as well as between the possible voltage levels of 120, 240 V and 480 V. Again, the methods used are described in [DGS, 2008].

$$P_{loss-AC-single} = 2 * R_{cable} * \left(\frac{P_{inverter}}{U_{AC-single\ phase}}\right)^2 \quad [5.20]$$

$$P_{loss-AC-3phase} = 3 * R_{cable} * \left(\frac{P_{inverter}}{U_{AC-multi\ phase}}\right)^2 \quad [5.21]$$

The ohmic resistance is calculated for a single length of the cable. Therefore, the constant factors at the beginning of the formulas above represent the number of active phases in the AC-cable.

- Degradation:

  The degradation of the analyzed PV modules is calculated as a linear reduction of the module's power over a single year. The final reduction after such a year equals the degradation defined in the worksheet "System data". It is recommended to set this value to the amount that is defined in the module's datasheet, since this represents the highest reduction that is within the guaranteed boundaries. In case of using CdTe-module technology it is further necessary to define an additional degradation value for the first year, since this module types show a significantly higher power reduction at the beginning of its operating time than in later years.

  The final financial analysis can cover a very long analysis period. Accordingly, the degradation is increased cumulatively every year for this calculation.

The final result after all these loss factors were taken into account represents the prediction of the final yield that can be achieved at the point of power metering. These data, or data that was read in from a second source, can then be used for further analysis.

5.2.4 CONSUMER TYPES

To enable a prediction of the amount of self-consumption it is necessary to have knowledge of the energy usage within the balance limits of an analyzed building or facility. To match with the data for electricity generation of the PV system it is decided to calculate with hourly time intervals. This interval length has the disadvantage that an energy consumption typically comes with a high number of short-time fluctuations. Therefore, data about these fluctuations are partly lost in the process of generating hourly averages. To compensate for this, a method is developed to estimate the losses in self consumption that can occur due to these fluctuations.

In general, the tool allows the definition of the type of energy consumption with four different methods. The first and probably most accurate way is to read in hourly consumption data from an external source if available. An example to this would be the half hourly data logging that is done by “Georgia Power” in its service area for some selected customers, like the Savannah Civic Center. The second method is to set the type of consumer. Therefore, a total of 19 different consumer types is available for selection. These profiles are provided by the National Energy Research Laboratory (NREL) and are further described in Chapter 5.2.4.1. Another method is the definition of the consumption as a constant usage. This is a possibility if none of the provided load profiles fit to the type of consumption and a constant load is seen as realistic, for example with constant lighting systems. Finally, when there is a lack of any information about the energy consumption it is also possible to define it as an estimated percentage of the energy yield, what represents the most inaccurate method.

5.2.4.1 NREL - LOAD PROFILES

NREL provides on their free accessible website “Open Energy Info” load profiles for a variety of different consumer types that come in hourly time intervals. *Table 9* lists the possible selections that are implemented in the tool, along with their annual energy consumption in kilowatt hours [OpenEI, 2013].

These 3 residential and 16 commercial profiles were computed by NREL based on the U.S. TMY3 weather dataset for the certain location of Savannah. As a result, the data were measured with the same weather station as the Meteonorm data, which is used for calculating the electricity generation of a PV system. However, when comparing their monthly data sums in *Table 4* on page 22 it can be obtained that there is a slight difference between them. The reason to this is probably the use of different measuring periods as well as the use of different statistical methods. Since this deviation is relatively low it is decided to neglect it. It is not decided to use U.S. TMY3 data for calculating the electricity generation, because this would complicate the energy yield modification process of Chapter 5.2.2 by increasing the error between the two simulations.

Table 9: NREL - Load profiles

Consumer type	**Profile name**	**Annual energy consumption [kWh/yr]**
Commercial:	Small office	74,271
	Medium office	772,092
	Large office	7,539,245
	Small hotel	654,918
	Large hotel	2,641,595
	Apartment	275,769
	Quick service restaurant	206,425
	Full service restaurant	349,849
	Hospital	10,514,615
	Outpatient	1,455,107
	Primary school	1,017,476
	Secondary school	4,415,645
	Stand-alone retail	387,055
	Warehouse	271,633
	Supermarket	1,868,716
	Strip mall	336,735
Residential:	Small house	8,706
	Medium house	20,626
	Large house	43,046

When choosing the option for using load profiles, these are scaled up or down in a way that their monthly sums match the monthly energy consumption. The latter is known for all existing buildings and facilities in the region of Savannah due to the fact that basically all customers of the company "Georgia Power" are equipped with smart meters and are billed monthly.

5.2.4.2 SHORT TIME FLUCTUATIONS

As mentioned before, energy consumptions within buildings or facilities typically come along with a high number of fluctuations. *Figure 27* shows an example load profile with hourly time intervals as well as with minute to minute intervals. It can be clearly seen that the hourly averaged data looses information about short peak loads and short low demand periods. In case of determining the possible self consumption these errors can have a high impact on the result that cannot be neglected.

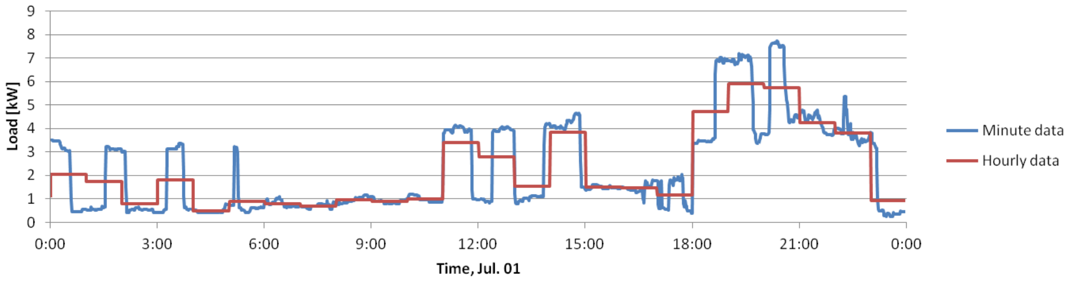


Figure 27: Example load profile – residential **[Pecan Street Inc., 2014]**

An example for such an error would be when the hourly load data suggests that the load is exceeded by the PV system's energy production, but in reality there are only short peak loads that cannot be covered by the energy yield. On the other hand, short periods without consumption cannot be used for self consumption, therefore more energy has to be sold to the grid.

To meet this problem, a total of five residential single-family homes are analyzed. The online platform "Pecan Street" offers minute-to-minute load profiles for these chosen buildings, which are located in Texas [Pecan Street Inc., 2014]. The data is then processed to get hourly averaged load profiles. The next step is to calculate the self-consumption rates for all load profiles and both time intervals for a variety of different PV system sizes. This variation is done to identify a possible connection between system size and annual energy consumption. By comparing the resulting errors between minute-to-minute simulations and their hourly counterparts the curves of *Figure 28* are developed. The x-axis in this graph shows the ratio between annual PV energy yield and the buildings annual energy consumption. It can be clearly seen that the peak in this error occurs with system ratios of 0.3 to 0.7 [-] with amounts of up to 18%, but decreases as expected with system sizes where the yield to usage ratios are much bigger or smaller.

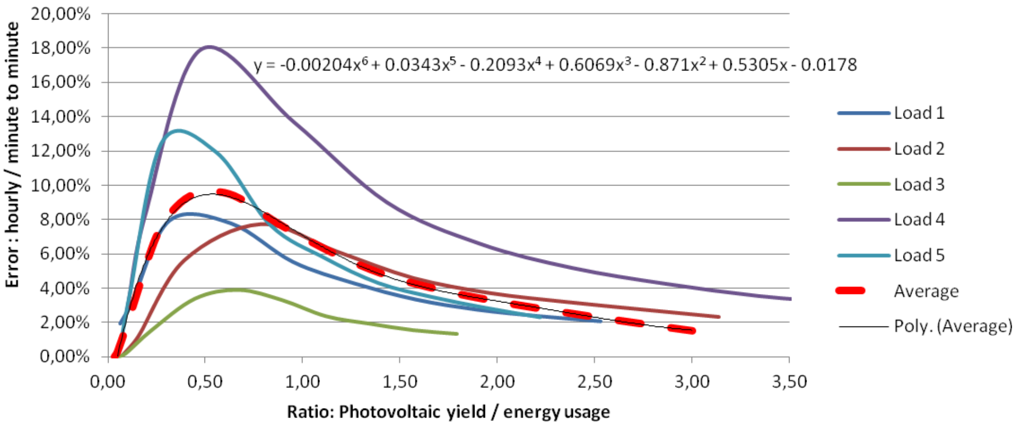


Figure 28: Self consumption error analysis

Since this error is highly dependent on the types of electrical users in a building, its exact variation cannot be predicted reliably without a detailed knowledge of all system components. Therefore, it is decided to form an average curve through these data points, which is represented by the dashed red line. The final result implemented in the tool is this curve's trendline formula, shown in *Figure 28*, which is used to modify the predictions tool internally, but only within the ratio limits displayed above. Exceeding ratios or ratios close to zero are set with a fixed value in respect to the expected trend, to prevent negative error predictions caused by the behavior of this formula.

5.2.5 ENERGY BALANCE

By applying the methods described above the tool provides hourly data for predicted PV energy generation and the building's or facility's energy consumption. In case of bidirectional metering the next step is the calculation of a balance of these two data series. As a result, the tool computes predictions for the energy that has to be sold to the grid, the energy that can be used directly within the balance limits as well as the new energy consumption of the building or facility. The self-consumption is then reduced by applying the formula developed in Chapter 5.2.4.2, with the excess energy assigned to the energy sold to the grid.

In case of single directional metering this balance is not necessary, since the entire generated electricity is sold to a utility.

Finally, these hourly data has to be prepared to allow the calculation of electricity bills with all available contract types. Since these are very different in their pricing structure, two separate methods have to be implemented in the tool. Their description follows in the next chapter.

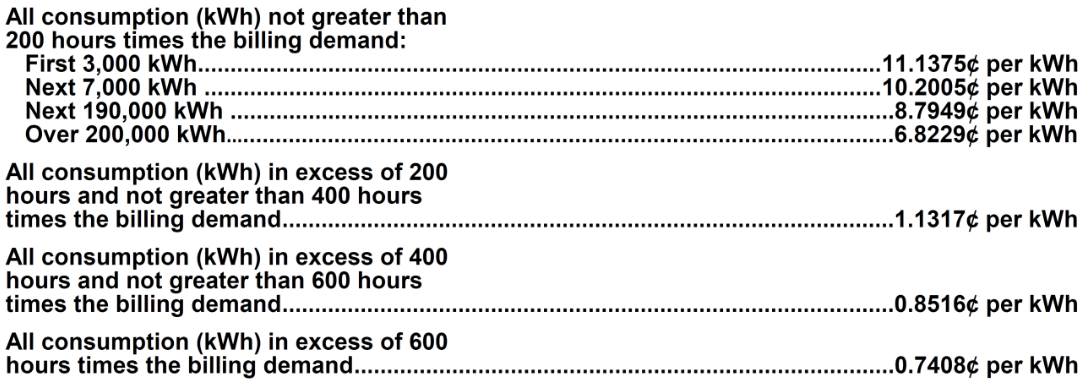
5.2.6 ELECTRICITY PURCHASE CONTRACTS

The knowledge of the electricity purchase contract is crucial if a system with bi-directional metering is analyzed. In this case, the major revenue of a system is generated due to savings in the electricity bill. To allow this, a detailed comparison between the energy bill before and after the implementation of a PV system has to be done.

It can be differed between three different methods that are available for calculating the electricity purchase bill. Their commonality is that they are all billed monthly, they are subject to a basic fee and that they are further increased by a number of fees and taxes, which are described later.

The first variant is a simple flat-rate tariff. It has a fixed rate for all energy units consumed, which are measured in kilowatt hours (kWh). There is only one tariff like this available for small businesses with an energy consumption of less than 3,000 kWh per month.

The second form of tariff is where the prices for each energy unit depend on the total amount of consumed energy per billing period and in some cases also on the maximum peak load. They represent the standard tariff for residential customers and are also the most commonly used form with buildings operated by Savannah’s city government. *Figure 29* shows one of the more complex examples for this method. At first, the prices are graded in dependency of consumed energy only. With ongoing consumption they can surpass the point where they exceed a certain limit and fall into the next category. These flexible limits are defined by the so called “Billing demand”. The billing demand is a result of the current month’s as well as previous month’s peak loads and is multiplied by a certain factor (200, 400 or 600 in case of *Figure 29*) to form the limits.



All consumption (kWh) not greater than 200 hours times the billing demand:	
First 3,000 kWh	**11.1375¢ per kWh**
Next 7,000 kWh	**10.2005¢ per kWh**
Next 190,000 kWh	**8.7949¢ per kWh**
Over 200,000 kWh	**6.8229¢ per kWh**
All consumption (kWh) in excess of 200 hours and not greater than 400 hours times the billing demand	**1.1317¢ per kWh**
All consumption (kWh) in excess of 400 hours and not greater than 600 hours times the billing demand	**0.8516¢ per kWh**
All consumption (kWh) in excess of 600 hours times the billing demand	**0.7408¢ per kWh**

Figure 29: Power & Light - Medium - tariff structure**[Georgia Power, 2014c]**

For these two tariff methods it is sufficient to calculate the monthly sums of the different parameters in the energy balance. Further, in theory it would be possible that a monthly peak demand is reduced due to the contribution of the PV system. This would reduce the described limits and in consequence also the unit price for the consumed energy. Though, since the prediction of a PV power production comes with high uncertainties due to unpredictable clouds, it cannot be assured that this reduction actually takes place. Therefore, it is decided not to reduce the billing demand when performing the simulation, to assure a low risk analysis.

Another point considered with tariffs that calculate limits by using peak demands is that the maximum electric loads are known due to the electricity bills. In this case, if it is chosen to simulate the analysis with use of the NREL – load profiles, it would be possible that these load profiles have higher peaks than actually measured. Therefore, an algorithm is implemented that cuts these peaks and credits the excess energy to the next time interval.

The third available method for electricity bills is the type “Time of use”. It splits a day in “on-”, “off-“, and in some cases also “shoulder-“ periods, each with different unit prices. This method requires to summarize the energy units monthly by their category of time when they have been consumed. Additionally to the charges per energy unit, bills of this type can be increased by a demand charge, which is calculated in dependency of a month’s peak consumption.

These three methods describe the basic costs of the electricity bill. To compute the total costs of electricity these have to be further increased by additional fees and taxes. The “Environmental Compliance Cost Recovery” (10.97 %), “Nuclear Construction Cost Recovery” (9.46 %) and the “Demand Side Management Schedule (2.13 %) are calculated as a percentage of the basic costs. Additionally, the “Fuel Cost Recovery” represents the actual cost for the production of the electricity and is charged per energy unit with a price range of 3 to 4 ₵/kWh. The so called “Municipal Franchise Fee” adds another 1 - 3 % to the sum of all charges described above. Finally, the bill has to be increased by the local sales tax of up to 7 %, but some customers like governmental facilities are excluded from this last obligation.

5.2.7 SCENARIOS

A PV systems typically represents a long-term investment, with analysis periods of up to 30 years. Therefore, the future developments of certain parameters should not be neglected for realistic results. This chapter describes the scenarios that were implemented in the tool for this cause.

- Discount rates and inflation:

  An important factor for comprehensive cash flow analyses is the discount rate. They represent the time value of money and are also used to account for the risks of an investment [Short et.al., 1995]. For governmental investments it is referred to the current rates that are published by the “Federal Office of Management and Budget”. In their circular A-94 Appendix C they list the recommended nominal and real interest rates, that are to be used by governmental entities for cost-effectiveness analyses in the year 2015. Nominal discount rates are set with 3.1 % for 20 years investments and 3.4 % for 30 years runtimes, real discount rates with 1.2 % (20 yrs) and 1.4 % (30 yrs) [OMB, 2014]. Due to the knowledge of both of these factors the predicted rate for the inflation (e) can be calculated by applying formula 5.22 [Short et.al., 1995].

$$e = \frac{(1+d_n)}{(1+d_r)} - 1 \qquad [5.22]$$

Where: d_n = nominal discount rate

d_r = real discount rate

- Electricity price:

  For the electricity rates it is recommended to use the scenario published by the Energy Information Agency (EIA) in their “Energy Outlook 2015”. Their official prediction estimates an average annual increase rate of 2.27 % until 2040 [U.S. EIA, 2015].

- Feed in tariff:

  For the development of feed-in tariffs it is decided to recommend the rates published in “Georgia Power’s – 2014 Avoided Costs and Solar Avoided Costs Projections”. They predict an average increase of 5.54 %/yr for the next 9 years [Georgia Power, 2014b]. It is noticed that this rate is relatively high, but it is provided by the local utility, what is considered to be the source with the most detailed knowledge about local future developments. Further, with the projects evaluated within this thesis the scenario for feed-in tariffs has only a minor impact on the total economics, since it is tried to achieve high self-consumption rates of around 80 %.

5.2.8 CASH FLOW

The actual economic analysis is done with use of a cash flow analysis. This method allows the detailed evaluation of annual expenditures and revenues with continuously occurring changes of boundary conditions caused by module degradation and scenario developments as well as by irregular events like loan payments or component replacements.

The following positions are computed tool-internally. They are calculated for every year of the analysis period and both for discounted and simple analysis. The latter doesn’t account for future scenarios, what allows the evaluation of the influence of chosen scenarios through a simple comparison.

Expenditures:

- Investment expenditures
- Loan- and bond payments
- Insurance-, operation- and maintenance costs
- Property tax

Revenues:

- Electricity savings (in case of bi-directional metering)
- Electricity sale (minus metering charge)

By calculating the balance of expenditures and revenues the development of capital can be shown for each year and cumulatively for the whole analysis period. As result, this allows the determination of simple and discounted payback times.

5.2.9 LEVELIZED COSTS OF ELECTRICITY

Another important characteristic number for economic evaluations of renewable energy systems is the levelized cost of electricity (LCOE). It represents the cost of a single electric energy unit generated by such a system, what allows a simple comparison with other technologies and their costs for electricity generation.

Equations 5.23 and 5.24 show the methods for calculating the total life-cycle cost (TLCC) and the LCOE where C_n represents the annual expenditures and Q_n the annual production of electric energy.

$$TLCC = \sum \frac{C_n}{(1+d_n)^n} \qquad [5.23]$$

$$LCOE = \frac{TLCC}{\sum \frac{Q_n}{(1+d_n)^n}} \qquad [5.24]$$

5.2.10 MODIFIED INTERNAL RATE OF RETURN

Finally, it is also decided to include the “modified internal rate of return” (MIRR) into the analysis. It represents the interest rate that an alternative investment would need to have to generate the same profit like the analyzed investment.

$$MIRR = r,\ where\colon\ \sum \frac{Fn_n}{(1+d)^n} = \sum \frac{Fp_n * (1+d)^{N-n}}{(1+r)^N} \qquad [5.25]$$

Where: Fn_n = net negative cash flow at time n

Fp_n = net positive cash flow at time n

The difference to a “simple” internal rate of return method is that the cash inflows are not reinvested with the assumption of the same rate of return as the investment itself, but with the typically lower discount rate [Short et.al., 1995].

6 ECONOMIC ANALYSES

The economic analysis tool developed here does not only allow the evaluation of a large number of projects in a relatively short time, but also the identification of the best financing option for city government or private customers by varying the crucial parameters. Therefore, the first project analysis for governmental ownership, is done in a greater detail, whereas following projects are done on basis of the best method that could be identified. Further, it is decided to design all systems with polycrystalline silicon module technology. This is done due to the attempt of the city government to maintain low risks by using well known and reliable technologies that were proven over a longer period.

The identification of the buildings and facilities that are evaluated is done as follows.

6.1 INFRASTRUCTURAL FACILITIES OF THE CITY OF SAVANNAH

The total consumption in 2014 of all 1,355 electricity metering points operated by the city government of Savannah amounts 85.03 GWh. Of this total consumption 38.7 GWh can be ascribed to the 10 biggest water- supply and treatment facilities, which are all found under the top 15 consumers of the city. Other big users are the "Savannah Civic Center" with 6.54 GWh electricity consumption, the "Whitaker - Parking garage" with 1.58 GWh usage, as well as the "Savannah Visitor Center" with 1.21 GWh. The total amount paid by the city government for electricity bills in 2014 was about $12.6 million.

The main goal of this thesis is the analysis of the applicability of the combination of PV systems with different consumer types within the city of Savannah. Therefore a number of facilities and buildings with different usage characteristics are chosen. This selection is described in *Table 10*.

Further, two residential options are included in the evaluation to allow a more extensive assessment of the economical applicability of PV systems in the region of Savannah.

Table 10: Facility selection - part 1

Project #	Name & address	Address	Consumer type
1	State Street Garage	Intersection State St. @ Abercorn St.	Lighting, elevator, small offices
2	City Hall	2 E Bay St	Medium office
3	Civic Center	301 W Oglethorpe Ave.	Multifunctional event hall
4	I&D Water Supply	Water Filtration Plant Rd, GA 31407	Water preparation facilities, pumps
5	Community Planning & Development	2203 Abercorn St.	Small office
6	Housing Department	5513 Abercorn St.	Small office
7	Development Services Department	5515 Abercorn St.	Small office
8	Gamble Building	6E Bay St.	Small office
9	Arts, Culture & Education	5 W Henry St.	Small office
10	Savannah Entrepreneurial Center	801 Gwinnett St.	Small office
11	Savannah Gardens	524-546 E Crescent Dr.	Residential apartment
12	Residential House	Anonymous	Residential single family house

It can be seen that the majority of the assessed buildings are office buildings. The reason to this choice is that they represent the largest number within all facilities operated by the city government and since their usage is mostly during daytime they promise a good qualification for an implementation of PV systems.

The “State street” - parking garage is chosen because of considerations within the city government to introduce a city-employee car fleet with electric cars and their idea to promote the possibilities for switching in this context to environmental friendly electricity production.

To assess the applicability of a combination of PV systems with facilities for water treatment, a water preparation facility located north of Savannah, the I&D water supply facility, is chosen.

Another choice for the evaluation is the “Savannah Civic Center”, which includes a multifunctional event hall and several smaller rooms and spaces for different occasions. The “Civic Center” is the 3rd biggest user within city government operated facilities.

Finally, it is also decided to include two residential buildings into this evaluation. The reason to this is that the city actively helps to promote PV systems for residential use. An example for this is the program “Solarize Tybee”, which was supported by the Sustainability Department of Savannah and tried to achieve low system and installment prices through a collective bidding process.

6.2 STATE STREET GARAGE

The first project analyzed is State Street – parking garage. It is located in downtown Savannah and is operated by the city government. Its electric consumption is caused to a big share by its lighting system, which is operated 24 hrs/day and 7 days/week. Additionally to this, there are city government offices in the 1st floor of the building. The annual load curve, shown in *Figure 30*, was measured for the year 2014 by Georgia Power. It can be clearly seen that the yearly peak load happens during winter, while a second lower peak occurs from June through September. The reason to this is interpreted to be the use of electrical heating and cooling systems within the offices. The utility contract type is the “Georgia Power – Power & Light Medium” (PLM) tariff for commercial customers.

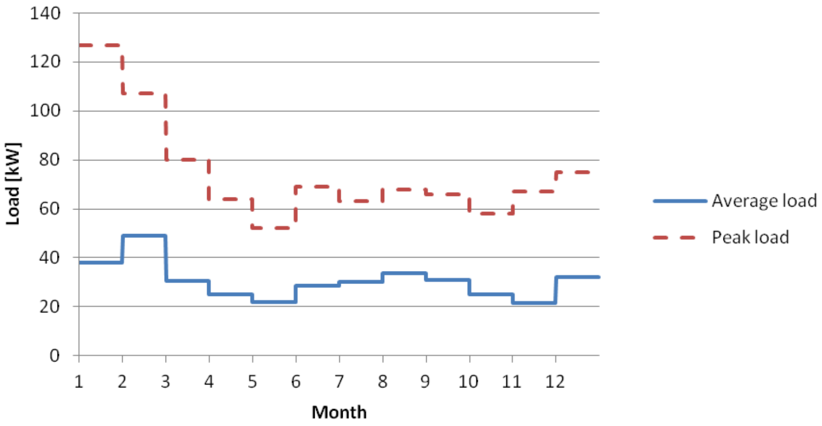


Figure 30: Monthly average load profile – State Street Garage

Due to the mix in electricity usage of office space and constant lighting system none of the example load profiles described in Chapter 5.2.4.1 seem to fit. Therefore, the assumption of a constant monthly average load is made. This is assumed to be a conservative assumption, since a high share of constant load is expected to be caused by the continuously operated lighting system. Further, the load for cooling and heating systems will likely occur during office times (daytime) and therefore correlating with the availability of irradiance and as result electricity generated by the PV system.

Photovoltaic system - design:

The building has a flat roof which is used as parking deck. Therefore, the PV system should be designed in a way that it does not affect or reduce the parking spots available. Two developed variants are introduced in the following.

***Figure 31: Aerial photography - State Street Garage* [SAGIS, 2015]**

- The first variant would allow an installable peak power of around 33,75 kW_P, under the assumption of using 250 W_P standard modules with a dimension of 64.5” x 38.7” each. The module tilt would be 10° and the orientation would deviate 16° from south to west.

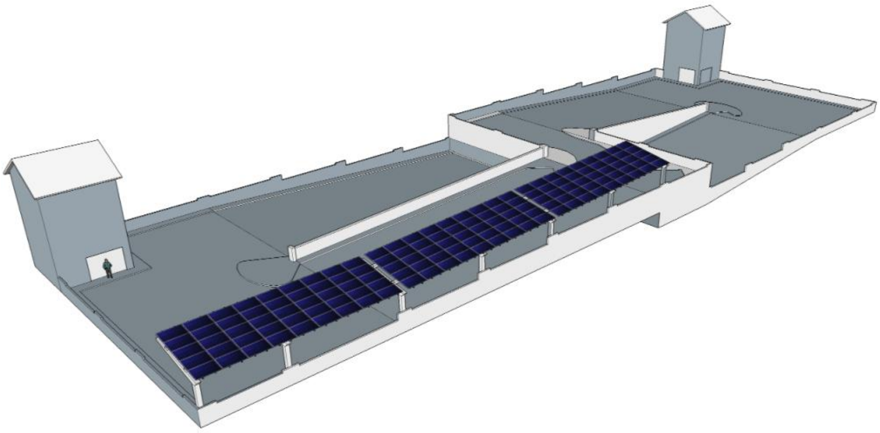


Figure 32: State Street Garage - Variant 1**[SketchUp, 2015]**

- The second variation is designed with an orientation of 106° from south to west and a module tilt of 2.8°. The total installable peak power could be 56 kW_P or smaller.

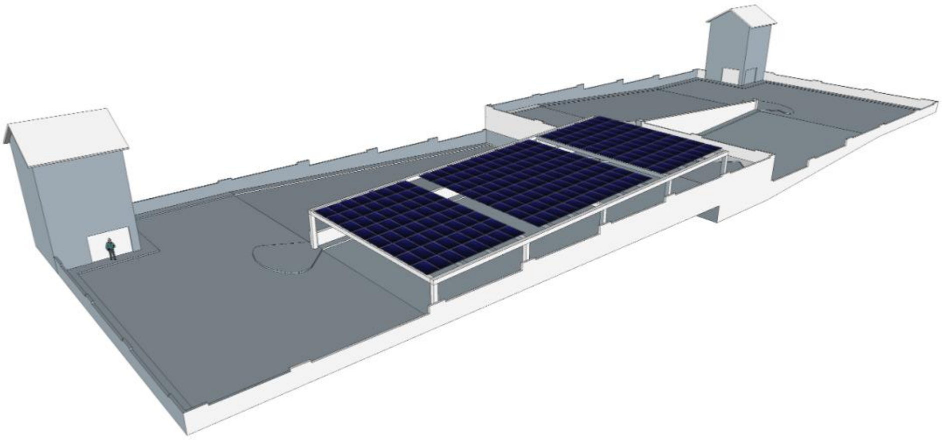


Figure 33: State Street Garage - Variant 2 **[SketchUp, 2015]**

Concerning the energy generation this second module orientation is disadvantageous compared to variant 1. Further the low module tilt could lead to increased soiling losses due to insufficient self-cleaning effects. On the other hand an advantage could be possibly lower costs for the mounting system and less strain of the underlying structure. The construction of variant 1 could introduce a high mechanical moment into its basis when exposed to high wind loads, whereas it is assumed that this variant would spread the load even over all columns.

Due to a higher possible electricity generation and a better match of the system size with the facility's energy demand variant 1 is chosen for further assessments.

Energy yield:

A simulation with the developed tool predicts an annual energy yield of 49,432 kWh/yr for variant 1. This equals an specific production of 1464.7 kWh/kW$_P$. To verify this result, a second simulation is done with the program PVSyst. This shows an annual expectable production of 49,488 kWh/yr or 1,466.3 kWh/kW$_P$. Therefore the deviation between these two simulations amounts 0.11 %, where the developed tool represents the slightly more conservative prediction.

To show the difference in production, variant 2 is also simulated tool-internally, resulting in an energy yield of 74,990.4 kWh/yr or 1339.1 kWh/kW$_P$. This is 8.6 % less production than with variant 1, but probably increased soiling losses are not yet included within this estimation.

Self consumption:

With the assumption of a constant load and the calculated energy generation of the PV system the possible self-consumption can be determined. By using the developed tool it is calculated that 98.0 % of the energy yield will be consumed within this facility. It is expected that this rate will not be decreased by the load fluctuations due to the influences of office spaces, but rather increased due to a shift from averaged loads to an increase in loads during daytime instead of nighttime.

Financial parameters:

It is decided to analyze a period of 30 years for this building. Further, it is expected that the inverter has to be replaced after an operating time of 15 years. For insurance and maintenance costs expenditures in the height of 0.25 %/yr and 0.5 %/yr are assumed. Since it is operated by the city, it is exempted from paying sales taxes on the purchased electricity as well as from paying property tax. On the contrary, it is not possible to apply for the federal tax credit of 30 %. Finally, the development of electricity costs, feed-in tariffs, inflation and discount rates is assumed to follow the scenarios described in Chapter 5.2.7. With these boundary conditions different investment methods are analyzed and compared to assess the economical possibilities that come with the described system.

- *Own*-capital financing:

  The possibility of financing the PV system with city owned capital is analyzed for two variations. With the first case the maximum costs are calculated which are allowed when the simple payback time should not be longer than 15 years. The second case is similar, but with a maximum simple payback time of 25 years. The resulting cost development is shown in *Figure 34* and *Figure 35*.

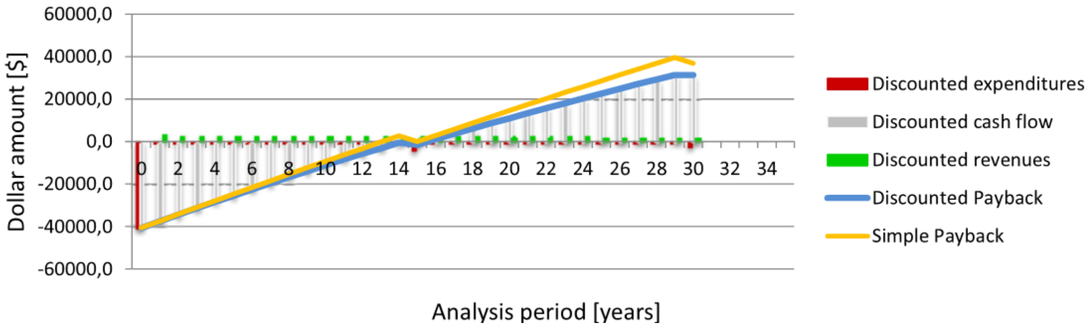


Figure 34: Cash-flow analysis - State Street Garage, own-capital, 15 years payback time

It can be shown that for a payback time of 15 years the costs for such a system are not allowed to be more than 1,181.6 $/kW$_P$ or $39,878 in total. This would be a very low price that is currently not realistic on the U.S. American market.

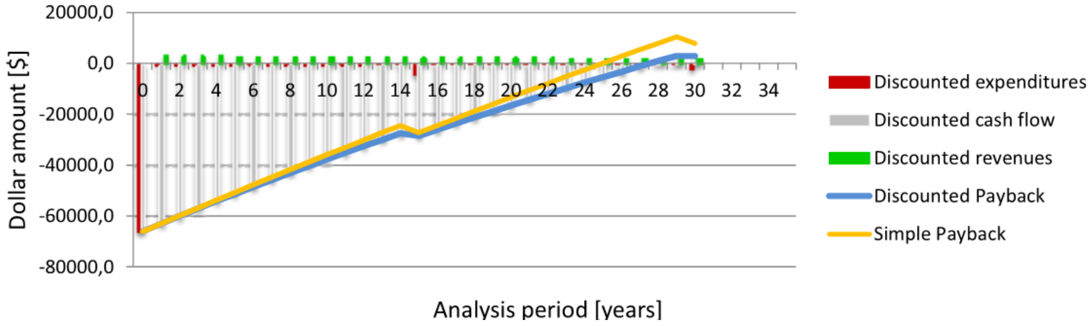


Figure 35: Cash-flow analysis - State Street Garage, own-capital, 20 years payback time

For a simple payback time of 25 years the allowable costs increase to 1,879.6 $/kW$_P$ or $63,436 in total. This is still a very low rate, but it is already closer to what was offered in the best case scenario of the "Solarize Tybee" – program, although only for simple rooftop installations, whereas this system would need a complete canopy – platform as mounting structure. Further, it can be seen that the discounted cash flow hardly reaches the breakthrough point. This is also shown by the modified internal rate of return, which is with 3.24 %/yr almost identical with the discount rate of 3.1 %/yr, meaning that it is only slightly more profitable than in comparison to an conservative investment in the financial market.

- Bond financing:

  The advantage of using a bond as a method to finance a PV power system is a drastic reduction of upfront costs, which are spreads over the bond payback period. Now, according to the theory of discount rates, a dollar spent today is worth more than a dollar spent tomorrow [Short et.al., 1995]. Therefore, by delaying payments to the future it would cost less than by paying them upfront. This is well known and typically negated by the interest rates of bonds, since they increase the future amounts that have to be paid back for the installments and which are usually higher than the inflation rate. However, in the case of governmental facilities there is the possibility of using bond incentives like CREB (Chapter 2.3.1.4) and QECB (Chapter 2.3.1.5). These two programs pay in a large part the bond interest rates, therefore effectively reducing the current dollar values of all future payments. The resulting effect is shown when comparing *Figure 36* and *Figure 37*. The bond interest rate for these calculations is defined with 3.5 %/yr, equal to a interest rate for a different bond that was purchased by the city government at the time this thesis was written.

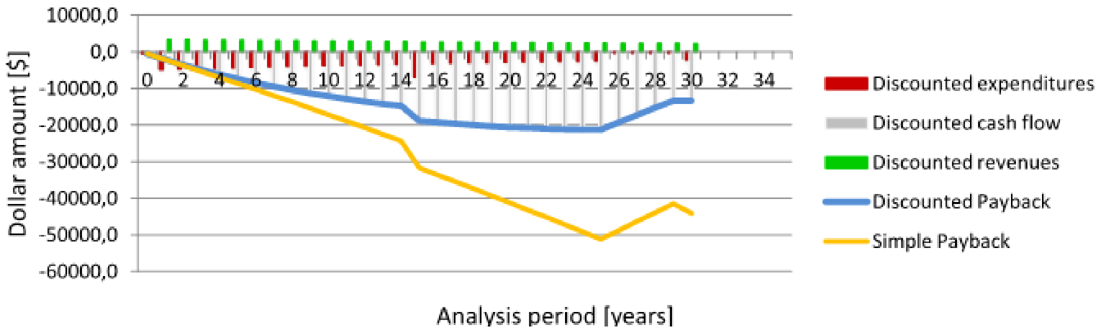


Figure 36: Cash-flow analysis - State Street Garage, 2200 $/kW$_P$, 25 yrs bond with 3,5 %/yr interest rate

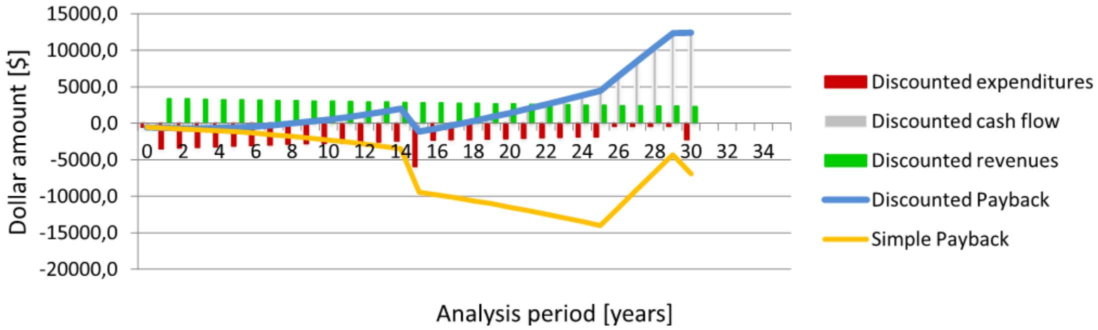


Figure 37: Cash-flow analysis - State Street Garage, 2200 $/kW$_P$, 25 yrs bond with 0,2 %/yr interest rate (e.g. QREB)

In both cases it can be clearly seen that the simple payback time would be longer than the discounted payback time, or not occurring at all. The reason to this is that it doesn't consider the decreasing value of future payments and revenues. Therefore, it is not recommended to use it for evaluating investments in combination with bonds or loans.

The trend of the discounted cash flow in *Figure 37* shows the possibilities that come along with bond incentives. Since the revenues in form of energy savings are almost equal to the bond installments that have to be paid back, there is only a slightly negative slope in the first years. The effect of the bond incentive develops later after a few years, when the revenues increase due to higher energy costs, but the bond installments stay almost the same due to the incentive. Further, since the effective interest rate of the bonds is even lower than the inflation rate, the net present value (NPV) of these future payments will decrease with ongoing time. The result is the curve of the trend line observable in *Figure 37* and the possibility for a relatively short payback time. Overall an modified internal rate of return of 8.17 % and a payback time of 8.1 years would be achievable with investment costs of 2,200 $/kW_P$. However, with increasing investment costs this short payback period would be prolonged very quickly, since the bias of the curve is very sensitive. To allow a risk analysis, *Table 11* summarizes a number of different modifications in the boundary conditions.

Table 11: State Street Garage - Investment costs and payback times

Investment costs [$/kW$_P$]	**Method**	**Simple payback time** [yrs]	**Discounted payback times** [yrs]	**Modified internal rate of return**	**Levelized costs of electricity** [$/kWh]
1,181.6	-Own capital -No incentive	15.0	15.6	5.03 %	0.0592
1,879.6	-Own capital -No incentive	25.0	27.6	3.24 %	0.0903
2,200.0	-25 yrs bond -No incentive	-	No profitability	- 0.24 %	0.1085
2,300.0	-10 yrs bond -Bond incentive	-	28.5	3.16 %	0.0927
2,200.0	-25 yrs bond -Bond incentive	-	8.1	8.17 %	0.0800
2,300.0	-25 yrs bond -Bond incentive	-	13.7	6.99 %	0.0833
2,400.0	-25 yrs bond -Bond incentive	-	25.7	5.68 %	0.0867

It can be seen that a bond without any incentive would not be economical, in very contrast to a system of same size and costs that benefits of a bond incentive. Further, since the combination of a bond incentive and long bond- payback time shows the best economical results, a variation of investment costs is done for this method. Starting with 2,200 $/kW_P$ a very short discounted payback time could be achieved. When increasing this value, a kind of breakover point can be observed between 2,300 and 2,400 $/kW_P$. The reason to this is that the increasing bond installments start to become higher than the revenues, leading to a partly negative curve development. However, after the bond is paid back, the profit increases dramatically, leading to a breakthrough point close to the end of the bond period.

Conclusion – State Street Garage:

It is shown that the combination of bond incentive with a long bond– payback time provides the best financial frame condition. With prices below 2,300 \$/kW$_P$ good economical results would be achieved. These prices are already within the range of current system prizes for commercial sized PV generators. However, this may not be the case if the underlying canopy structure is assigned to this system costs, since it would drastically increase them. As a result of the assessment of the State Street - Parking Garage it is decided to use the best case scenario as standard for all further evaluations of city government operated facilities.

6.3 CITY HALL

Built in 1906, the Savannah City Hall is now home to municipal government offices. With an annual electricity consumption of 452,700 kWh in 2014 (Tariff: PLM) this building can be classified to the category “Medium office” of the NREL load profiles. It has a tarboard flat roof which is oriented south with a deviation of 16.5 ° to west. The entire roof was refurbished in the year 2008. *Figure 38* shows a close-up view of the roof’s structure. It can be seen that there is a high risk of shading objects due to different height levels. Therefore, the system has to be designed in a way that it can cope with this condition.

Figure 38: City Hall roof **[Wimmer, 2015]**

Photovoltaic system - design:

Figure 39 shows the system design, developed with use of structure plans provided by the city archive and in a way that they would not be visible from the streetside. A total number of 30 modules with a tilt of 20 ° could generate a nominal peak power of about 7.5 kW_P. Due to the high shading risk it is decided to use module - power optimizers. These minimize energy losses in strings, that would otherwise occur due to shadings of single modules, by transforming voltage and current of each module to a level that the connection in series does not result in losses.

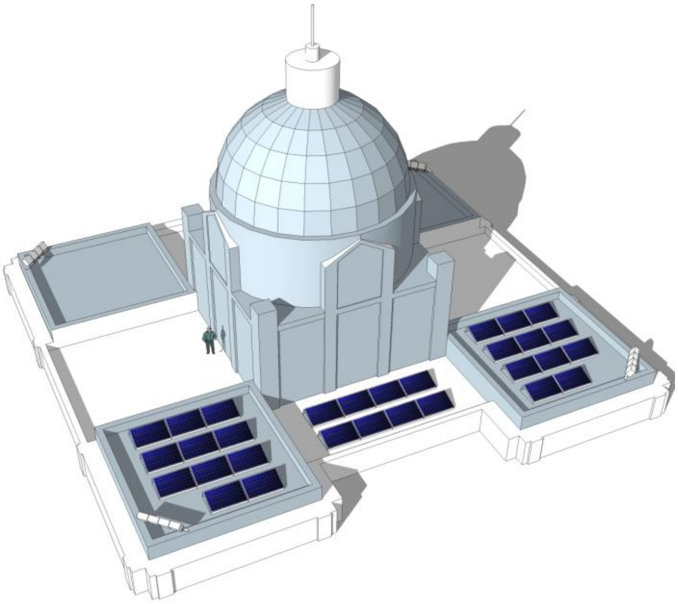


Figure 39: City Hall - System design **[SketchUp, 2015]**

Energy yield:

Due to this more complex system design and the difficult shading conditions it is decided to simulate the system in the simulation program “PVSyst 6.3.5” and read in the generated data on an hourly basis into the economic analysis tool. The result is a predicted energy yield of 10,433 kWh/yr or 1,391 kWh/(kW_P *yr). *Figure 40* shows the shading analysis that is done in the 3D – analysis tool of “PVSyst 6.3.5”.

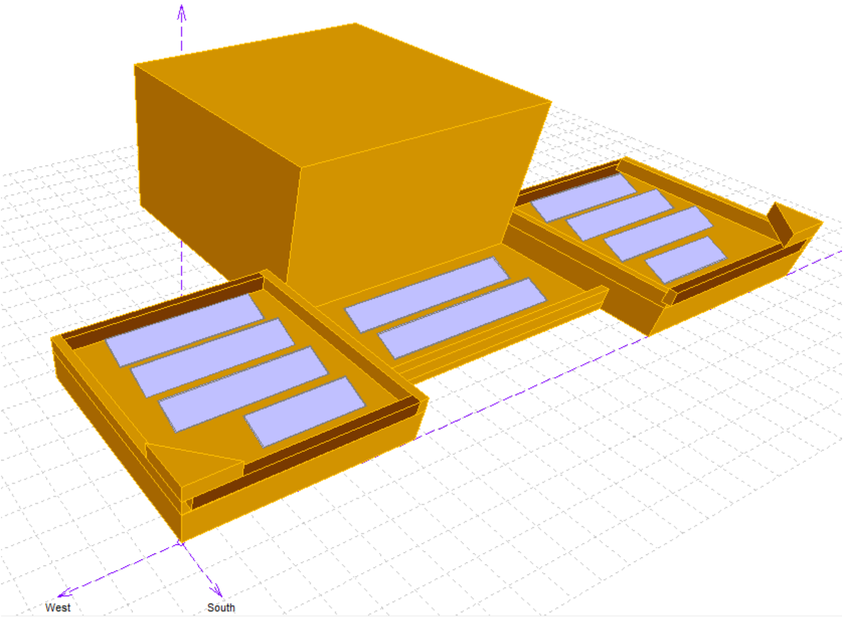


Figure 40: City Hall - Shading analysis **[PVSyst SA, 2015]**

Self consumption:

The economic analysis tool predicts a self consumption for this system of 100 %. This is assumed to be a realistic estimation due to the combination of a relatively small PV system with a comparatively very high electricity consumption.

Financial parameters:

The financial parameters are set accordingly to the “best practice” method that was evaluated with the “State Street” parking garage. Therefore the analysis is done with the assumption of a bond incentive in combination with a 25 years payback period. The investment costs are then varied to determine the highest investment costs that are possible for reasonable economic result.

Conclusion – City Hall:

The result of this variation is shown in *Figure 41*. The highest system price allowed would be 1,800 $/kW$_P$. Unfortunately, this is currently a non- realistic price on the U.S. market.

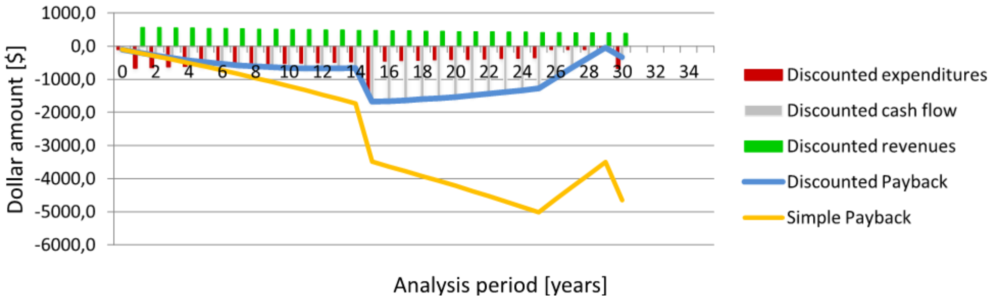


Figure 41: Cash flow analysis – City Hall, 1800 $/kW$_P$, 25 yrs bond with 3,5 %/yr interest rate

As a conclusion, it is currently not recommended to install a PV system on City Hall. The reason to this is that the high usage within this building in connection with the Georgia Power tariff "Power & Light – Medium" offers an electricity rate that is too low to save money in a sufficient amount through self- consumption.

6.4 CIVIC CENTER

The Savannah Civic Center is a multifunctional event hall and represents the 3rd biggest consumer operated by the city government of Savannah. Its electricity tariff "Multiple Load Management" is a "time of use" contract, which provides different rates for on-, off- and shoulder-periods. Since this billing method requires a detailed knowledge of when and in what amount energy is consumed, Georgia Power measures and logs consumption data in half - hourly intervals. This allows the input of this consumption data into the economic analysis tool after transforming it into hourly averages.

Figure 42: Savannah Civic Center - aerial view **[SAGIS, 2015]**

Photovoltaic system - design:

The central roof area of the Civic Center, shown in *Figure 42*, provides enough space for a PV system with a peak power generation of 100 kW_P. This is also the biggest system that is allowed by Georgia Power for bi-directional metering.

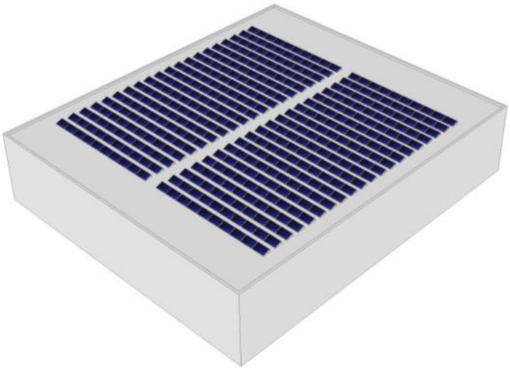


***Figure 43: Civic Center - System design* [SketchUp, 2015]**

Figure 43 shows the proposed system layout with an orientation of 18° from south to west and a module tilt of 25 °.

Energy yield:

The resulting energy yield computed tool internally is 146,526 kWh/yr or 1,465 kWh/(kW_P *yr). This equals a reduction of 2,519.3 metric tons of carbon dioxide emissions, that would have otherwise been emitted during the analysis period for conventional electricity production.

Self consumption:

With the knowledge of the half-hourly measured consumption data and the predicted PV power production, a self-consumption of 100% is calculated. The fact that the measured consumption load is almost the entire year between 400 and 700 kW supports the reliability of this estimation.

Financial parameters:

The financial parameters are set according to the "best practice" method with a bond incentive and 25 years bond-payback time.

Conclusion – Civic Center:

As result, it can be shown that a relatively short discounted payback time of 13 years would be possible with a specific system price of 2,200 $/kW_P. This is already a realistic price with systems of this large dimension. Still, it has to be mentioned that with the expectable exchange of the inverter the balance is again shifted into the negative zone and it takes until the operating year 22 to finally get into the positive zone again. However, for these 22 years the difference between annual bond installments and immediate energy savings is very low, resulting only in low net payments that have to be done for this period.

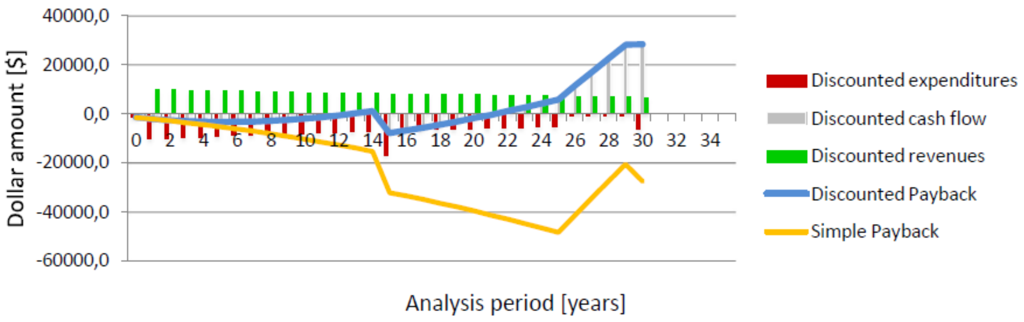


Figure 44: Cash flow analysis – Civic Center, 2200 $/kW$_P$, 25 yrs bond with 3,5 %/yr interest rate

With increasing system prices the breakthrough point is quickly shifted to the end of the payback period of 25 years. The maximum system costs for still maintaining any economical benefits at all is 2,500 $/kW$_P$ for an analysis period of 30 years.

6.5 I&D WATER SUPPLY

The “I&D water supply” is a water treatment facility located north of Savannah. In 2014 it showed a total electricity consumption of 449,400 kWh. Due to insufficient knowledge about the load curve or the type of electric consumers within the facility the I&D Water Supply is assumed to have constant usage for first assessments. The tariff contracted with Georgia Power is “Power & Light – Medium”. *Figure 45* shows the roof area that is available for system installments.

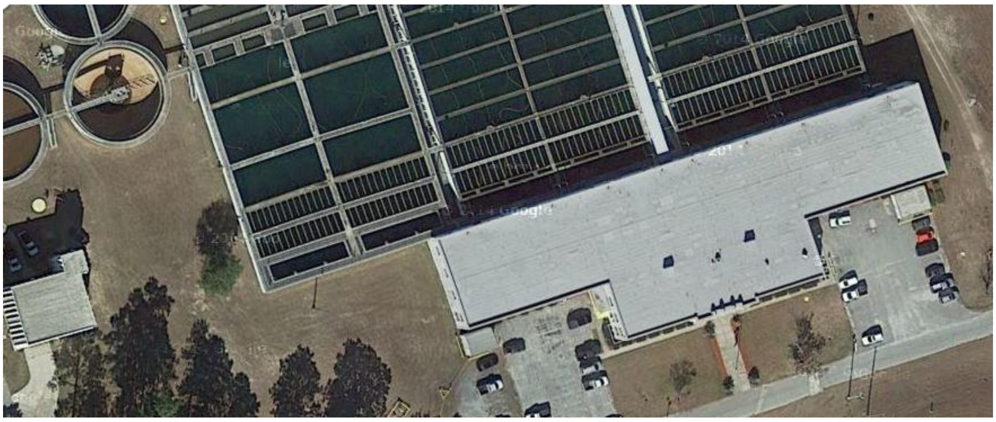


Figure 45: I&D Water Supply - aerial view **[SAGIS, 2015]**

Photovoltaic system - design:

The system layout proposed in *Figure 46* would allow a total installable power of 100 kW_P with an orientation of 18 ° from south to east and a module tilt of 25 °.

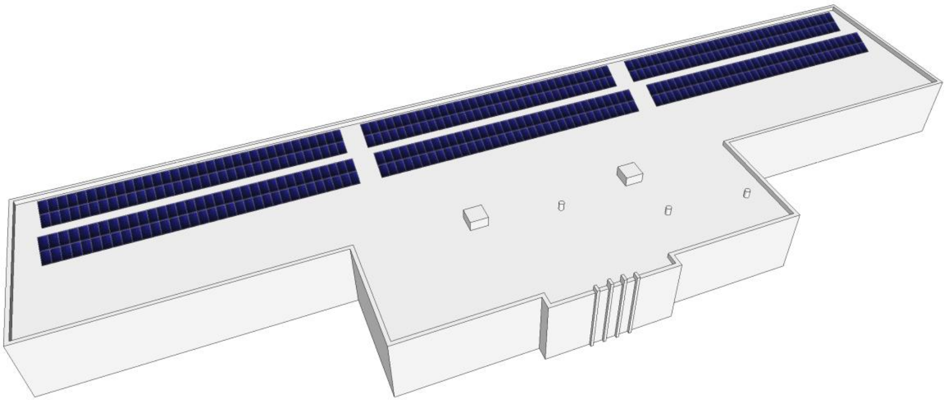


Figure 46: I&D Water Supply - System design **[SketchUp, 2015]**

Energy yield & Self consumption:

The prediction for this 100 kW_P system calculates a possible energy generation of 146,059 kWh/yr or 1,460 kWh/(kW_P *yr). The resulting self-consumption of 87.6 % is only a rough estimation due to the lack of knowledge about the actual load curve. Therefore, it is seen as best case scenario.

Financial parameters:

Equal to previous calculations, a 25 years bond is chosen in combination with a bond incentive.

Conclusion – Civic Center:

With a maximum system price of 1,900 $/kW_P$ for any economical benefits within 30 years the I&D Water Supply facility does not qualify for current available PV systems. It would need a price lower than 1,700 $/kW_P$ to achieve a discounted payback time within 25 years of operation.

Another aspect that was analyzed is a reduction of the system size. By cutting the number of modules in half, the self-consumption can be increased to 98.5 %. This change leads contrary to the expectations not to increased economics, but instead lowers the profitability achievable. The reason to this can be found in the structure of the electricity purchase contracts, shown in *Figure 29* on page 58. Only a high self consumption can reduce the demand far enough that also the more expensive price categories are affected and higher cost savings are achieved.

Further, also if this price would become realistic, there is need for more information about the load profile of this facility, to allow a more reliable estimation for the self consumption.

6.6 OTHER OFFICE BUILDINGS

The facilities and buildings of the Chapters 6.2 to 6.5 represent the major projects that were analyzed for the city government. To allow a more general evaluation of the applicability of PV systems on office buildings, a number of smaller offices is analyzed and compared in this chapter. *Table 12* summarizes the evaluated objects and their specifications. Again, the financing method for all systems is chosen to be a 25 years bond in combination with a federal bond incentive. The resulting project reports are attached in Appendix C.

Table 12: Office buildings

Object	**Usage 2014** [kWh/yr]	**Tariff**	**Orientation** [from south]	**Roof tilt**
Gamble Building Offices	158,840	PLM	16.5 °	Flat roof
Community Planning & Development Services	52,928	PLS	16.5 °	Flat roof
Housing Construction Department	20,181	GS	16.5 °	Flat roof
Development Services Department	166,400	PLM	16.5 °	Flat roof
Cultural Affairs Department	102,080	PLM	16.5 °	Flat roof
Savannah Entrepreneurial Center	86,240	PLS	-73.5 °	20°

Gamble Building:

The flat roof of the Gamble Building is equipped with a number of air conditioning units, chimneys and pitheads, which hinder the installment of a big PV system. However, the south edge of the roof provides enough space for a single row of PV modules on a length of 28 meters. The resulting possible peak power is 7 kW_P. A module tilt of 25° allows an energy yield of 10,174 kWh/yr or 1,453 kWh/(kW_P *yr). A self-consumption of 95,4 % is calculated by assuming the load profile of a small office.

Conclusion: The Gamble Building shows a good possibility for a 7 kW_P PV system with a discounted payback time of only 11.7 years for a system cost of 2,500 $/$kW_P$. This is still considered to be a low rate for a system of this dimension, but could be achieved in the close future when the development of system prices continues in the way it did in the past years.

Community Planning & Development Services:

The building for community planning & development services has a flat roof with an estimated suitable are of ~ 130 m² for PV installments. By defining a module tilt of 20 ° this allows a number of 45 installable modules with a peak power of 11.25 kW_P, resulting in an energy yield of 16,360 kWh/yr and a self-consumption of 82.5 %.

Conclusion: Good economical results with payback times shorter than 12.2 years could be achieved with system prizes of less than 2,600 $/kW_P$, but even with a price of 2,800 $/kW_P$ the system would pay for itself within 26 years.

Housing Construction Department:

With an available flat roof area of ~ 180 m² this building would provide enough space for 60 modules, but to achieve a higher rate for self consumption of 79.4 %, this number is reduced to 24 modules, respectively 6 kW_P$.

Conclusion: This building provides with its "General Service" contract ideal conditions for the implementation of a PV system. Even with a system price of 2,800 $/kW_P$ the revenues would immediately exceed the bond installments, resulting in savings starting with the first year. When it would be decided that the relatively small system size does not justify a bond contract, a funding based on own capital without any incentive would still lead to a discounted payback time of 19.3 years.

Development Services Department:

The roof area allows the installation of 66 south oriented modules with a tilt of 20°, resulting in a peak power of 16.5 kW_P$. The so achievable energy yield of 23,988 kWh/yr could be consumed to a calculated percentage of 87.8 % directly within the building, when the user profile of a small office is assumed.

Conclusion: As result, it can be shown that economical results with payback times shorter than 10 years could be realized with system prices of 2,400 $/kW_P$ or less, while a maximum cost of 2,550 $/kW_P$ should not be exceeded to stay within a payback time of 25 years.

Cultural Affairs Department:

About 900 m² of available flat roof area would provide enough space for a PV system with 80 kW_P$. However, the building's energy demand is not high enough to justify this system size. Therefore, it is decided to analyze a 25 kW_P$ system, which would result in a self-consumption of 78.4 % and a total production of 36,142 kWh/yr. This allows also more flexibility in the system's design, to meet the shading situation that is caused by the neighboring building which is equipped with a very high antenna.

Conclusion: It can be shown that the department's level of energy consumption in combination with its energy tariff provides excellent conditions for a PV system. The discounted payback time for a 25 kW_P system with a specific cost of 2,800 $/$kW_P$ would be less than 3 years, resulting in a modified internal rate of return of 11.48 % over the analysis period of 30 years.

Savannah Entrepreneurial Center:

This building has an east – west oriented roof with a tilt of about 20 °. It is decided to simulate a system with 10 kW_P mounted on the east side of this roof, due to a slight deviation of its orientation to south. The simulation predicts an energy yield of 13,549 kWh/yr with a self-consumption of 89,1 %.

Conclusion: Similar to the Cultural Affairs Department this buildings provides also excellent conditions for an economical PV system. A price of 2,800 $/$kW_P$ would result in a discounted payback time of less than 5 years and a modified internal rate of return of 9.7 %.

6.7 SAVANNAH GARDENS

"Savannah Gardens" is the name of a residential neighborhood in the eastern part of Savannah. It is a project, assisted by the local "Housing Department", that tries to offer affordable housing for low- and medium income households. In this context the city tries to promote the use of modern technologies like ground-source heat pumps and PV systems. Therefore, one particular house, which is soon to be refurbished, was chosen for showing the applicability of a PV system.

System design:

The building contains two apartments with base areas of ~1000 sqft (~95 m^2) each and an east – west oriented roof with a tilt of 30 °. It is decided to analyze a system with 2 kW_P mounted on the west side of this roof, despite a slight orientation to north, but with the advantage of less shading objects.

This designed system with 30 ° module tilt and an orientation of 105 ° from south to west would produce an energy yield of 2,362 kWh/yr or 1,181 kWh/(kW$_P$*yr) according to the tool internal simulation. Since the building is not yet inhabited there is also no data available for its energy usage. Therefore, it is assumed to follow the NREL load profile for a small residential building with a base area of 1,000 sqft and an annual energy consumption of 8,706 kWh. The result is a predicted self-consumption of 84,9 %.

Financial parameters:

For the financing methods it is chosen to analyze the system with own capital financing and a system prize of 2,800 $/kW$_P$. Further, since it is intended to be in private ownership, a rate of 12.5 mills on the system's assessed value has to be paid annually as property tax. On the other hand, it is chosen to set the percentage for annual maintenance expenditures to 0.25 % of the system costs instead of 0.5 %, since it is assumed that small works like module cleaning can be done by the owner himself. Finally, a federal tax credit is set to 30 % of the system's upfront costs.

Conclusion – Savannah Gardens:

Both discounted- and simple- payback times are close to the end of the chosen analysis period of 25 years. Therefore, the system has the potential to pay for itself, but due to the bad orientation a high self consumption is crucial to achieve this at all. With a different orientation better economics could be a result, but since the main goal is to show the possibility of mounting such a system a location with good visibility from the street side has higher importance.

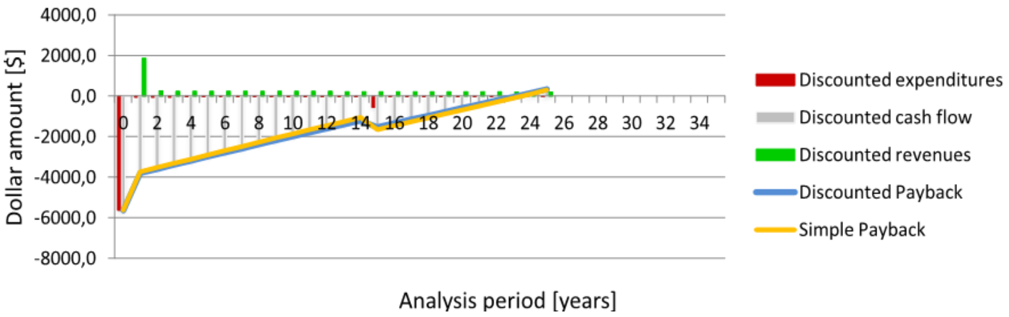


Figure 47: Cash flow analysis – Savannah Gardens, 1800 $/kW$_P$, own capital

6.8 RESIDENTIAL BUILDING

The last object to be analyzed is a residential building in the suburbs of Savannah. Built in 2005, it has a base area of 3,580 sqft and is occupied by 2 residents. The annual energy demand was 22,399 kWh in the year 2014. The owner applied to take part in the “Solarize Tybee” program and was offered a PV system with 3 kW_P for a total price of $8,400 (2,800 $/$kW_P$).

System design:

With the roof oriented to south and a tilt of 30° a total electric production of 4,413 kWh/yr and 1,471 kWh/(kW_P*yr) is simulated with the programmed tool. In combination with the load profile of a medium residential building this results in a self-consumption of 85,4 %. The financing options are chosen equal to the system for Savannah Gardens.

Conclusion – Residential Building:

As result it can be shown that a realistic payback time of less than 18 years can be achieved with residential applications of PV systems in the region of Savannah. This equals a modified internal rate of return of 4.19 %/yr over the chosen analysis period of 25 years. However, a comparison with the building analyzed in Savannah Gardens shows that this is only possible when the circumstances allow both a high production as well as a high self consumption.

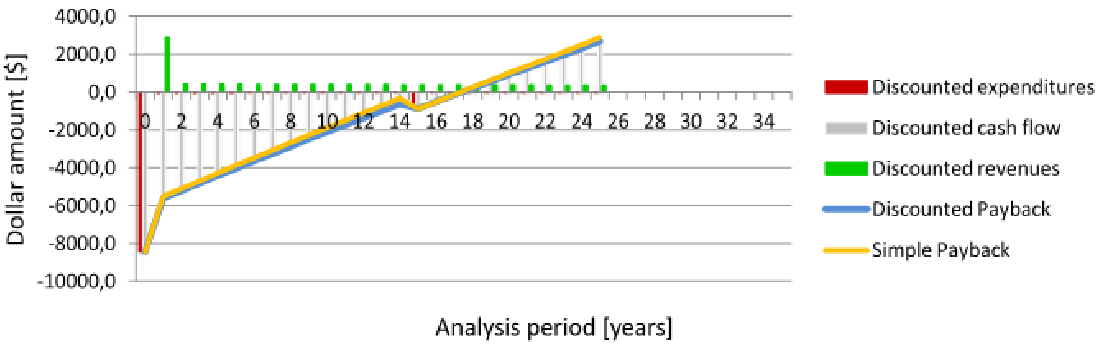


Figure 48: Cash flow analysis – Residential Building, 1800 $/$kW_P$, own capital

7 SUMMARY / CONCLUSION

The goal of this thesis was to analyze the potential of PV systems in the region of Savannah, Georgia. The focus was set on answering the question if the application of this technology could help the local city government to reduce its carbon footprint while saving money at the same time.

Therefore, a simulation spreadsheet-tool was programmed that allows the user to calculate the predicted energy yield of PV systems, the possible self-consumption rate of the generated electricity, depending on a building’s energy consumption, as well as the calculation of several economical key figures over the expected lifetime of the system. In addition, it enables the user to analyze the effects of different forms of subsidies and financing methods to identify the best option.

Within this thesis 12 different buildings and facilities located in Savannah were evaluated, resulting in recommendations about the maximum system costs that would be necessary for good economical results. This approach was chosen due to the fact that the specific prices for PV applications can widely vary depending on the system size, mounting method, contractor and the quality of installed products. Therefore, the knowledge of a maximum cost can help the persons in charge to come to decisions if a presented offer should be approved or not.

It was shown that especially small offices with an energy consumption of less than 100,000 kWh/yr can provide very good frame conditions for implementing PV systems. Very short payback times and in one case savings beginning with the first year of operation are achievable with currently system prices. As financing method the combination of a long term bond and a federal bond incentive was identified to be the best method for governmental entities. However, despite an identical cumulative usage, the economic results can vary considerably depending on the consumer’s peak demand. Therefore, it is not possible to provide a general recommendation, but each building has to be analyzed separately.

As for the bigger systems analyzed here, a recommendation can be made concerning the Savannah Civic Center. With its high energy usage and big available flat roof area it would allow the installation of a 100 kW_P PV system. If a system price of 2,200 $/$kW_P$ could be obtained in combination with a federal bond incentive, this system would pay off within 13 years when considering a discounted cash flow scenario. This equals an expected modified internal rate of return of 7,24 %/yr over the considered period and would help the city government to prevent 2,519 metric tons of carbon emissions over the next 30 years.

Finally, also the applicability for residential systems was analyzed. It was found that such system are definitely economical at the appropriate boundary conditions, which are a high energy yield in combination with a high self-consumption rate. Achievable payback times are about 17 to 18 years, if a system price of 2,800 $/kWp is assumed, based on 100 % equity financing.

In conclusion, the situation in the region of Savannah, Georgia, definitely provides a high potential for PV systems and their economical application, but it is strongly depending on the specific frame conditions that are given. It is recommended that the city government uses this analysis to start considering the implementation of PV systems as a viable method to reduce future electricity costs. With the developed tool it is possible to quickly analyze buildings or facilities of interest to see if the combination of energy usage, electricity purchase contract and PV system provides potential for an economical solution.

8 LIST OF ABBREVIATIONS

Abbreviation	**Explanation**
PV	Photovoltaic
W_P	Watt Peak-Power
kW_P	Kilo-Watt Peak-Power
MW_P	Mega-Watt Peak Power
IRS	Internal Revenue Service - agency
CREB	Clean Renewable Energy Bond
QECB	Qualified Energy Conservation Bond
NREL	National Renewable Energy Laboratory
USt.	“Umsatzsteuer” (Austrian form of sales tax)

9 LIST OF FIGURES

Figure 1: Electricity rates in Georgia, 2014 [U.S. EIA, 2014b]......................................4
Figure 2: Average residential electricity rates by states [U.S. EIA, 2014b]....................5
Figure 3: Electricity production by energy source - Georgia [U.S. EIA, 2014b]............6
Figure 4: Historic electric energy production by source – Georgia [U.S. EIA, 2014a]..6
Figure 5: Electricity - carbon dioxide emissions – Georgia [U.S. EIA, 2014a] 7
Figure 6: REC retail price development [U.S. EERE, 2014]...9
Figure 7: PV system cost development – USA [U.S. DOE, 2014].................................14
Figure 8: Monthly horizontal irradiation data..23
Figure 9: Monthly average air temperature and min-/ max- temperatures....................24
Figure 10: Monthly average and monthly maximum wind-speeds................................24
Figure 11: Monthly average relative humidity...25
Figure 12: Irradiation data - Georgia [Meteonorm, 2015]..28
Figure 13: Required total area...29
Figure 14: General information – Utility contract - inputs..32
Figure 15: General information – Electricity sale contract - inputs..............................34
Figure 16: System data – Generator – inputs...35
Figure 17: System data - System – inputs..35
Figure 18: System data - Facility – inputs..36
Figure 19: Financing- Method and System – inputs..37
Figure 20: Financing- Financing – inputs..38
Figure 21: Financing- Incentive and Scenario – inputs...39
Figure 22: Final tool report..40
Figure 23: Incident angle on fixed surface [Quaschning, 2006]...................................43
Figure 24: Relative error - silicon module to south, 30° tilt...47
Figure 25: Variables "K" & "d" with respect to module tilt..48
Figure 26: Variable "K" with respect to module orientation..49
Figure 27: Example load profile – residential [Pecan Street Inc., 2014].......................55
Figure 28: Self consumption error analysis..56
Figure 29: Power & Light - Medium - tariff structure[Georgia Power, 2014c].............58

Figure 30: Monthly average load profile – State Street Garage 66
Figure 31: Aerial photography - State Street Garage [SAGIS, 2015] 66
Figure 32: State Street Garage - Variant 1[SketchUp, 2015] 67
Figure 33: State Street Garage - Variant 2 [SketchUp, 2015] 67
Figure 34: Cash-flow analysis - State Street Garage, own-capital, 15 years payback time 69
Figure 35: Cash-flow analysis - State Street Garage, own-capital, 20 years payback time 70
Figure 36: Cash-flow analysis - State Street Garage, 2200 \$/kW$_P$*, 25 yrs bond with 3,5 %/yr interest rate* 71
Figure 37: Cash-flow analysis - State Street Garage, 2200 \$/kW$_P$*, 25 yrs bond with 0,2 %/yr interest rate (e.g. QREB)* 71
Figure 38: City Hall roof [Wimmer, 2015] 73
Figure 39: City Hall - System design [SketchUp, 2015] 74
Figure 40: City Hall - Shading analysis [PVSyst SA, 2015] 75
Figure 41: Cash flow analysis – City Hall, 1800 \$/kW$_P$*, 25 yrs bond with 3,5 %/yr interest rate* 76
Figure 42: Savannah Civic Center - aerial view [SAGIS, 2015] 76
Figure 43: Civic Center - System design [SketchUp, 2015] 77
Figure 44: Cash flow analysis – Civic Center, 2200 \$/kW$_P$*, 25 yrs bond with 3,5 %/yr interest rate* 78
Figure 45: I&D Water Supply - aerial view [SAGIS, 2015] 79
Figure 46: I&D Water Supply - System design [SketchUp, 2015] 79
Figure 47: Cash flow analysis – Savannah Gardens, 1800 \$/kW$_P$*, own capital* 84
Figure 48: Cash flow analysis – Residential Building, 1800 \$/kW$_P$*, own capital* 85

10 LIST OF TABLES

Table 1: Investment costs - residential systems, Austria 17
Table 2: Incentive comparison 17
Table 3: Facility selection - part 1 18
Table 4: Horizontal Irradiation data - monthly and from different sources 22
Table 5: Silicon type efficiencies 26
Table 6: Thin-film type efficiencies 27
Table 7: Temperature efficiency coefficients 30
Table 8: Program worksheets – overview 31
Table 9: NREL - Load profiles 54
Table 10: Facility selection - part 1 64
Table 11: State Street Garage - Investment costs and payback times 72
Table 12: Office buildings 81

11 LIST OF EQUATIONS

No.	**Name**	**Equation**
5.1	Sun vector	$\vec{s} = \begin{pmatrix} \cos\alpha_S * \cos\gamma_S \\ -\sin\alpha_S * \cos\gamma_S \\ \sin\gamma_S \end{pmatrix}$
5.2	Module plane vector	$\vec{n} = \begin{pmatrix} -\cos\alpha_E * \sin\gamma_E \\ \sin\alpha_E * \sin\gamma_E \\ \cos\gamma_E \end{pmatrix}$
5.3	Incident angle 1	$\theta_{gen} = \arccos\,(\vec{s} * \vec{n})$
5.4	Incident angle 2	$\theta_{gen} = \arccos\,(-\cos\alpha_S * \cos\gamma_S * \cos\alpha_E * \sin\gamma_E - \sin\alpha_S * \cos\gamma_S * \sin\alpha_E * \sin\gamma_E + \sin\gamma_S * \cos\gamma_E)$
5.5	Direct irradiance on generator	$E_{dir,gen} = E_{dir,hor} * \left\{ max \left\{ 0, \frac{\cos\theta_{gen}}{\sin\gamma_S} \right\} \right\}$
5.6	Diffuse irradiance on generator	$E_{diff,gen} = E_{diff,hor} * \frac{1}{2} * (1 + \cos\gamma_E)$
5.7	Diffuse light - incident angle (2-axis tracking)	$\gamma_E = 90° - \gamma_S$
5.8	Reflected irradiance on generator	$E_{refl,gen} = E_{G,hor} * A * \frac{1}{2}(1 - \cos\gamma_E)$
5.9	Total irradiance on generator	$E_{G,gen} = E_{dir,gen} + E_{diff,gen} + E_{refl,gen}$

No.	**Name**	**Equation**
5.10	Module temperature	$U * (T_{module} - T_{amb}) = \alpha * E_{G,gen} * (1 - \eta_{module})$
5.11	Total generator yield 1	$P_{Peak} = E_{STC} * A_{gen} * \eta_{gen}$
5.12	Total generator yield 2	$\begin{aligned} P_{Gen} &= E_{G,gen} * A_{gen} * \eta_{gen} \\ &\quad * \left(1 - \Delta\eta_{Pmpp} * (T_{module} - T_{STC})\right) \\ &= E_{G,gen} * \frac{P_{Peak}}{E_{STC}} * \left(1 - \Delta\eta_{Pmpp} * (T_{module} - T_{STC})\right) \end{aligned}$
5.13	Yield error	$e_{relative} = \frac{E_{PVSyst}}{E_{tool}}$
5.14	Error modification	$f(GHI) = K * \left(1 - e^{\left(\frac{-GHI}{a}\right)}\right) + b * \sin\left(\frac{GHI}{c}\right) - d * GHI$
5.15	Variable k_1	$k_1(\gamma_E) = e * {\gamma_E}^3 + f * {\gamma_E}^2 + g * \gamma_E + h$
5.16	Variable d	$d(\gamma_E) = l * {\gamma_E}^3 + m * {\gamma_E}^2 + n * \gamma_E$
5.17	Variable k_2	$k_2(\alpha_E) = (m * {\alpha_E}^2 + n * \alpha_E) * (\frac{1+\gamma_E}{k})^3$
5.18	Ohmic resistivity	$R_{cable} = \mathrm{\rho_{cable}} * \frac{\mathrm{l_{single\ length}}}{\mathrm{A_{cable}}}$

No.	Name	Equation
5.19	DC – power loss	$P_{loss-DC} = R * I^2 = 2 * R_{cable} * n_{string} * \left(\frac{P_{gen}}{n_{string} * U_{string}}\right)^2$
5.20	AC – power loss, single phase	$P_{loss-AC-single} = 2 * R_{cable} * \left(\frac{P_{inverter}}{U_{AC-single\ phase}}\right)^2$
5.21	AC – power loss, multi phase	$P_{loss-AC-3phase} = 3 * R_{cable} * \left(\frac{P_{inverter}}{U_{AC-multi\ phase}}\right)^2$
5.22	Inflation rate	$e = \frac{(1+d_n)}{(1+d_r)} - 1$
5.23	Total life cycle costs	$TLCC = \sum \frac{C_n}{(1+d_n)^n}$
5.24	Levelized cost of energy	$LCOE = \frac{TLCC}{\sum \frac{Q_n}{(1+d_n)^n}}$
5.25	Modified internal rate of return	$MIRR = r,\ where\text{:}\ \sum \frac{Fn_n}{(1+d)^n} = \sum \frac{Fp_n * (1+d)^{N-n}}{(1+r)^N}$

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13 APPENDIX A

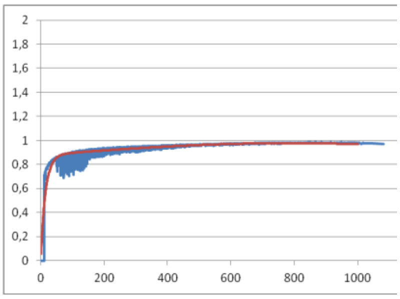
Utility Contracts - Overview			
	Code	**Name**	**Used within the Tool**
Residential:			
	R-20	Standard Service	✓
	Flat-5	FlatBill®	✗
	TOU-REO-8	Nights & Weekends	✓
	TOU-PEV-4	Plug-In Electric Vehicle	✓
	TOU-RD-1	Residential Demand	✓
Small Business:			
	GS-8	General Service	✓
	Flat-5	Flatbill	✗
	OGS-13	Optional General Service	✗
	PLS-9	Power and Light - Small	✓
	TOU-EO-8	Time-of-Use - Energy Only	✗
	UC-8	Unmetered Communication	✗
Medium Business:			
	PLM-9	Power and Light - Medium	✓
	TOU-GSD-8	Time-of-Use - General Service Demand	✗
	TOU-MB-5	Time-of-Use - Multiple Business	✗
Large Business:			
	PLL-9	Power and Light - Large	✓
	PLH-9	Power and Light - High Load Factor	✗
	TOU-HLF-7	Time of Use - High Load Factor	✗
	MLM-8	Multiple Load Management	✓
	TOU-RN-4	Time-of-Use - Revenue Neutral	✗
Marginally-Priced Business:			
	FPA-7	Fixed Pricing Alternative	✗
	TOU-SC-6	Time-of-Use - Supplier Choice	✗
	RTP-DA-4	Real Time Pricing - Day Ahead	✗
	RTP-HA-4	Real Time Pricing - Hour Ahead	✗
	RTP-DAA-5	Real Time Pricing - Day Ahead with Adjustable CBL	✗
	RTP-HAA-5	Real Time Pricing - Hour Ahead with Adjustable CBL	✗
	PPP-2	Price Protection Products	✗
	EAF-3	Electric Arc Furnace	✗

Governmental/ Institution:			
	SCH-16	School Service	✓
	SLM-12	School Load Management	✓
	G-17	Full Use Service to Governmental Institutions	✘
	ET-15	Electric Transportation Service	✘
	TC-U-21	Traffic Control Unmetered Service	✘
	TC-M-4	Traffic Control Metered	✓
Agricultural:			
	IOP-12	Irrigation Off-Peak Service	✘
	FS-8	Farm Service	✘
	SAS-ND-7	Seasonal Agricultural Service - Non Demand	✘
	SAS-7	Seasonal Agricultural Service	✘
	APS-8	Agricultural Process Service Rate	✘
Outdoor Lighting:			
	OLG-8	Outdoor Lighting Service, Governmental	✘
	OLNG-9	Outdoor Lighting Service, Non-Governmental	✘
	EOL-9	Energy for Outdoor Lighting Service	✘
	TOU-EOL-1	Tim-of-Use - Energy for Outdoor Lighting Service (Pilot)	✘

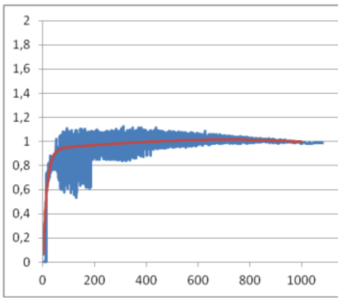
14 APPENDIX B

Error of internal energy prediction. Blue represents the error, red the developed trend line.

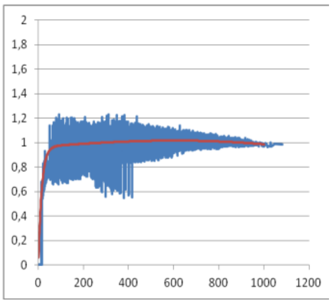
Silicon, south, 0° tilt:



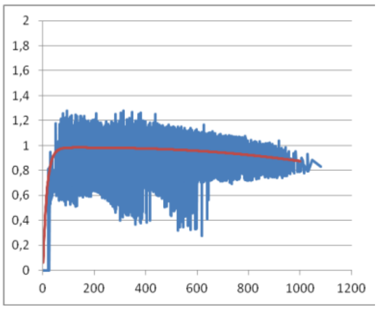
Silicon, south, 30° tilt:



Silicon, south, 60° tilt:



Silicon, south, 90° tilt:



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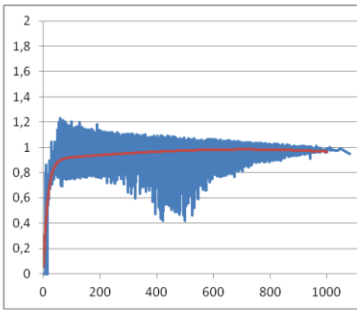

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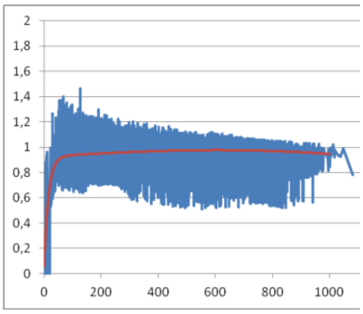

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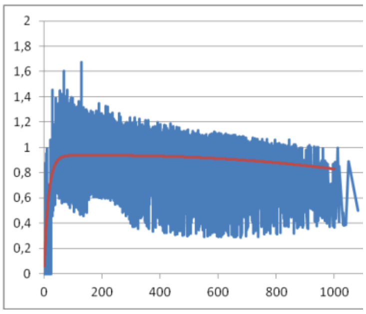

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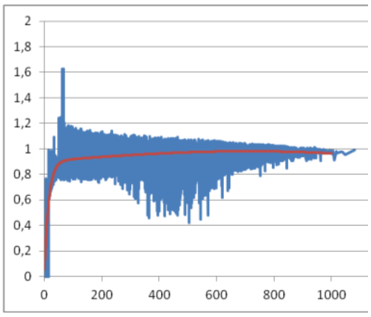

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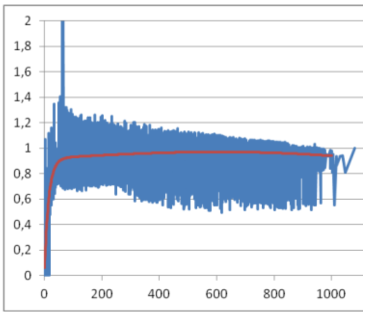
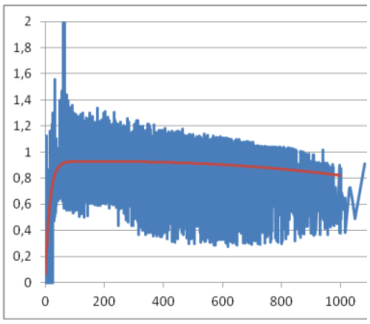
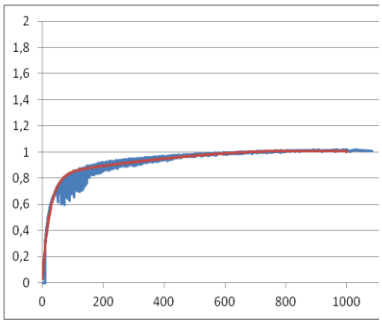


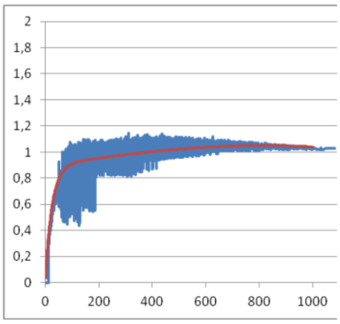
Silicon, west, 90° tilt:



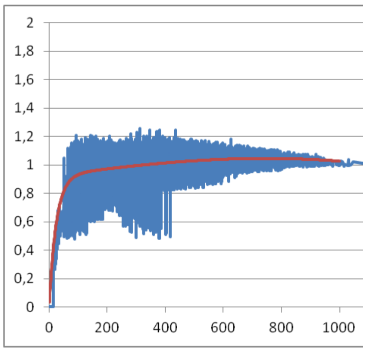
CIS, south, 0° tilt:



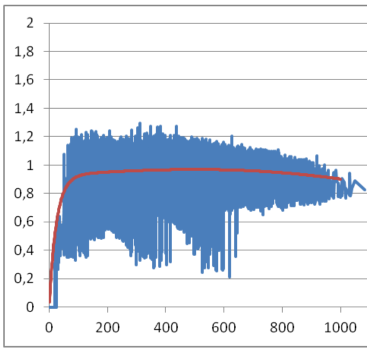
CIS, south, 30° tilt:



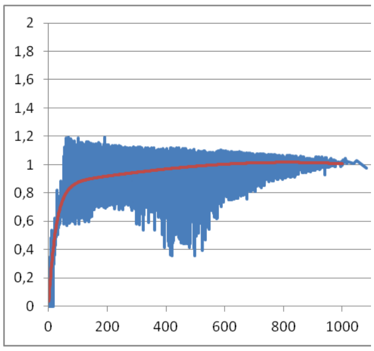
CIS, south, 60° tilt:



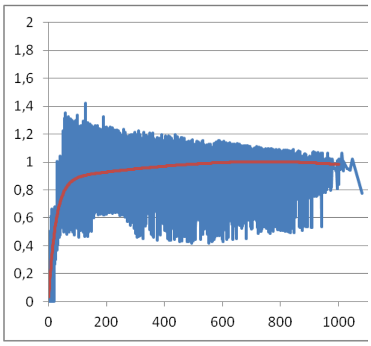
CIS, south, 90° tilt:



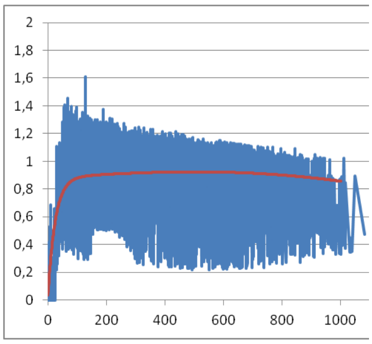
CIS, east, 30° tilt:



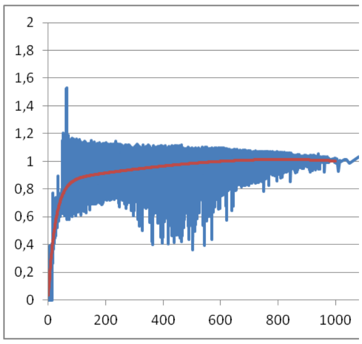
CIS, east, 60° tilt:



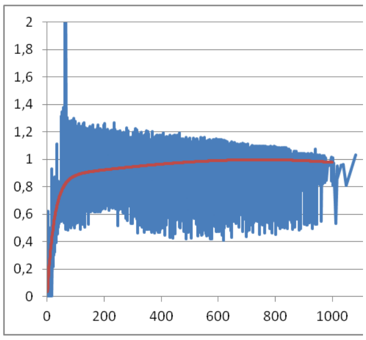
CIS, east, 90° tilt:



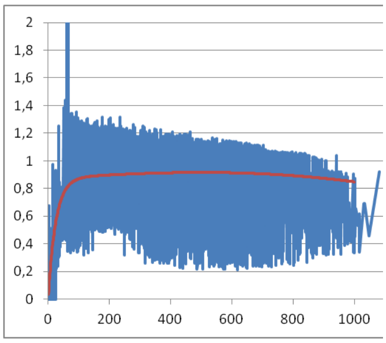
CIS, west, 30° tilt:



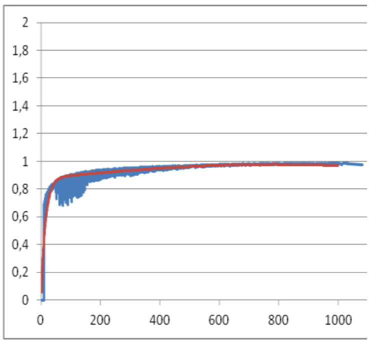
CIS, west, 60° tilt:



CIS, west, 90° tilt:



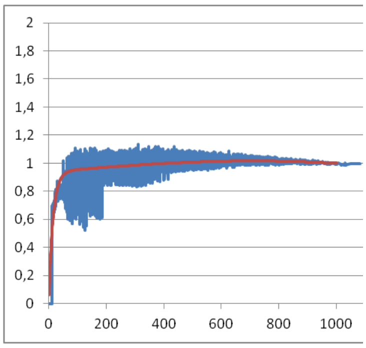
CdTe, south, 0° tilt:

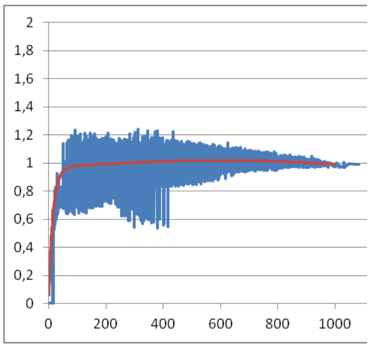


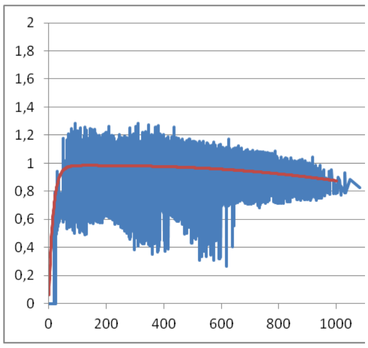
CdTe, south, 30° tilt:

CdTe, south, 60° tilt:

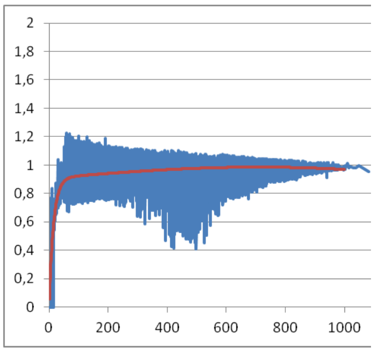
CdTe, south, 90° tilt:



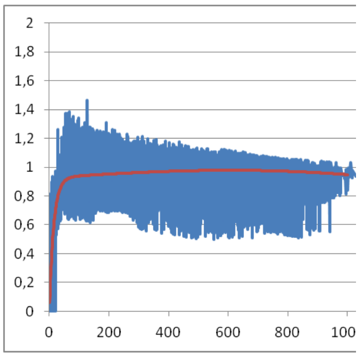




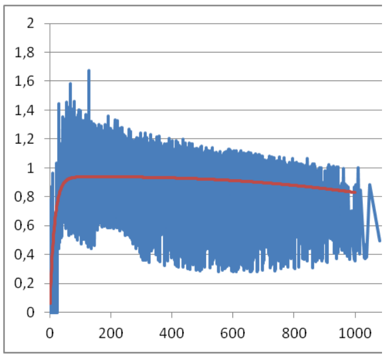
CdTe, east, 30° tilt:



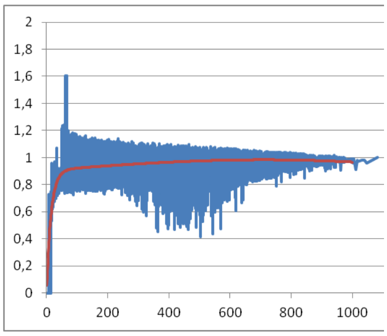
CdTe, east, 60° tilt:



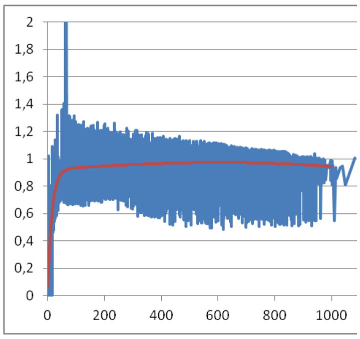
CdTe, east, 90° tilt:



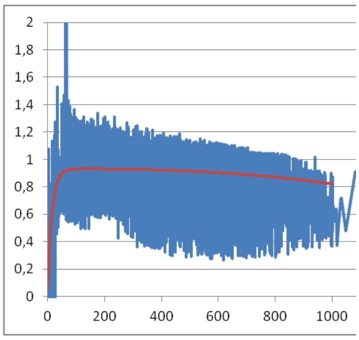
CdTe, west, 30° tilt:



CdTe, west, 60° tilt:

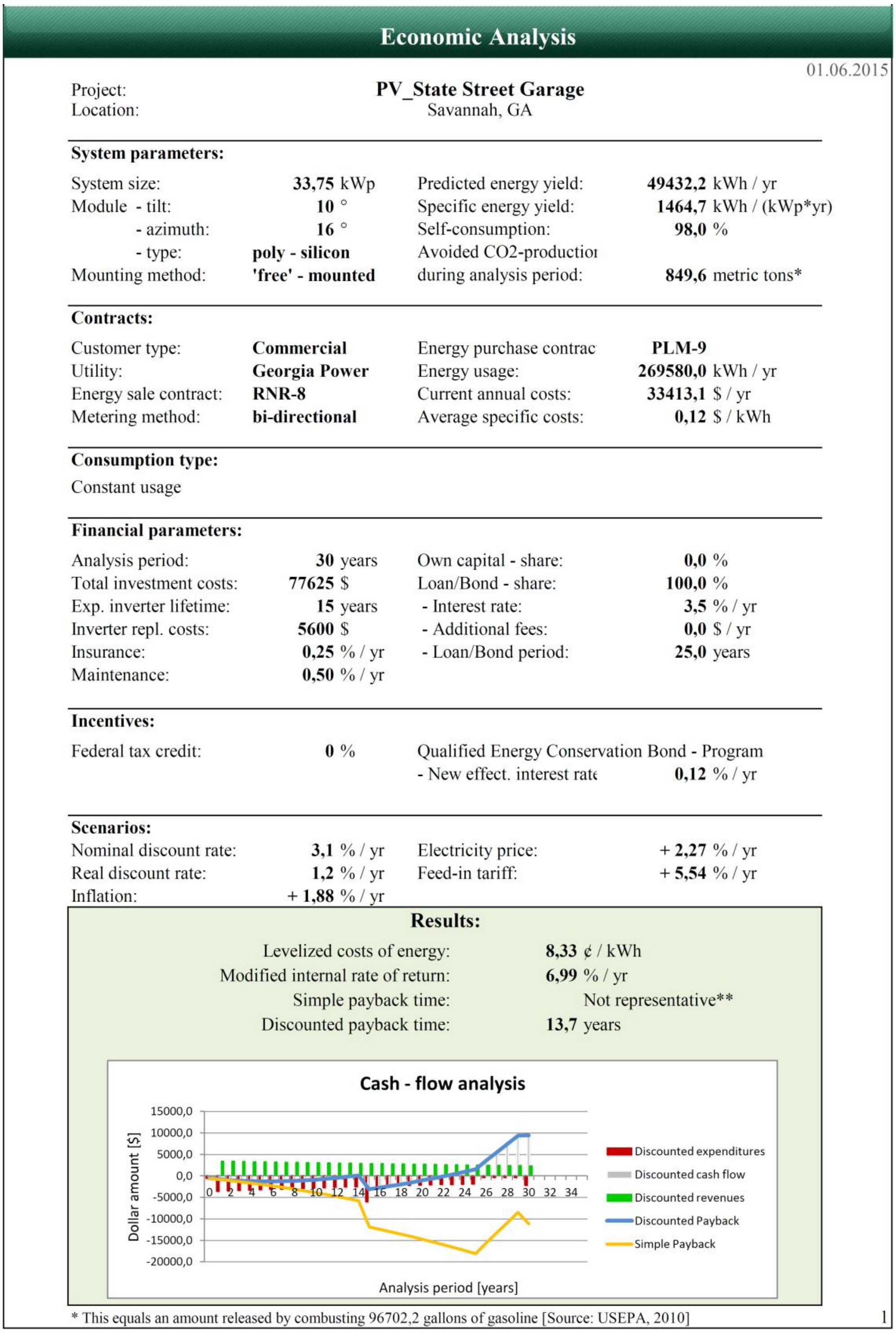


CdTe, west, 90° tilt:



15 APPENDIX C

- Report: “State Street Garage”



Economic Analysis

01.06.2015

Project:	**PV_State Street Garage**
Location:	Savannah, GA

System parameters:

System size:	**33,75** kWp	Predicted energy yield:	**49432,2** kWh / yr
Module - tilt:	**10** °	Specific energy yield:	**1464,7** kWh / (kWp*yr)
- azimuth:	**16** °	Self-consumption:	**98,0** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**'free' - mounted**	during analysis period:	**849,6** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**269580,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**33413,1** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,12** $ / kWh

Consumption type:

Constant usage

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**77625** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**5600** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	**+ 2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	**+ 5,54** % / yr
Inflation:	**+ 1,88** % / yr		

Results:

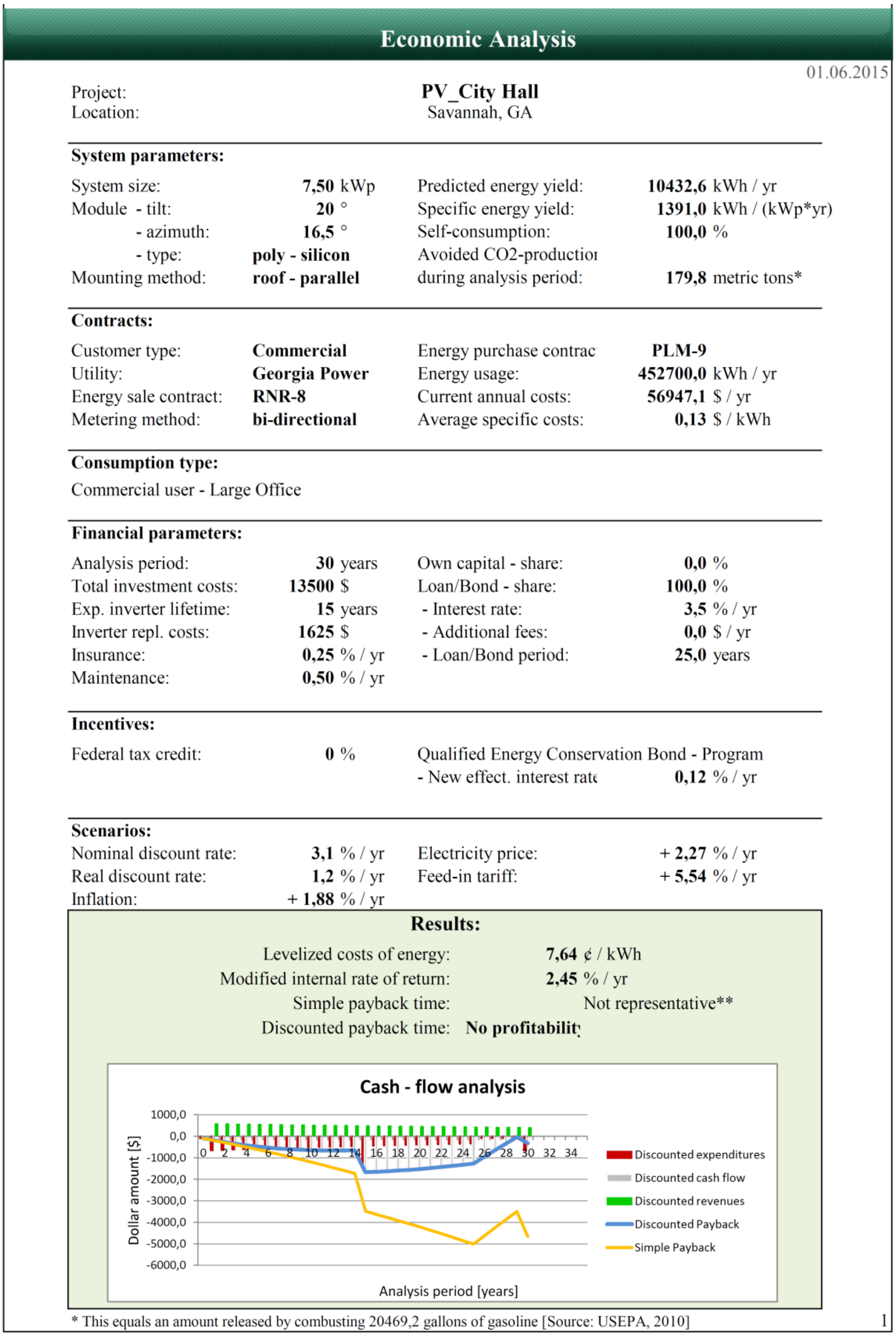
Levelized costs of energy:	**8,33** ¢ / kWh
Modified internal rate of return:	**6,99** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**13,7** years

Cash - flow analysis

* This equals an amount released by combusting 96702,2 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “City Hall”



Economic Analysis

01.06.2015

Project:	**PV_City Hall**
Location:	Savannah, GA

System parameters:

System size:	**7,50** kWp	Predicted energy yield:	**10432,6** kWh / yr
Module - tilt:	**20** °	Specific energy yield:	**1391,0** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**100,0** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**179,8** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**452700,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**56947,1** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,13** $ / kWh

Consumption type:

Commercial user - Large Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**13500** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**1625** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	**+ 2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	**+ 5,54** % / yr
Inflation:	**+ 1,88** % / yr		

Results:

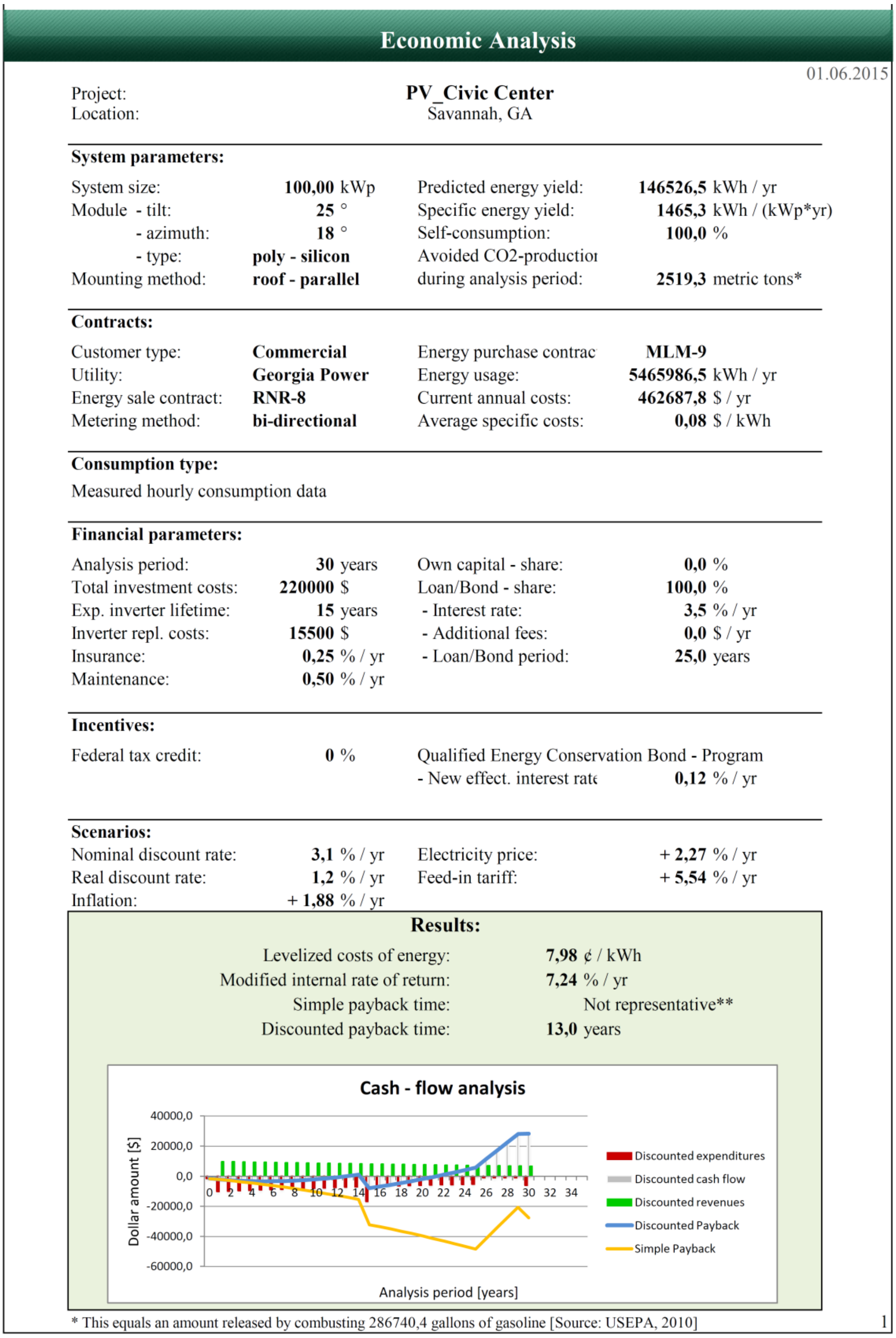
Levelized costs of energy:	**7,64** ¢ / kWh
Modified internal rate of return:	**2,45** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**No profitabilit**

Cash - flow analysis

* This equals an amount released by combusting 20469,2 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “Civic Center”



Economic Analysis

01.06.2015

Project:	**PV_Civic Center**
Location:	Savannah, GA

System parameters:

System size:	**100,00** kWp	Predicted energy yield:	**146526,5** kWh / yr
Module - tilt:	**25** °	Specific energy yield:	**1465,3** kWh / (kWp*yr)
- azimuth:	**18** °	Self-consumption:	**100,0** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**2519,3** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**MLM-9**
Utility:	**Georgia Power**	Energy usage:	**5465986,5** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**462687,8** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,08** $ / kWh

Consumption type:

Measured hourly consumption data

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**220000** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**15500** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	**+ 2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	**+ 5,54** % / yr
Inflation:	**+ 1,88** % / yr		

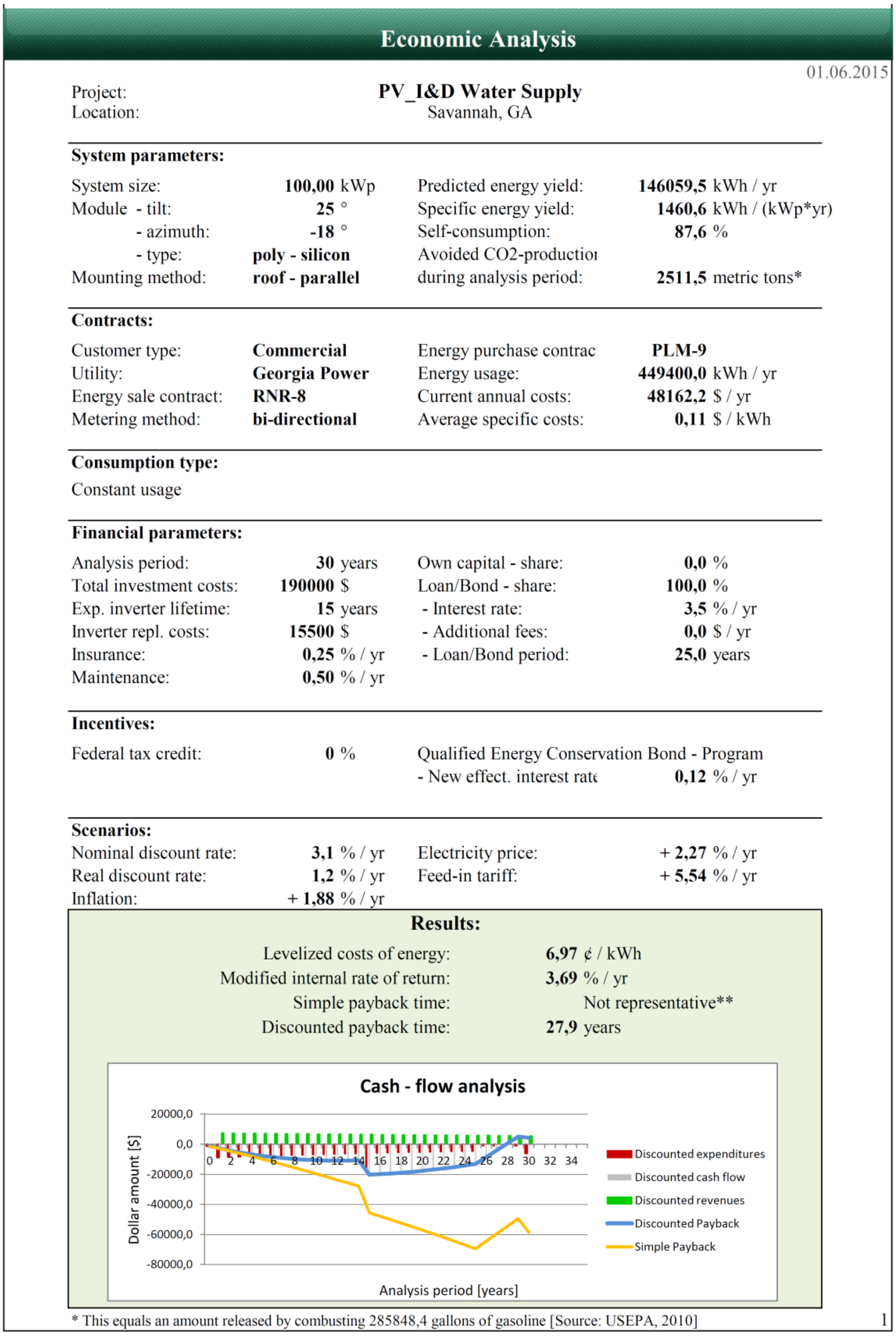
Results:

Levelized costs of energy:	**7,98** ¢ / kWh
Modified internal rate of return:	**7,24** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**13,0** years

* This equals an amount released by combusting 286740,4 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “I&D Water Supply”



Economic Analysis

01.06.2015

Project:	**PV_I&D Water Supply**
Location:	Savannah, GA

System parameters:

System size:	**100,00** kWp	Predicted energy yield:	**146059,5** kWh / yr
Module - tilt:	**25** °	Specific energy yield:	**1460,6** kWh / (kWp*yr)
- azimuth:	**-18** °	Self-consumption:	**87,6** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**2511,5** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**449400,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**48162,2** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,11** $ / kWh

Consumption type:

Constant usage

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**190000** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**15500** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

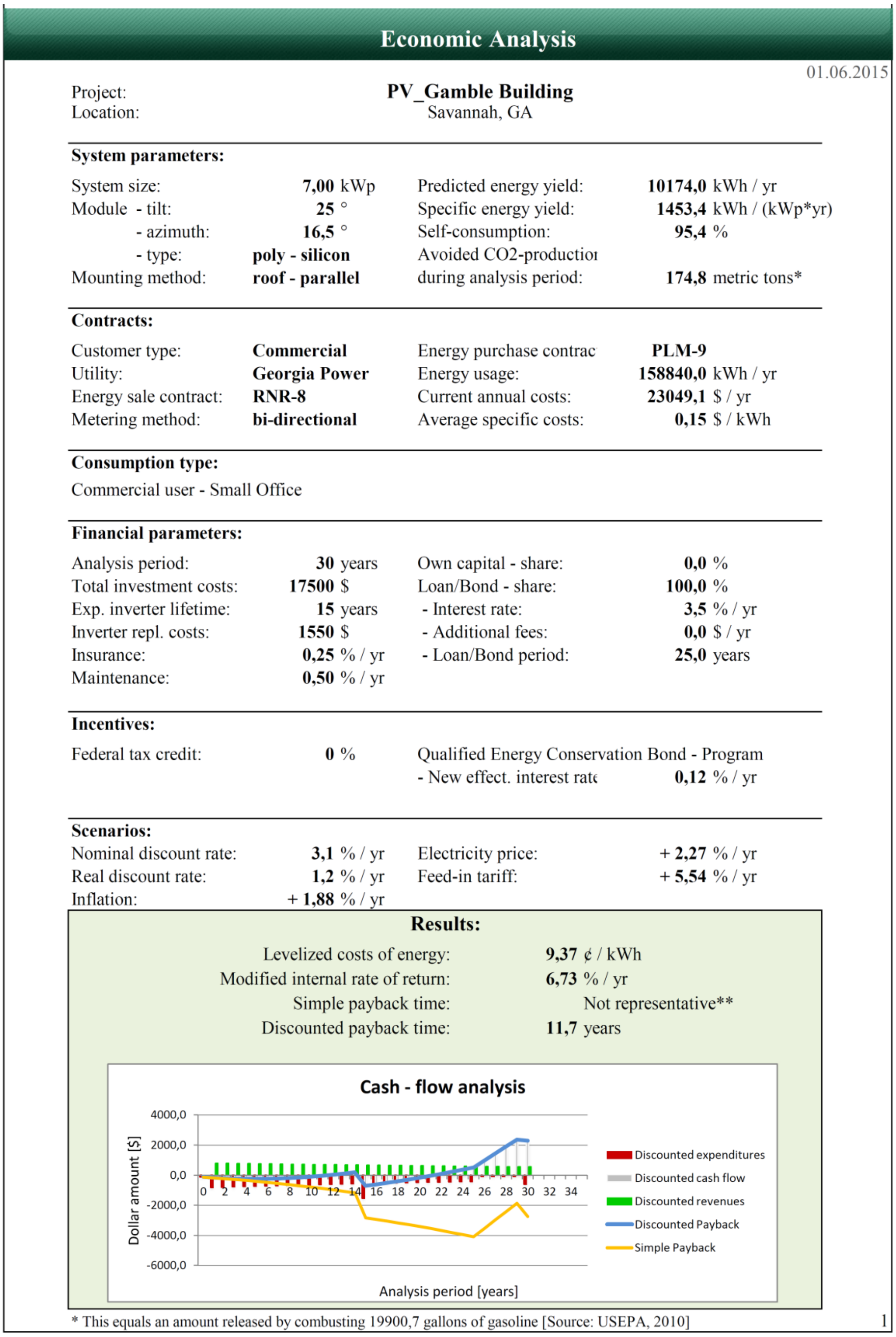
Levelized costs of energy:	**6,97** ¢ / kWh
Modified internal rate of return:	**3,69** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**27,9** years

Cash - flow analysis

* This equals an amount released by combusting 285848,4 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “Gamble Building”



Economic Analysis

01.06.2015

Project:	**PV_Gamble Building**	
Location:	Savannah, GA	

System parameters:

System size:	**7,00** kWp	Predicted energy yield:	**10174,0** kWh / yr
Module - tilt:	**25** °	Specific energy yield:	**1453,4** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**95,4** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**174,8** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**158840,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**23049,1** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,15** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**17500** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**1550** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

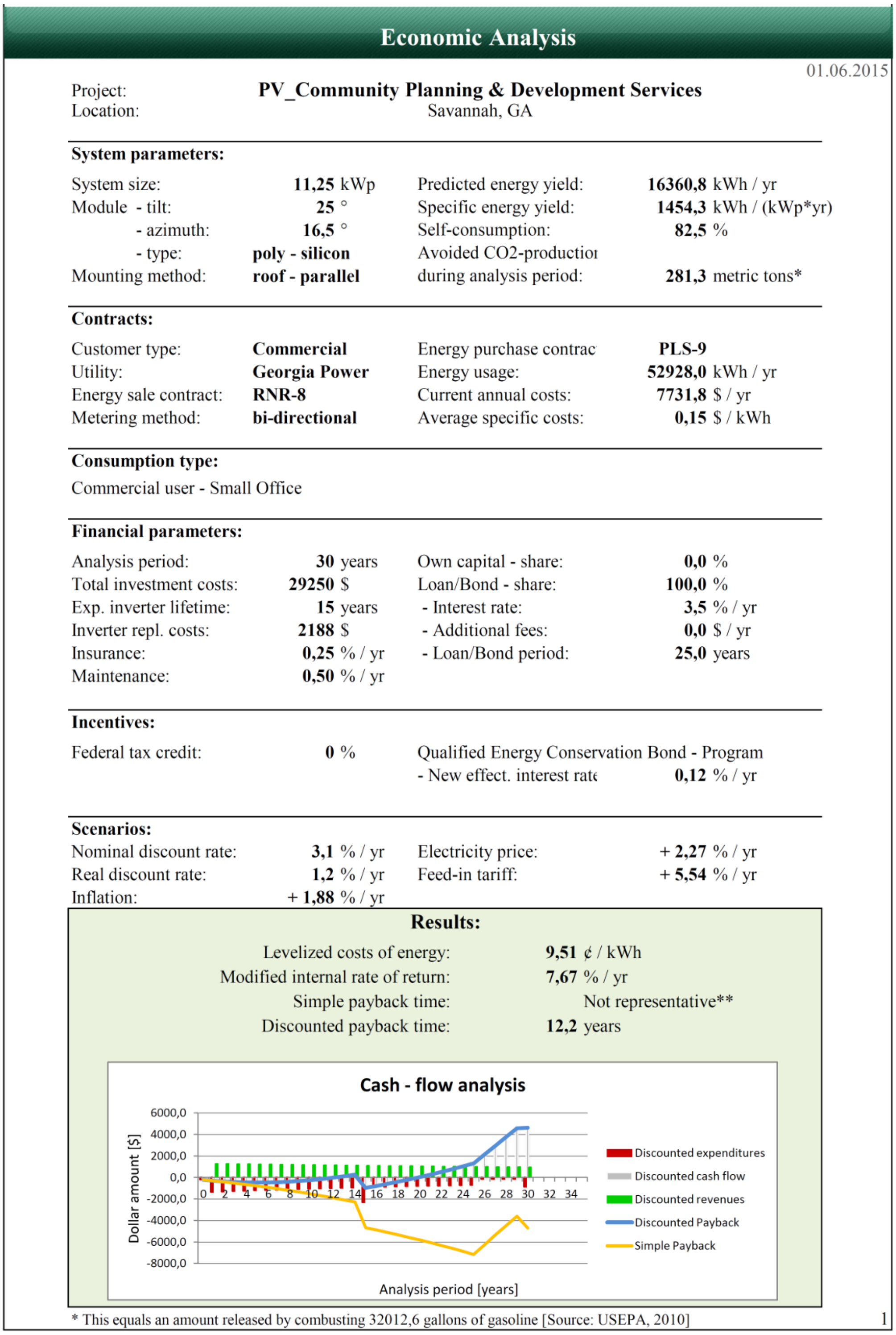
Results:

Levelized costs of energy:	**9,37** ¢ / kWh
Modified internal rate of return:	**6,73** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**11,7** years

* This equals an amount released by combusting 19900,7 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “Community Planning & Development Services”



Economic Analysis

01.06.2015

Project:	**PV_Community Planning & Development Services**
Location:	Savannah, GA

System parameters:

System size:	**11,25** kWp	Predicted energy yield:	**16360,8** kWh / yr
Module - tilt:	**25** °	Specific energy yield:	**1454,3** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**82,5** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**281,3** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLS-9**
Utility:	**Georgia Power**	Energy usage:	**52928,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**7731,8** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,15** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**29250** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**2188** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

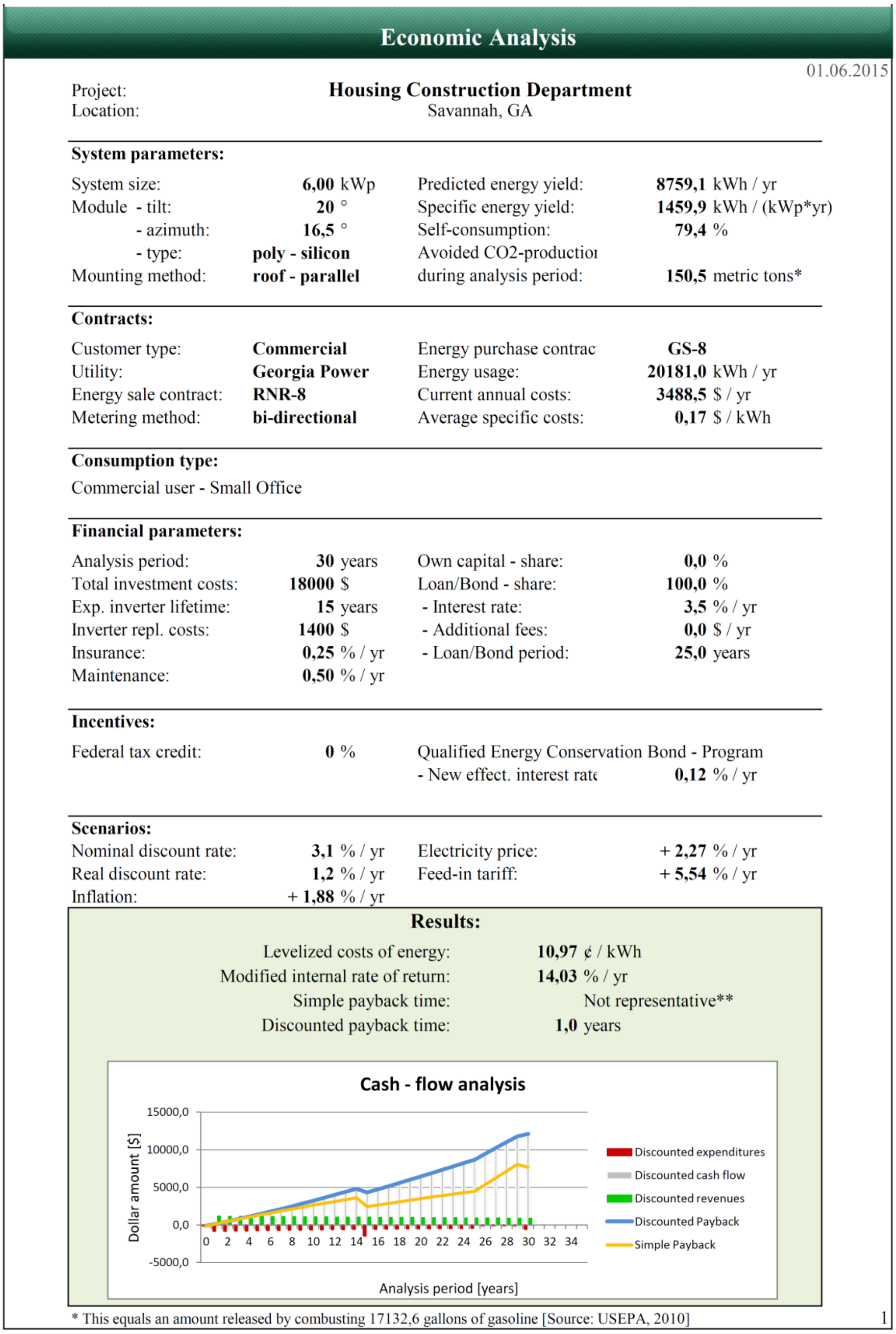
Results:

Levelized costs of energy:	**9,51** ¢ / kWh
Modified internal rate of return:	**7,67** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**12,2** years

* This equals an amount released by combusting 32012,6 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “Housing Construction Department”



Economic Analysis

01.06.2015

Project:	**Housing Construction Department**
Location:	Savannah, GA

System parameters:

System size:	**6,00** kWp	Predicted energy yield:	**8759,1** kWh / yr
Module - tilt:	**20** °	Specific energy yield:	**1459,9** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**79,4** %
- type:	**poly - silicon**	Avoided CO2-productioı	
Mounting method:	**roof - parallel**	during analysis period:	**150,5** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**GS-8**
Utility:	**Georgia Power**	Energy usage:	**20181,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**3488,5** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,17** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**18000** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**1400** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rate	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

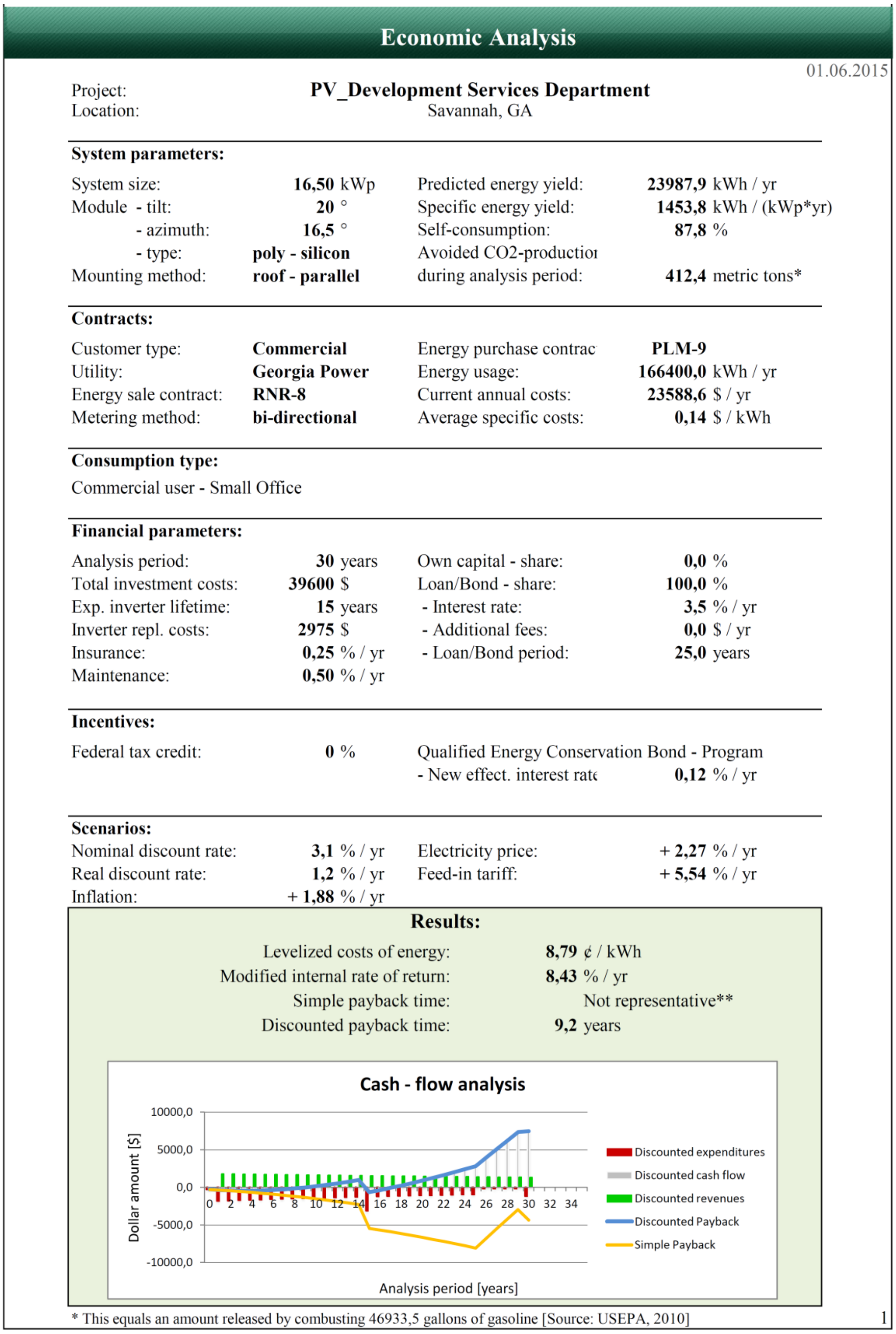
Levelized costs of energy:	**10,97** ¢ / kWh
Modified internal rate of return:	**14,03** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**1,0** years

Cash - flow analysis

* This equals an amount released by combusting 17132,6 gallons of gasoline [Source: USEPA, 2010]

1

- Report: “Development Services Department”



Economic Analysis

01.06.2015

Project:	**PV_Development Services Department**
Location:	Savannah, GA

System parameters:

System size:	**16,50** kWp	Predicted energy yield:	**23987,9** kWh / yr
Module - tilt:	**20** °	Specific energy yield:	**1453,8** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**87,8** %
- type:	**poly - silicon**	Avoided CO2-productioı	
Mounting method:	**roof - parallel**	during analysis period:	**412,4** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**166400,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**23588,6** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,14** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**39600** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**2975** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rate	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

Levelized costs of energy:	**8,79** ¢ / kWh
Modified internal rate of return:	**8,43** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**9,2** years

Cash - flow analysis

* This equals an amount released by combusting 46933,5 gallons of gasoline [Source: USEPA, 2010]

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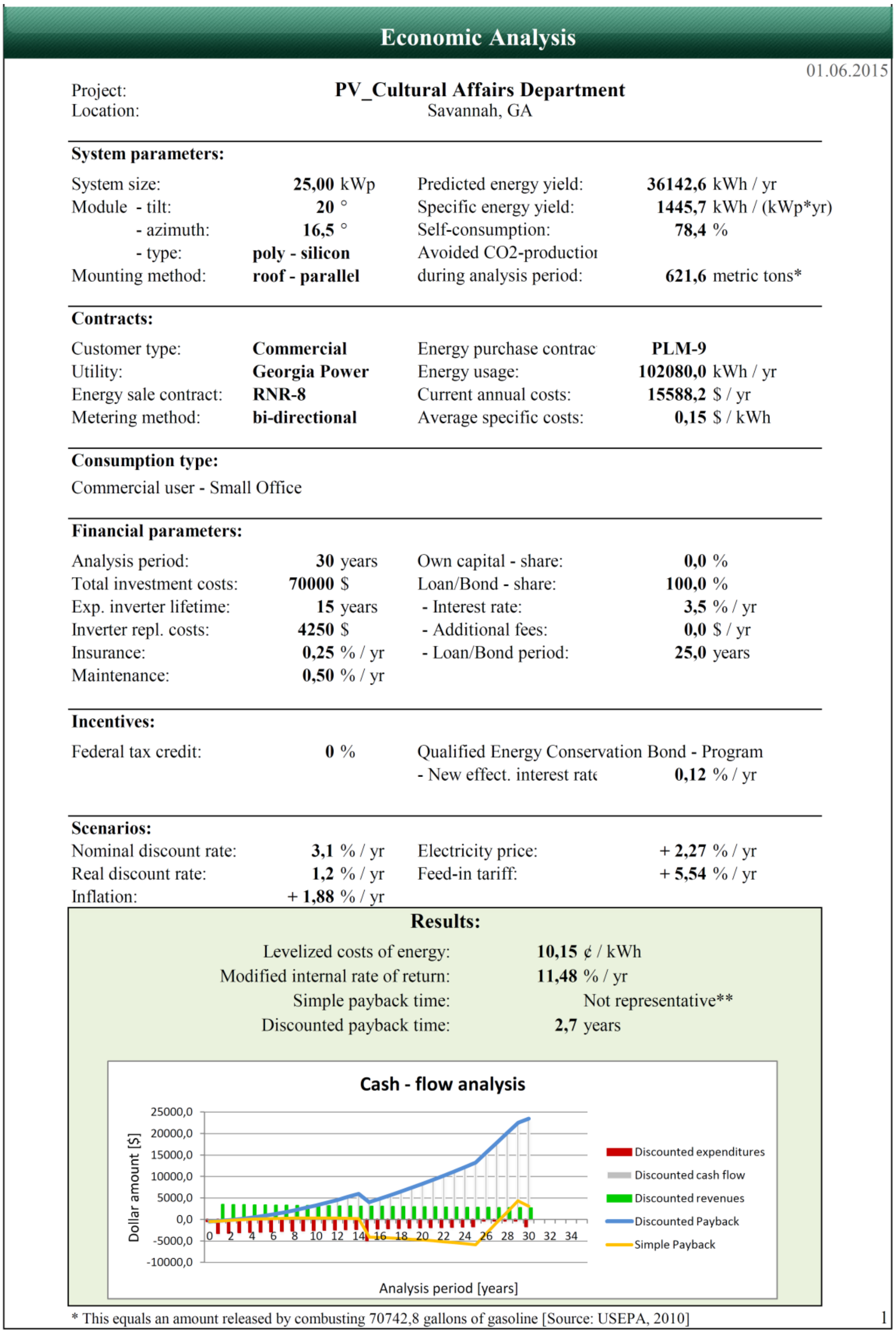
- Report: “Cultural Affairs Department”



Economic Analysis

01.06.2015

Project:	**PV_Cultural Affairs Department**
Location:	Savannah, GA

System parameters:

System size:	**25,00** kWp	Predicted energy yield:	**36142,6** kWh / yr
Module - tilt:	**20** °	Specific energy yield:	**1445,7** kWh / (kWp*yr)
- azimuth:	**16,5** °	Self-consumption:	**78,4** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**621,6** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLM-9**
Utility:	**Georgia Power**	Energy usage:	**102080,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**15588,2** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,15** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**70000** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**4250** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

Levelized costs of energy:	**10,15** ¢ / kWh
Modified internal rate of return:	**11,48** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**2,7** years

* This equals an amount released by combusting 70742,8 gallons of gasoline [Source: USEPA, 2010]

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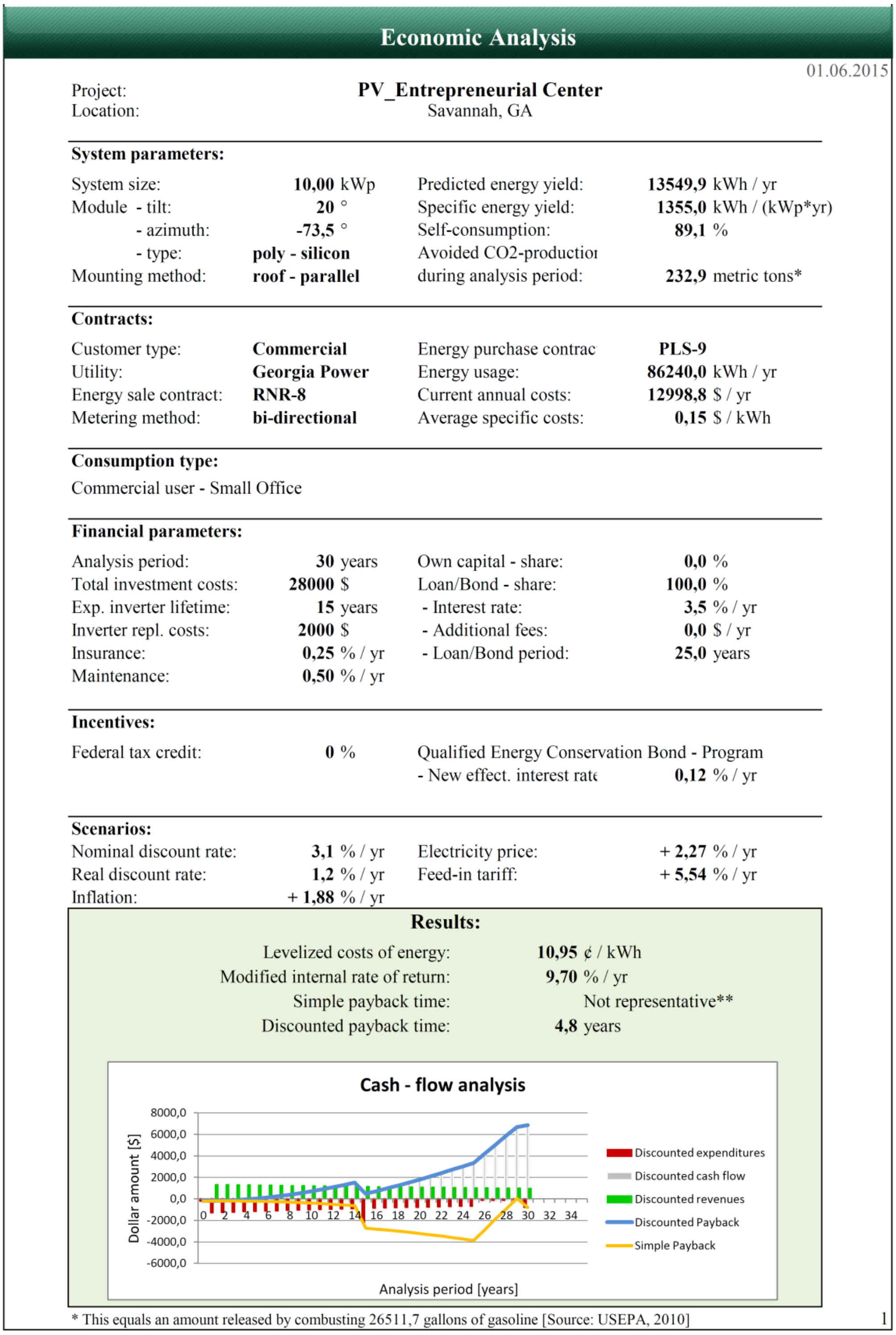
- Report: “Savannah Entrepreneurial Center”



Economic Analysis

01.06.2015

Project:	**PV_Entrepreneurial Center**
Location:	Savannah, GA

System parameters:

System size:	**10,00** kWp	Predicted energy yield:	**13549,9** kWh / yr
Module - tilt:	**20** °	Specific energy yield:	**1355,0** kWh / (kWp*yr)
- azimuth:	**-73,5** °	Self-consumption:	**89,1** %
- type:	**poly - silicon**	Avoided CO2-productio	
Mounting method:	**roof - parallel**	during analysis period:	**232,9** metric tons*

Contracts:

Customer type:	**Commercial**	Energy purchase contrac	**PLS-9**
Utility:	**Georgia Power**	Energy usage:	**86240,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**12998,8** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,15** $ / kWh

Consumption type:

Commercial user - Small Office

Financial parameters:

Analysis period:	**30** years	Own capital - share:	**0,0** %
Total investment costs:	**28000** $	Loan/Bond - share:	**100,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**3,5** % / yr
Inverter repl. costs:	**2000** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,50** % / yr		

Incentives:

Federal tax credit:	**0** %	Qualified Energy Conservation Bond - Program	
		- New effect. interest rat	**0,12** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,27** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

Levelized costs of energy:	**10,95** ¢ / kWh
Modified internal rate of return:	**9,70** % / yr
Simple payback time:	Not representative**
Discounted payback time:	**4,8** years

Cash - flow analysis

* This equals an amount released by combusting 26511,7 gallons of gasoline [Source: USEPA, 2010]

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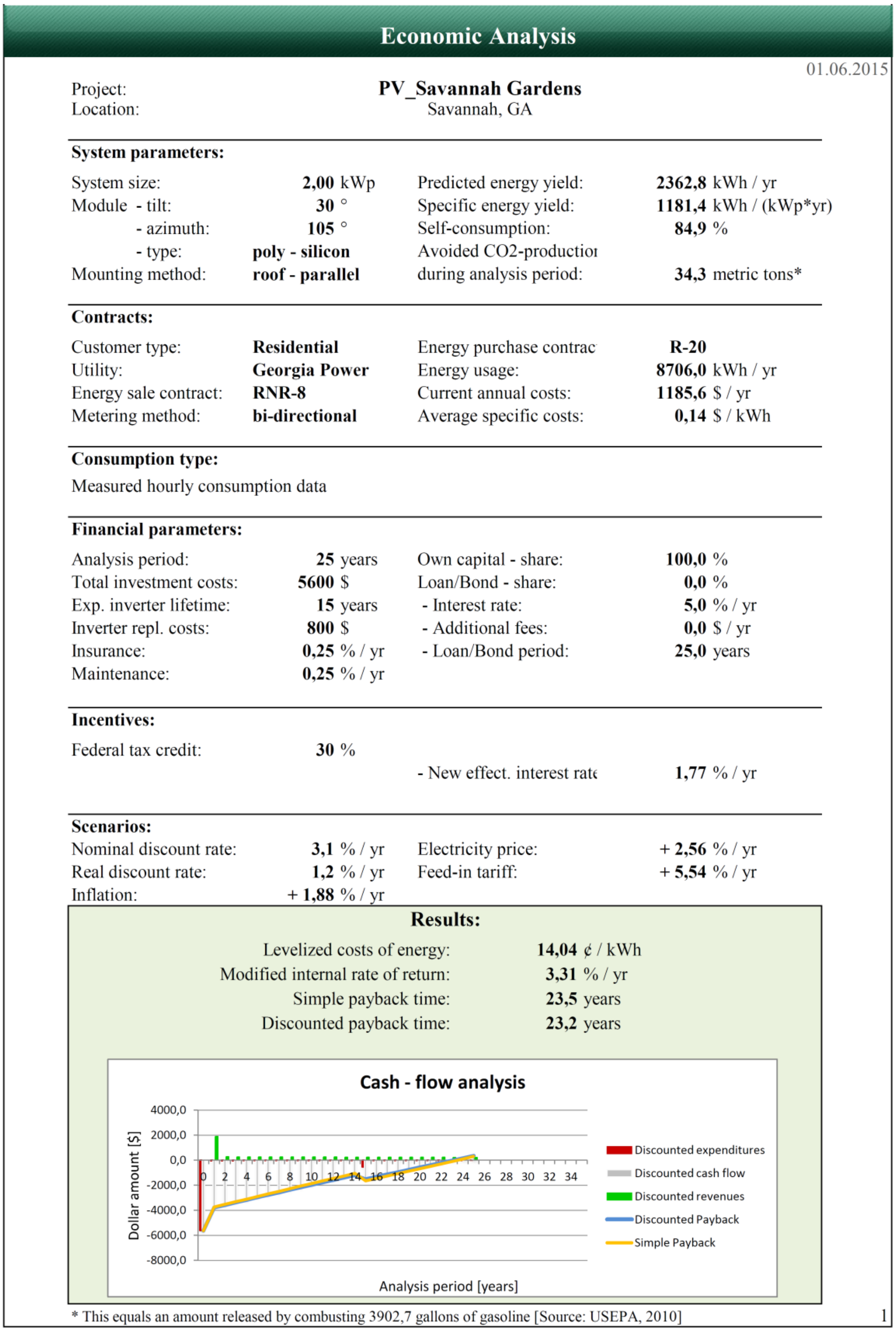
- Report: “Savannah Gardens”



Economic Analysis

01.06.2015

Project:	**PV_Savannah Gardens**
Location:	Savannah, GA

System parameters:

System size:	**2,00** kWp	Predicted energy yield:	**2362,8** kWh / yr
Module - tilt:	**30** °	Specific energy yield:	**1181,4** kWh / (kWp*yr)
- azimuth:	**105** °	Self-consumption:	**84,9** %
- type:	**poly - silicon**	Avoided CO2-productioı	
Mounting method:	**roof - parallel**	during analysis period:	**34,3** metric tons*

Contracts:

Customer type:	**Residential**	Energy purchase contrac	**R-20**
Utility:	**Georgia Power**	Energy usage:	**8706,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**1185,6** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,14** $ / kWh

Consumption type:

Measured hourly consumption data

Financial parameters:

Analysis period:	**25** years	Own capital - share:	**100,0** %
Total investment costs:	**5600** $	Loan/Bond - share:	**0,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**5,0** % / yr
Inverter repl. costs:	**800** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,25** % / yr		

Incentives:

Federal tax credit:	**30** %		
		- New effect. interest rate	**1,77** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,56** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

Levelized costs of energy:	**14,04** ¢ / kWh
Modified internal rate of return:	**3,31** % / yr
Simple payback time:	**23,5** years
Discounted payback time:	**23,2** years

* This equals an amount released by combusting 3902,7 gallons of gasoline [Source: USEPA, 2010]

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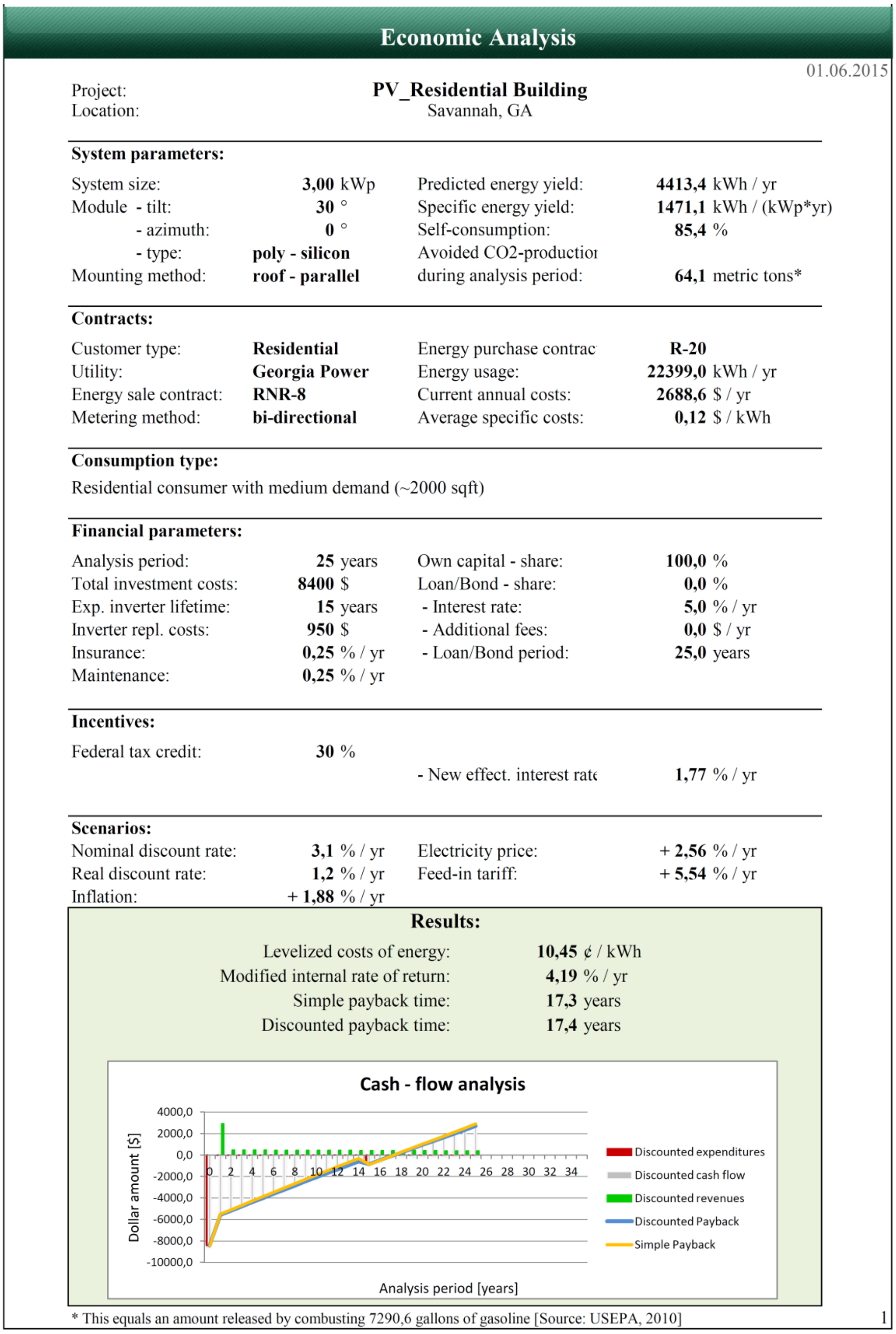
- Report: “Residential Building”



Economic Analysis

01.06.2015

Project:	**PV_Residential Building**	
Location:	Savannah, GA	

System parameters:

System size:	**3,00** kWp	Predicted energy yield:	**4413,4** kWh / yr
Module - tilt:	**30** °	Specific energy yield:	**1471,1** kWh / (kWp*yr)
- azimuth:	**0** °	Self-consumption:	**85,4** %
- type:	**poly - silicon**	Avoided CO2-productior	
Mounting method:	**roof - parallel**	during analysis period:	**64,1** metric tons*

Contracts:

Customer type:	**Residential**	Energy purchase contrac	**R-20**
Utility:	**Georgia Power**	Energy usage:	**22399,0** kWh / yr
Energy sale contract:	**RNR-8**	Current annual costs:	**2688,6** $ / yr
Metering method:	**bi-directional**	Average specific costs:	**0,12** $ / kWh

Consumption type:

Residential consumer with medium demand (~2000 sqft)

Financial parameters:

Analysis period:	**25** years	Own capital - share:	**100,0** %
Total investment costs:	**8400** $	Loan/Bond - share:	**0,0** %
Exp. inverter lifetime:	**15** years	- Interest rate:	**5,0** % / yr
Inverter repl. costs:	**950** $	- Additional fees:	**0,0** $ / yr
Insurance:	**0,25** % / yr	- Loan/Bond period:	**25,0** years
Maintenance:	**0,25** % / yr		

Incentives:

Federal tax credit:	**30** %		
		- New effect. interest rate	**1,77** % / yr

Scenarios:

Nominal discount rate:	**3,1** % / yr	Electricity price:	+ **2,56** % / yr
Real discount rate:	**1,2** % / yr	Feed-in tariff:	+ **5,54** % / yr
Inflation:	+ **1,88** % / yr		

Results:

Levelized costs of energy:	**10,45** ¢ / kWh
Modified internal rate of return:	**4,19** % / yr
Simple payback time:	**17,3** years
Discounted payback time:	**17,4** years

* This equals an amount released by combusting 7290,6 gallons of gasoline [Source: USEPA, 2010]

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