MASTER'S DEGREE PROGRAMME

Sustainable Energy Systems

City Electric Vehicle Fleet Powered by the Sun - Cost Benefit Analysis for the Integration of Solar Powered EV's into the City of Savannah

SUBMITTED AS A MASTER THESIS

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by

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PREFACE/ACKNOWLEDGEMENTS

The author wishes to extend his sincere thanks to Lukas Graber, Nick Deffley, Peter Shonka and Peter Zeller. Each of them played a significant role in making this thesis possible. Be it with expert knowledge, the provision of data, scientific discussions, arrangements of meetings, but also and expressively for the warm welcome in Savannah and the good southern hospitality – each part contributed and deserves gratitude. My thanks go furthermore to the city of Savannah, which takes a pioneering role by dedicating itself to improve energetic and ecologic aspects of its city. Only because of this thinking ahead the conduction of the very interesting project was possible. Furthermore my thanks go to my home University of Applied Sciences - FH Wels, which only made this stay abroad, this intercultural project, and this thesis possible. Last but not least my gratitude is also expressed towards the host University of GA Tech Atlanta, which cordially welcomed and contributed a great deal to the facilitation of the stay and the creation of this thesis too.

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SWORN DECLARATION

I hereby declare that I prepared this work independently and without help from third parties, that I did not use sources other than the ones referenced and that I have indicated passages taken from those sources.

This thesis was not previously submitted in identical or similar form to any other examination board, nor was it published.

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Dominik Pfaffenbichler

Wels, September 2016

KURZFASSUNG

Die Regierung der Stadt Savannah hat sich dazu verpflichtet, Energie und CO_2 Emissionen zu reduzieren. Eine Möglichkeit, diesem Ziel näherzukommen, ist die Implementierung von Elektroautos in den Fuhrparks der Stadt Savannah. Dies ist in dieser Arbeit analysiert worden. Darüber hinaus soll auch die Idee, Elektroautos mit erneuerbarer Energie, sprich mit Solarstrom zu laden, überprueft werden.
Für diese Analyse ist ein Berechnungs-Tool erzeugt worden, dass die drei wichtigsten Faktoren, Energiereduktion, Treibhausgasreduktion und Kosteneffizienz, analysieren kann.

Dieses Tool ist so gestaltet, dass es flexibel auf geänderte Rahmenbedingungen reagieren kann, wenn sich zum Beispiel der Benzinpreis oder die gesetzliche Förderbedingungen ändern. Dadurch kann der Berechnungsapparat auch in Zukunft gut eingesetzt werden.

Als erster Schritt ist das Berechnungsprogramm erstellt worden. Dieses kann die Analyse von Elektroautos im Vergleich Zu Benzinautos auf stündlicher Basis für bis zu 10 Autos berechnen.
Im nächsten Schritt ist das Programm benutzt worden, um eine Beispielanalyse für die Stadt Savannah durchzuführen.

Diese Beispielanalyse zeigt deutlich, dass sowohl eine Energieeinsparung als auch eine Treibhausgasreduktion möglich ist. Auch Kosten können eingespart werden, dies hängt jedoch stärker von Faktoren ab, wie zum Beispiel dem momentanen Benzin- und Strompreis, dem Anschaffungspreis der Elektroautos, staatlichen Subventionen und der jährlich gefahrenen Kilometer.

ABSTRACT

The city of Savannah has set itself ambitious goals to reduce both energy consumption and CO_2 emissions of their public sector. The idea is to achieve both aims with the implementation of Electric Vehicles into the city fleet of Savannah. For even higher benefits, it is also thought to power them, at least partially, by the sun and not only by the local electricity grid.

For the investigation a calculation tool was designed to analyze the benefits and drawbacks focusing on the 3 major impact factors energy efficiency, global warming potential (measured in CO_2 – equivalents) and costs.

Generating a flexible tool for this investigation made sense, since the section of electric cars is still relatively new and quickly developing, thus prices tend to change rapidly and be unsteady. Also gasoline prices have a fluctuational nature. It was of interest to generate a calculation tool, with which the analysis can easily be carried out again, if or when a major input parameter changed.

In a first step an Excel Calculation Tool was designed that allows to calculate the impacts of car substitution on an hourly level over the course of a year. This level of precision is important to make the impact of solar charging apparent. As mentioned above, the tool is designed to be highly flexible to allow future use or the use at different locations.

In a second step an analysis for replacing 10 conventional city fleet vehicles by 10 electric vehicles is carried out with the program for the location of Savannah. This is done by inputting all location relevant data and then run the calculation process.

The specific analysis with local solar and climate conditions, shows that the substitution of gasoline cars with electric vehicles has significant potential for reducing both energy consumption and CO_2e emissions. Also financially a replacement can have positive impact. However this depends strongly on influencing parameters such as the purchase prices of vehicles, the current energy prices for gasoline and electricity or the yearly traveled distance.

CONTENTS

1 INTRODUCTION

With respect to the title of the topic, the aim of the thesis must be explained first. The In times where the global energy consumption rises constantly, and topics such as fossil fuel shortage, emission targets, global warming and its corresponding consequences, are frequently in the news, it is important to find new and innovative ways and answers to counter current developments.

The following project aims to be one of these innovative ways to reduce both energy consumption and CO_2 emissions. Electric Vehicles are seen to be energy efficient, low emissive and reaching market maturity. Therefore it is worth to consider further investigations.

The motivation for this project is mainly given with the Governor's Energy Challenge [cf. Georgia Tech, 2015], the Compact of Mayors [cf. Compact of Mayors, 2015], and the idea of reducing costs. The initiatives either attempt to fight energy consumption or CO_2 emissions.

1.1 MOTIVATION AND FRAMEWORK

The first section deals with the motivation and framework of the carried out thesis.

1.1.1 ENERGY REDUCTION

The city of Savannah has set itself an ambitious goal with the Governor's Energy Challenge to work against the global trend of rising energy consumption. The government of the city agreed to a 15% energy reduction, applicable to the city's official energy use (public sector, not including private energy consumption) until the year 2020, based on the consumption in 2007 [cf. Georgia Tech, 2015].

Besides industry and household energy consumption, transportation is one of the biggest sectors of energy consumption in the United States. In 2014 transportation accounted to 28% of the total energy consumption in the USA. 92% of this share was based on petroleum fuel (gasoline, diesel, jet fuel, and other petroleum based products) [cf. EIA I, 2015].

With these figures on hand, the transportation sector can be a promising aspect for implementing efficiency and energy reduction measures.

Higher efficiency can be achieved, among other measures, by the implementation of electric vehicles (in the following abbreviated as EV's) and hybrid electric vehicles (HEV's) into the transportation sector and consequently replacing conventional cars / internal combustion engine vehicles (in the following written as ICEV's).

Electric Vehicles have the benefit of higher efficiency values (efficiency of electric engines versus combustion engines), and therefore carry the potential to reduce overall energy consumption. Likewise the investigation of an electric fleet conversion can consequently lead to reduced overall energy consumption and in doing so helping to address the targets of the Governor's Energy Challenge.

1.1.2 CO_2 Emission Reduction

With the Compact of Mayors the city of Savannah also agreed to fight greenhouse gas emissions. Launched in 2014 at the United Nations Climate Summit, with focus already on the COP21 in Paris in 2015, the Compact of Mayors is the largest alliance of city leaders to address climate change by pledging to reduce greenhouse gas emissions. In this treaty, the cities will have to come up with emission reduction projects, protocol them and track their progress [cf. Compact of Mayors, 2015].

Considering ICEV's, the combustion of fossil fuels will inevitably emit CO_2 emissions. Moreover, at least in small fractions, it will emit hazardous fumes like nitrogen oxides (NOx), carbon monoxide (CO) and unburned hydrocarbons (HC) [cf. Ehsani, Yimin, Ali, 2010, p.1-5].

Especially the CO_2 emission is of interest since it is mentioned in the Compact of Mayors that it contributes to the greenhouse effect and to global warming and its consequences [cf. Compact of Mayors, 2015].

All these emissions are a direct result of the combustion of fossil fuels. Contrary EV's are not powered by petroleum fuel and therefore have the ability to make transportation less CO_2 intense.

An additional aspect is that ICEV's generate their emissions wherever they drive, also in highly populated areas. Electricity production is centralized and not directly emitting emissions in high density settlements.

Anyhow also the generation of electricity produces emissions. For a holistic analysis the utilized sources for electricity production have to be included. CO_2 emissions strongly depend on the amount of coal/fossil powered power plants in the electricity mix. A real green transportation (i.e. not only energy reduction but also limitation of CO_2 generation) can only be achieved with a significant share of renewable energy technologies in the process of electricity generation. A change of the centrally provided electricity mix is not scope of this investigation. However the adding of renewable power generation locally is within the scope of the thesis. Adding solar power can help reducing the amount of emitted CO_2 further.

1.1.3 FINANCIAL FEASIBILITY

Lastly it is important that this investigation in EV's is cost efficient. Increasing sale numbers and continuous advances in the technology sector lead to falling purchase prices of electric vehicles. Also the low running costs due to fuel cost savings have influence on the feasibility of EV's.

At this point where EV's and HEV's are not totally new and expensive technologies anymore, the technology finally can be seen as market mature. As a result it makes sense to look at the financial feasibility at this point. A cost comparison will comprise purchase costs for EV's and solar panels, maintenance costs, fuel and electricity costs, subsidies and financial aids from the federal government, etc.

1.1.4 City Fleet Conversion

Renowned private companies such as FedEx, Frito-Lay, and Coca-Cola have started to convert part of their fleet into hybrid or fully electric vehicles [cf. Green Fleet Magazine I, 2016].

In addition to this private initiatives also public sectors such as city fleets of Houston, New York, Seattle, San Francisco, Los Angeles and Cobb County(Atlanta) using already Electric Vehicles in their fleet.

Summarizing, the motivation for this project is the reduction of energy consumption in the public sector, the reduction of greenhouse gases and other hazardous gases, especially in highly populated areas, and the reduction of costs. Additional benefits can be higher independence from fossil imports or green advertisement.

1.2 Problems

The positive results of EV-implementation are dependent on many things. Impact of EV’s is dependent from, the following main parameters:

- Time of using EVs (lights on/off, air condition on/off)
- Way of using EVs (inner city, outside the city)
- Frequency of use (deterioration)
- Intensity of use (amount of miles per year)
- Fuel economy of both gasoline cars and electric vehicles
- Purchase and maintenance costs
- Battery life time and battery exchange costs
- Weather (mainly temperature)
- Federal incentives on EV-purchase
- Federal incentives on Solar production(if charged with solar power)
- Availability of charging stations (or necessity of purchase)
- Electricity Mix – Ecology of the grid
- Electricity Price

- Gasoline Price
- Price Development expectations

Considering the high number of variables having influence on the financial feasibility, it cannot be stated in general whether EV – implementation has positive or negative impact on costs. Each case of investigation will yield different results.

2 THEORETICAL BACKGROUND

This chapter deals with the analysis of problems that are faced during the investigation of this of and Literature Research.

2.1 IMPACT OF ELECTRIC VEHICLES ON ENERGY CONSUMPTION

According to the Environmental Protection Agency (EPA), the average gasoline car in the United States has a fuel economy of 26 MPG (miles per gallon) (9.1 liter / 100km). [cf. EPA, 2011, et al].

Fuel efficient cars can reach a higher MPG-rating.

The labeling for fuel efficiency in MPG, as it is used for conventional cars by EPA, is presented in Fig. 1.

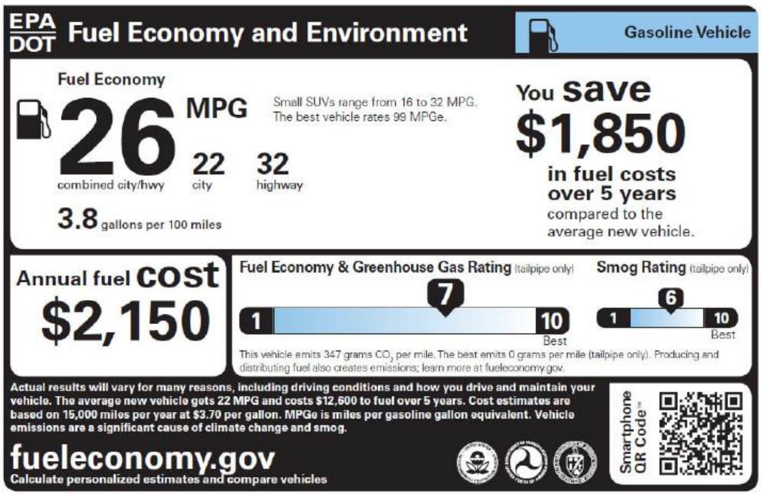


Fig. 1 Miles per Gallon label for conventional cars [EPA, 2011, p.3]

Fully electric vehicles however cannot be rated in miles per gallon, because of the simple fact that they do not use gasoline. In order to enable a comparison set up, EPA launched a label for the comparison of fuel economy for both electric and conventional cars. The efficiency of electric vehicles is given with miles per gallon equivalents. Instead of presenting miles per gallon of the vehicle’s fuel type, it represents the number of miles you can go using an amount of fuel with the same energy content as a gallon of gasoline. This can then be easily compared to the miles per gallon efficiency rating of conventional cars [cf. US.-Department of Energy I, 2016].

The in this connection used conversion factor for the energy content of gasoline is 33.7 kWh /gal [cf. EPA, 2011, et al].

The labeling for fuel efficiency in MPGe, as it is used by EPA to label electric vehicles, is presented in Fig. 2.

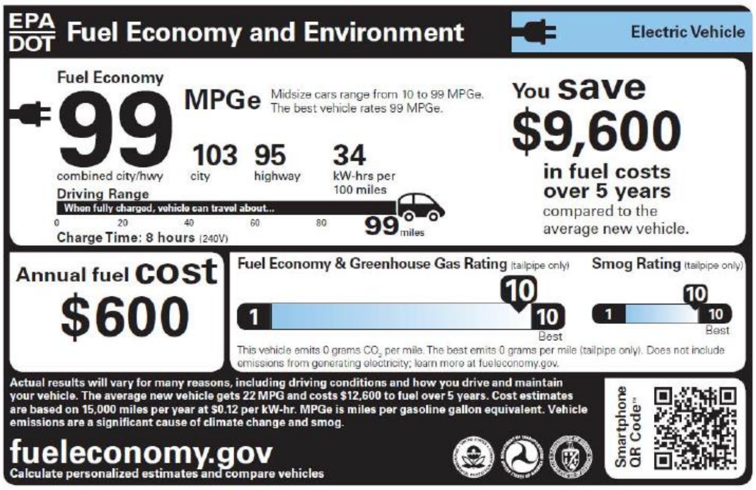


Fig. 2 Miles per Gallon Equivalents Label for Electric Vehicles [EPA, 2011, p.4f]

An average electric vehicle reaches fuel efficiency values above 100 MPGe, the Nissan Leaf for example runs with an efficiency of 115 MPGe [cf. Hybridcars, 2013].

Another comparison is the efficiency of energy conversion within the vehicle (tank to wheel, not well to wheel). The US.-Department of Energy states that electric vehicles convert about 59% to 62% of the electrical energy into moving energy (energy directly at the wheels). A conventional gasoline car with its internal combustion engine only manages to transfer the chemical energy into 17 % up to 21 % of power at the wheels [cf. US.-Department of Energy II, 2016].

2.2 Impact of EV's on Greenhouse Gas Emissions

CO_2 emissions of gasoline cars and electric cars happen in different phases or stages of their lifetime. Most commonly the usage period is looked at for CO_2 emission comparison. But there is also the manufacturing stage and the decommissioning stage, both of which have impact on the overall life cycle CO_2 emissions. Use stage can be divided into direct emissions and indirect / upstream CO_2 emissions.

2.2.1 Use Phase – Direct Emissions

The following chapter shows direct emissions of different vehicle types.

2.2.1.1 Electric Vehicles

The direct emissions or tailpipe emissions of Electric Vehicles are 0. There are no exhaust fumes due to the lack of any internal combustion engine. No CO_2 or other gaseous emissions leave the car's tailpipe [cf. AFDC I, 2016]. Overall use phase emissions of Electric Cars are not 0, as the next chapter will show.

2.2.1.2 Gasoline Vehicles

Internal combustion engine vehicles however do have direct emissions. According to the United States Environmental Protection Agency (EPA), and their Office of Transportation and Air Quality, a new car in the USA emits on average 230 gCO_2/km (368.4 gCO_2/mile) [cf. EPA, 2008].

EPA further states that the average emissions of a typically used US passenger vehicle are 259.6 gCO_2/km of (411 gCO_2/mile) [cf. EPA, 2014]. AFDC - city vehicle fleet conversion tool even puts the average CO_2 emissions to 273.7 gCO_2/km (438 gCO_2/mile) [cf. AFDC II, 2016].

2.2.2 UPSTREAM CO_2 EMISSIONS – USE PHASE

Upstream emissions are emissions that occur in addition to the direct emissions of the car. They can occur before or at a different location than where and when the car is actually used. These emissions are a necessary side product because for the production of both gasoline and electricity there are certain processes required that generate CO_2 emissions already.

2.2.2.1 ELECTRIC VEHICLES

The upstream CO_2 emissions of an EV depend on the source of electricity that is used to charge. How the electricity is generated has a significant influence. The used power plants to produce electricity vary by country and even by region. Electricity generation can be based strongly on hydropower and other renewables, rely on coal and other fossil fuels, focus on nuclear power, or be a mix of the above mentioned [cf. AFDC I, 2016].

In geographic areas with low polluting energy sources for the production of electricity, EVs have a significant advantage over similar conventional gasoline or diesel vehicles. A fossil light country like France, which relies strongly on nuclear power for electricity production, the average CO_2 emissions are only 23 gCO_2/km (148.8 gCO_2/mile) [cf. Wilson, 2013, p. 7f].

Countries like China and India rely heavily on coal, which raises the CO_2 generation per km significantly to values between 188 and 300 gCO_2/km (412.8 to 592 gCO_2/mile) [cf. Wilson, 2013, p. 7f].

The US – grid is on an intermediate level. It is fossil heavy but not relying entirely on coal. This leads to an average emission value of 132 gCO_2/km (323.2 gCO_2/mile) [cf. Wilson, 2013, p. 7f].

However even within the USA, the grid is not uniform. The CO_2 emissions per generated MWh of electricity depend on the state or region it is produced in.

Following Fig. 3 shows the split diagram for different sources of electricity generation in the USA.

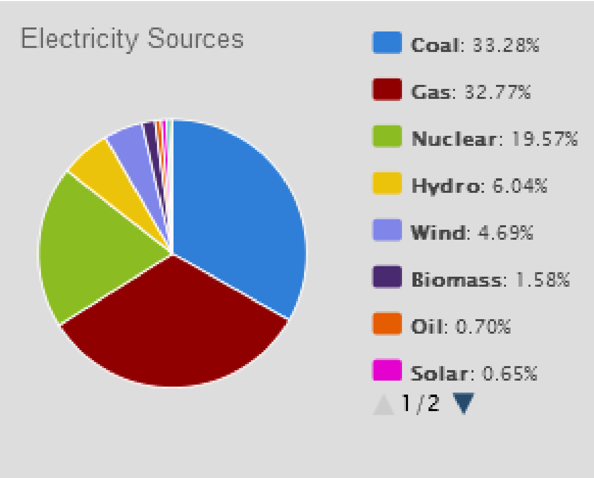


Fig. 3 Electricity Generation by Fuel Type of US-grid [AFDC III, 2016]

This share of power plants leads to average CO_2 emissions of 554 kg CO_2/MWh (1222 lbs CO_2/MWh) in the USA [cf. Diem, Quiroz: 2012, p.14] See also Attachment.

Fig. 4 shows the split diagram for different sources of electricity generation for the grid of Georgia.

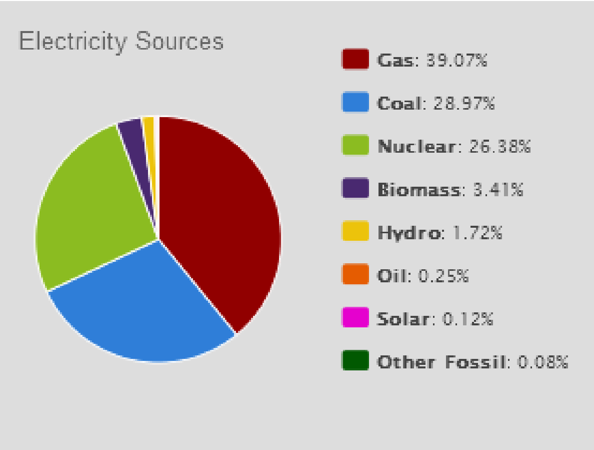


Fig. 4 Electricity Generation by Fuel Type for Georgia Grid [AFDC III, 2016]

According to the AFDC tool, the grid of Georgia is slightly greener (because of a smaller share of coal power plants) than the US average [AFDC III, 2016].

Looking at the emitted emissions over a certain distance, an average new electric vehicle emits 115 g CO_2/km (184 g CO_2/mile) in the general US – grid, and with 111 g CO_2/km (178 CO_2/mile) slightly less when driving in Georgia. [AFDC II, 2016].

A report from the Environmental Protection Agency, >>How to use eGRID for Carbon Footprinting << analyzes grid ecology of all US- States. It claims worse efficiency values for Georgia however [cf. Diem, Quiroz, 2012 p.14].
1 MWh of produced electricity accounts in Savannah for 604.54 kg (1332.59 lbs) of CO_2 [cf. Diem, Quiroz, 2012 p.14]. It furthermore states that CO_2 emissions vary_between 227 kg (500 lbs) CO_2 /MWh for Upstate New York and 828 kg (1825 lbs) CO_2 /MWh in the Middle West. The average CO_2 emission of the US grid is defined to be 554.4 kg (1,222.29 lbs) [cf. Diem, Quiroz, 2012 p.14]. Since also the GEFA report for Energy, Land and Water reports higher pollution values than the AFDC tool [cf. GEFA Energy Land Water, 2012 p.6], the more conservative source is chosen to use with the EPA report [cf. Diem, Quiroz, 2012 p.14]. Its values are displayed also in the attachment.

2.2.2.2 Internal Combustion Engine Vehicles

The upstream CO_2 emissions for Gasoline are also not 0. Upstream emissions come from drilling, venting, flaring gas, shipment, marketing, transportation, but most of all from the refinement process. In the life cycle of gasoline, upstream emissions of CO_2 are about 24 to 28 % [cf. Cowart, Pesinova, Saile, 2003, p.10f].

When assuming efficient upstream processes and addressing the CO_2 emissions while combusting 1 gallon of gasoline with 8887 gCO_2/ gal of gasoline (19.59 lbs CO_2/gal) [cf. EPA, 2014] the additional CO_2 emissions due to upstream processes are with 2222 gCO_2/ gal (4.9 lbs CO_2/gal) substantial [cf. Cowart, Pesinova, Saile, 2003, p.10f].

For gasoline cars the combined use phase emissions are 287.5g CO_2 / km (460g/mile), while for electric vehicles the combined emissions (only upstream emissions since tailpipe emissions are non-existent) only range around 132 gCO_2/km (323.2 gCO_2/mile) [cf. Wilson, 2013; et al] down to 115 g CO_2/km (184 g CO_2/mile) [cf. AFDC II, 2016].

2.2.3 Manufacturing CO_2 Emissions

Also manufacturing the vehicles has influence on the overall lifecycle emissions.

2.2.3.1 Electric Vehicles

Electric vehicles tend to be more energy intense in manufacturing. This results strongly from the big battery packs that are required. Emissions of manufacturing an average electric car can be accounted for with 9,400 kg (20,723 lbs) of CO_2 a compact car [cf. Nealer, Reichmuth, Anair. 2015].

A full size model emits accordingly more with approximately 13,400 kg (29,540 lbs) of CO_2 emissions while manufacturing it [cf. Nealer, Reichmuth, Anair. 2015].

2.2.3.2 Internal Combustion Engine Vehicles

For standard gasoline cars the manufacturing accounts for 6,650 kg (14,660 lbs) of CO_2 for a compact gasoline car, and 8,000 kg (17,637 lbs) of CO_2 for a full size car [cf. Nealer, Reichmuth, Anair. 2015].

2.2.4 Decommissioning CO_2 Emissions

There are possibilities for second use of electric car batteries. They can in be used for solar power day storage batteries. Theoretically a lot of the manufactured car components could be reused or recycled. This holds true for conventional cars and electric ones alike. Keeping this in mind, for both car types very similar recycling effects would take place. Thus it is possible to omit the recycling process from the life cycle analysis, without causing major influences on the ecologic comparison. Other life cycle studies of Electric Vehicles do not focus on decommissioning either, see >>Cleaner Cars from Cradle to Grave How Electric Cars Beat Gasoline Cars on Lifetime Global Warming Emissions<< [cf. Nealer, Reichmuth, Anair, 2015 p.16ff], or >>Shades of Green: Electric Cars' Carbon Emissions Around the Globe<< [cf. Wilson, 2013 p.16ff].

2.2.5 LIFE CYCLE ASSESSMENT

Using the manufacturing emissions of Electric Vehicles and divide it by the average life time distance, 70 g / km (112 g/mile) of CO_2 emissions can be added to the emissions during use phase. For gasoline cars an additional 50 g /km (80 g/mile) can include the manufacturing process into the analysis [cf. Wilson, 2013 p.7f].

Fig. 5 shows the level of pollution (CO_2 emissions) that goes along with electricity consumption of Electric Vehicles. It focuses on life cycle emissions, thus not only the level of CO_2 emissions for producing electricity, but also manufacturing and grid efficiency play an additional role. It is displayed in grams of CO_2 per kilometer for various countries. The United States are positioned in the middle section, when considering the grid efficiency, grid losses and the electricity production hence its ecological amount [cf. Wilson, 2013 p.8].

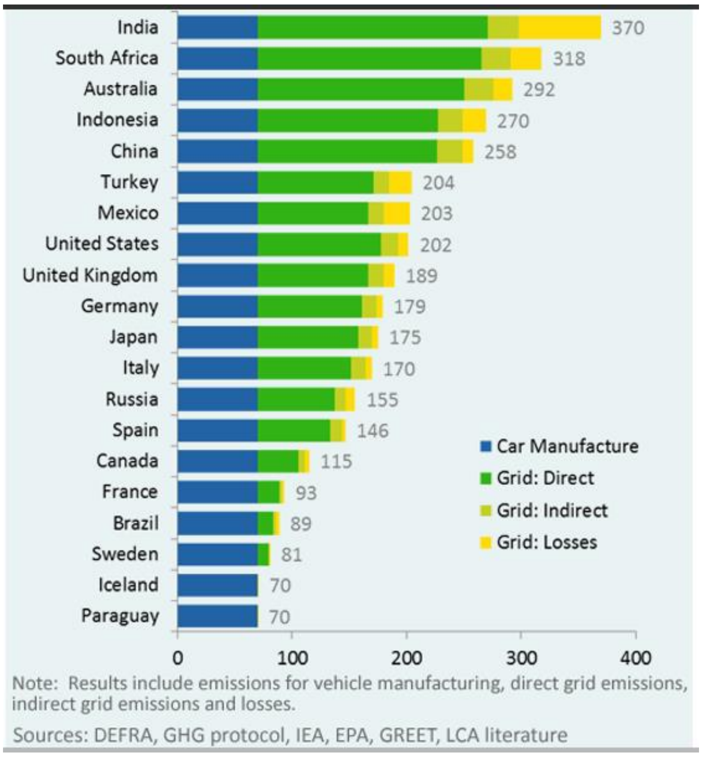


Fig. 5 Emissions Breakdown for different Countries [Wilson, 2013 p.8]

Focusing on the influence of the vehicle size on CO_2 emissions, the following Fig. 6 shows both the comparison of compact cars (1 EV and 1 ICEV) and full size cars (again 1 EV and 1 ICEV) . The chart is again a life cycle assessment, thus manufacturing emissions are accounted for. The unit is in g of CO_2e emissions per mile [cf. Nealer, Reichmuth, Anair, 2015 p.12].

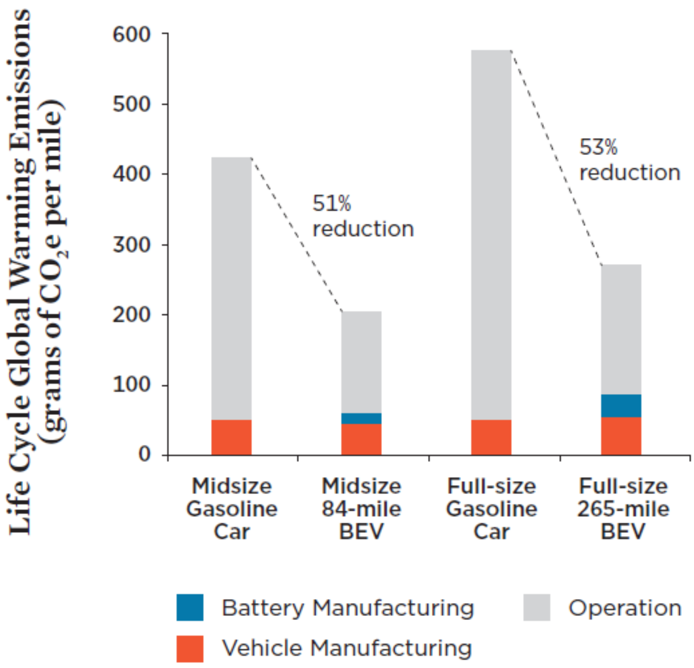


Fig. 6 LCA -CO_2 emissions of Electric Vehicles [Nealer, Reichmuth, Anair, 2015 p.21]

This life cycle emission analysis also includes the necessity of exchanging the battery pack of the vehicle. Most EV manufacturers claim a battery lifetime of around 100,000 miles (160,000 km) or 8 years [cf. NissanUSA I, 2016].

2.2.6 Additional Influence by Solar Power Charging

Also a solar power plant has certain CO_2e emissions over a lifetime. Most of it is emitted during the manufacturing process. But also the decommissioning and partly the use phase account for emissions. The ecology of a solar power plant is here rated according to following factors:

- Manufacturing: 28 g (0.0617 lbs) of CO_2e/kWh

- Decommissioning: 16 g (0.0353 lbs) CO_2e/kWh
- Solar Power during use phase: 10.4 g (0.0229 lbs) CO_2e/kWh

[cf. NREL. 2012, p.1].

2.3 Market Situation

The following chapter describes the current market situation of electric vehicles.

2.3.1 Increasing Sales Numbers

The following illustration shows the monthly sales of battery electric vehicles and plug in hybrid electric vehicles from 2011 to 2015.

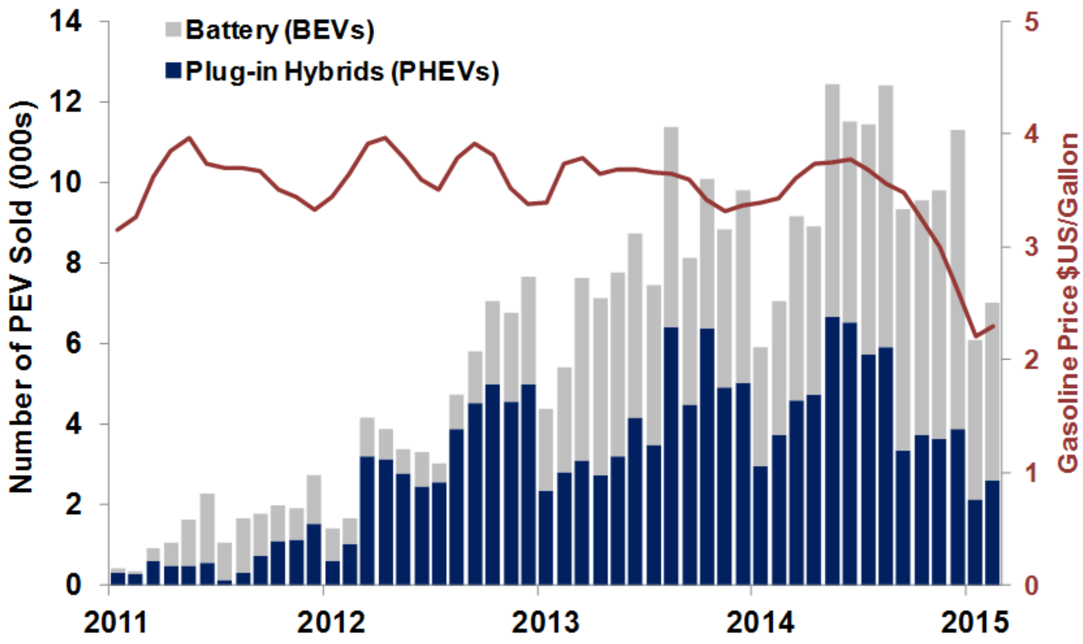


Fig. 7 Sales Numbers of Electric Vehicles [ARC Financial, 2016]

It can be seen that there is a continuous rise in sales numbers. In 2015 there is a drop in sales numbers visible. This might be because of the very low gasoline price in 2015[cf. ARC Financial, 2016]. Not just the number of vehicles sold rose but also the number of different electric vehicles offered to customers rises steadily. Chevrolet intends to bring its first fully electric vehicle on the market in 2017. The biggest sales numbers in the electric vehicle market are at the moment achieved by Nissan and Tesla [cf. Green Fleet Magazine II, 2016].

2.3.2 INCREASING RANGE

Still ongoing advances in battery technology and overall efficiency of electric vehicles makes them gaining range. Nissan's current model of the Leaf has a its 30 kWh of battery capacity a range of 108 miles, compared to the previous model which achieved only 84 miles. Nissan furthermore plans to introduce a new Leaf model to the market in 2018. This one is expected to have a 60kWh battery and range values way above 500 km (more than 300 miles) [cf. Motor Report, 2016].

Also Chevrolet plans with the soon available fully electric Chevy Bolt, to offer an electric vehicle with 60 kWh of battery pack and a range of 200 miles plus [cf. Chevrolet I, 2016].

All these advances in technology and range lead to a decreasing range anxiety, hence more people become interested in electric vehicles.

2.3.3 CHARGING LOCATIONS

Currently (2014) there are 20,000 plus charging stations across the United States available, which are accessible to the public. And this number is still rapidly growing [cf. US: Department of Energy, 2014].

The improvement of the charging locations network leads to a reduction of the anxiety while driving an electric car. To further reduce unpleasantness, the geographic position of these stations is very simple to locate. Either the use of the Alternative Fueling Station Locator (afdc.energy.gov/stations) from the US. Government, or other similar Apps for smart phones help to fast and conveniently locate the closest charging station. Most electric vehicles have these systems installed as a standard anyway.

2.4 Impact of Electric Vehicles on costs

With their impact on energy efficiency and ecology electric vehicles have shown already their big potential. The third impact to look at is costs. This is more delicate to say, because some of the cost-factors are highly fluctuating, like the gasoline price. Other input parameters like electricity price, purchase price, tax credits, etc. might vary too.

Nevertheless also here EV's can have some advantages over gasoline cars.

2.4.1 Fuel Costs

The electricity price in Georgia is stable at around 11.6 $cents per kWh on an average, for commercial buildings it can be as low as 9.29 $cents per kWh [cf. Georgia Power I, 2016]. Thus the electricity price is slightly higher in Savannah than on the standard Georgia level, which is stated by the International Energy Agency to be at 10.03 $cents per kWh for the state Georgia [cf. EIA I, 2016]. See also attachment.

These statements are for the normal tariff. Georgia Power furthermore offers different power tariffs. One of them for example has different rates for summer and winter, one is specifically designed for EV's. The tariff suggests using electricity only at nights and offers very low rates for charging off peak. Contrary during day time the price rises significantly, why this tariff really only makes sense when it can be assured that the vehicle does not have to be charged at day time but can be charged overnight. The following figure, Fig. 8 demonstrates the Georgia Power EV-tariff.

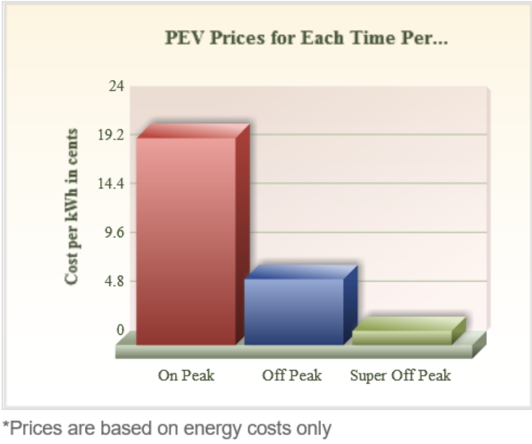


Fig. 8 Georgia Power Off-Peak Tariff [Georgia Power II, 2016]

The gasoline price is subject to big and frequent changes, as can be seen in Fig. 9.

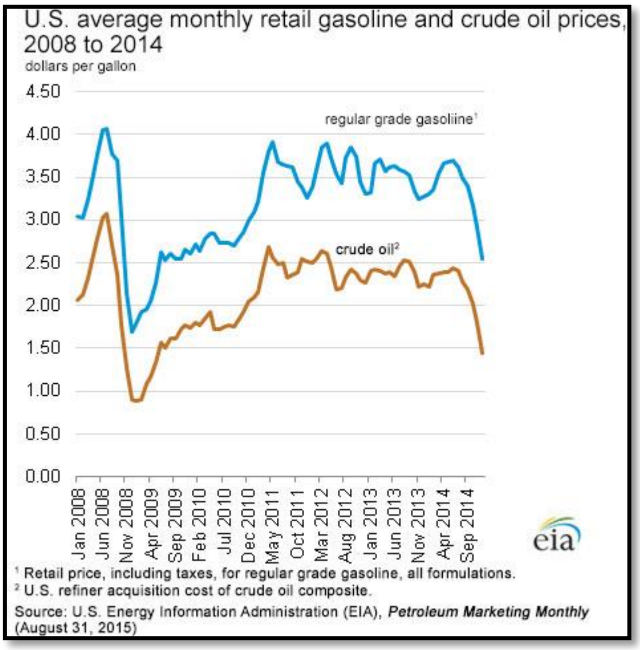


Fig. 9 Retail Gasoline Price from 2008 to 2014 [EIA II, 2016]

Current gasoline price in the USA fluctuates around the 2$ per gallon mark (52$cent per liter), as the following chart from the International Energy Agency proofs. Latest update for July 2016 in Savannah, the gasoline price was at 2.31$ per gallon [cf. Georgia Gas, 2016].

Electricity is not only cheaper than gasoline, its next advantage is that the price development for electricity is much more stable and therefore easier to forecast.

Forecasts for Gasoline prices however show that the time of cheap gasoline is almost over. The International Energy Agency shows in the Fig. 10from the Energy Outlook 2015 with their gasoline price development scenarios that a price rise can be expected in the future years [cf. EIA III, 2016].

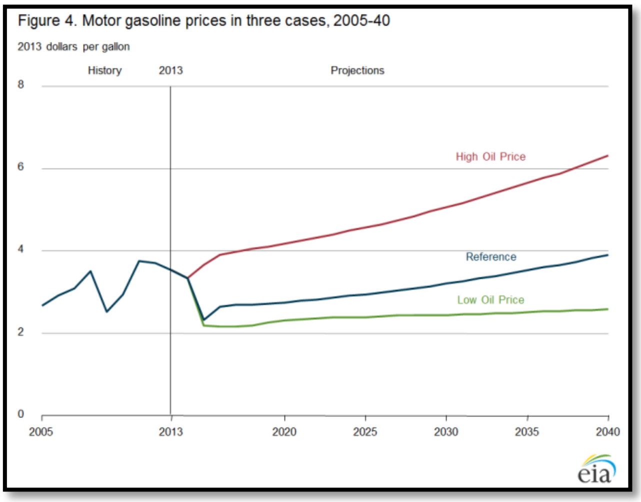


Fig. 10 Gasoline Price Development expectation [EIA II, 2015]

2.4.2 Fuel Costs per Mile

The high efficiency of Electric Vehicles (see Impact on Energy) further helps to make electricity the most cost efficient way to run a vehicle. With current electricity price, an electric vehicle can run on 0.013$ to 0.025$ per km (0.02$ to 0.04$ per mile) [cf. US. Department of Energy, 2014].

A conventional car with an average fuel economy runs on 0.10$ to 0.15$ per mile with current gasoline prices [cf. US. Department of Energy, 2014].

Comparing the fuel prices of an electric vehicles with a conventional car, the savings in fuel costs per year can be up to 1000$ and beyond, depending on the travelled distance. [cf. US. Department of Energy, 2014].

2.4.3 Maintenance

In general electric vehicles have less moving parts, which already signalizes a less maintenance intense vehicle. Looking into details, for example at the battery, the electric motor and associated electronics only minimal to no scheduled maintenance is required.

Furthermore electric vehicles are often equipped with regenerative braking. Thanks to regenerative braking the wear on the brakes can be reduced, which improves the lifetime of the braking system significantly. Also there are less fluid parts that are required to change in frequent time steps [cf. US. Department of Energy, 2014] and [cf. AFDC IV, 2016].

All these mentioned aspects lead to a significant decrease in maintenance effort, and consequently to reduced maintenance costs.

According to Cobb County, the county of Atlanta that has introduced Electric Vehicles 1.5 years ago into their city fleet, so far the required maintenance of their electric cars in operation can be reduced to checking the tire air pressure and cleaning [cf. interv. Rafay. 2016].

2.4.4 Purchase Costs

Up to now, purchase costs of Electric Vehicles are still more expensive in comparison to average new gasoline cars. Influence on this has the relative recency of this technology and the accordingly lower sales numbers. Also the higher manufacturing intensity and namely the battery production have influence on the purchase price. However on the way of reaching market maturity, purchase prices will continue to decrease, as the next chapter shows.

2.4.5 Battery Pack Costs

Electric Vehicle technology advances rapidly still. This leads to falling prices, especially in terms of batteries, which are up to now still the most expensive part of electric cars. But a lot has changed already since electric vehicles were first launched on the market.

The price of a Nissan Leaf Battery exchange decreased from roughly 18,000$ at the beginning to a competitive price of only 5,500$ for current exchanges [cf. Inside EV's I, 2016]. Prices are expected to further drop to a 50-percent margin from today's industry average until 2020 [cf. Green Fleet Magazine III, 2016].

Also the production process for the soon available Chevy bolt will be done at very competitive battery costs of only 145 $/kWh, and a further significantly decrease to only 100 $/kWh is expected [cf. Inside EV's II, 2016].

2.4.6 Incentives – Federal Tax Credit

Even though initial costs of electric vehicles are higher than their conventional counterpart, there are several incentives to make the purchase of electrical cars financially more attractive.

One of them is the Federal Tax Credit. With the >>Plug-In Electric Drive Vehicle Credit (IRC 30D)<< there is an incentive that provides a credit for qualified plug-in electric and hybrid vehicles. If the vehicle is acquired after December 31, 2009, the credit is equal to 2,500$ plus. It furthermore credits 417$ for a vehicle which draws propulsion energy from a battery that is at least 5 kWh of capacity. Finally for every kWh that exceeds this 5 kWh capacity minimum, there is another 417$ granted. The maximum amount of the credit given for any vehicle is limited to 7,500$ however [cf. IRS, 2016].

This means, an electric vehicle must have at least a 16 kWh battery pack capacity in oder to qualify for the full credit. Thus the full 7,500$ is also only available for cars with a reasonable big size of battery. Most hybrids do not qualify for the full credit due to their significantly smaller batteries compared to fully electric vehicles. For fully electric vehicles, those cars this survey is about, the battery size requirement does not really show a problem since electric vehicles currently have 20 kWh or above. See the previous chapter about electric vehicle range.

A further limitation for the credit is the number of sold cars. it only holds true for cars that have not yet reached a sale number of 200,000 or above. With the beginning of increasing sales numbers the credit begins to phase out. The basis for sales numbers was December 31, 2009. Until now the sales number of 200,000 is not penetrated by any electric car producer [cf. IRS, 2016].

The federal tax credit is directly applicable only to the owner of the car. However also in case of leasing an electric vehicle rather than buying it, the tax credit incentive is moved on to the leasing party, because the owner of the car (leasing company) can make more competitive offers due to the receipt of the tax credit [cf. IRS, 2016].

There are also state specific incentives, such is the 2,500 $ tax bonus an electric car owner is qualified to with the Clean Vehicle Rebate Project (CVRP). This is however only for the state of California [cf. Plug in America I, 2016]

Further financial benefits for EV use in the State of Georgia are:

- Heavy duty trucks for commercial use that are purchased after July 1st, 2015, can be eligible for a tax credit. This tax credit must be lesser than the income tax liability of the owner.
- Electric vehicles are allowed to use HOV lanes, without paying extra for them. A prerequisite is only to have the correct license plate.
- Georgia power offers the above mentioned special tariff for charging overnight
- Electric vehicles are not subject of emission tests.
- Various parking zones have special places only for EV-drivers.
- EVSE programs are currently fully subscribed at Georgia Power.

- There might be discounts on insurance for EV’s. This however is not guaranteed.

[cf. Plug in America I, 2016].

Summing up the financial situation of electric vehicles, even though there are a lot of advantages by driving electric vehicle, the net benefit is more delicate to answer on a general level.

Many factors such as gasoline price, electricity price, purchase price, Tax credits or other incentives, yearly distance etc. have influence on the feasibility. Thus it cannot be said in general whether it is financially feasible to exchange any car to an electrical vehicle. Each car has to be looked at individually. This is why the calculation tool is needed to be able to analyze different cars, evaluate the specific benefits of exchanging it to an EV. In this way the most promising candidates for exchanging to EV’s can be found.

2.5 Electric Vehicle Charging stations in general

The following Table 1 shows the difference of different charging levels and the impact on charging time [cf. US. Department of Energy, 2014].

Table 1 Charging Levels and Charging Time [US-Department of Energy, 2014]

EVSE Opions					
Charging Level	**Amperage**	**Voltage**	**Kilowatts**	**Charging Time**	**Primary Use**
AC Level 1	12 to 16 amps	120V	1.3 to 1.9 kW	2 to 5 miles per hour	Residential and workplace charging
AC Level 2	Up to 80 Amps	208V to 240V	Up to 19.2 kW	10 to 20 miles per hour	Residential, workplace and public charging
DC Fast Charging	Up to 200 amps	208V to 600v	50 to 150 kW	60 to 80 miles in less than 20 min	Public Charging

The safe connection of the EV to the grid, which is necessary for charging, is done by so called electric vehicle supply equipment (EVSE). These charging stations allow charging the car on different levels of power and or voltage. Two types, AC level 1 and level 2 chargers provide alternating current. The difference between level 1 and level 2 charging is the input voltage and amperage. While level 1 charging uses only 120 V for charging, level 2 has voltage levels of 208 to 240 V and an amperage of up to 80 amps, which leads subsequently to significantly higher charging power and reduced charging time compared to level 1 charging. Since with both charging levels the input power is in AC, the current is then converted by the vehicles' onboard equipment to the required direct charging current. The fast charging (also level 3 charging or DC fast charging) provides directly DC current to the vehicle. There is no need for further conversion. Level 3 charging is on much higher power levels than level 1 and 2 chargers [US. Department of Energy, 2014].

The required time for charging the vehicle depends on the power input. It varies from several hours for level 1, to a couple of hours for level 2 and to less than one hour for a DC fast charger. Charging time depends furthermore also on the battery size to charge and on the level of depletion [US. Department of Energy, 2014].

While installation costs for level 1 and level 2 chargers are cheap (literally any plug can be used for level 1 charging, and many plugs are able to provide higher power outputs, hence provide level 2 charging possibility) costs for one single DC fast charger can be up to 100,000$ and more. Thus they are too expensive to be of interest for public city fleet applications [cf. Plug in America II, 2016].

2.6 SOLAR POWERED CHARGING OF ELECTRIC VEHICLES

Considering further the idea of charging electric vehicles with solar power, the charging level (or charging power) has to be adapted according to the available solar power. For a brief investigation in what charging levels are reasonable, the following diagram was created. It shows solar energy production over the course of a day for 3 different PV-installation sizes:

- 10 kWp (bright blue)
- 20 kWp (blue)

- 40 kWp (dark blue)

[cf. PVSol Report]

A sunny summer day was chosen to show the maximum output of solar energy. In the following diagram the bluish lines represent the available solar energy for charging over the course of a day (See Attachment for precise solar data used, Data calculated with PVSol for May 4th).

In comparison to this it furthermore shows the charging process of a random electric vehicle with the current available battery pack of 30 kWh. The charging process does not claim the approach to show the real charging behavior. It is rather a quick investigation into what can be a reasonable charging power for solar charging. This is why the maximum battery capacity (30 kWh) is divided by the charging input power to obtain the necessary charging time (total linear approach, it leads to rectangular figures in the following diagram).

The current available charging powers can be found here [cf. Yilmaz, Krein, 2012]
For the investigation.

Different charging levels are applied to charge the Nissan Leaf or any electric vehicle with a battery capacity of 30 kWh, the diagram Fig. 11 shows both the level of charging power (on the y axis) and the respective time required to charge (x axis) the 30 kWh battery. The dotted lines represent fast charging devices, which are chosen to be:

- 120 kW Tesla Super Charging (Purple dotted line)
- 50 kW Nissan Fast Charging (Pink dotted line) [cf. Yilmaz, Krein, 2012].

While the other lines represent level 1 and level 2 charging. Fig. 11 focuses on the fast charging devices. For the other charging lines (level 1 and level 2) in the diagram look at Fig. 12, which focuses on lower charging powers and thus longer charging times.

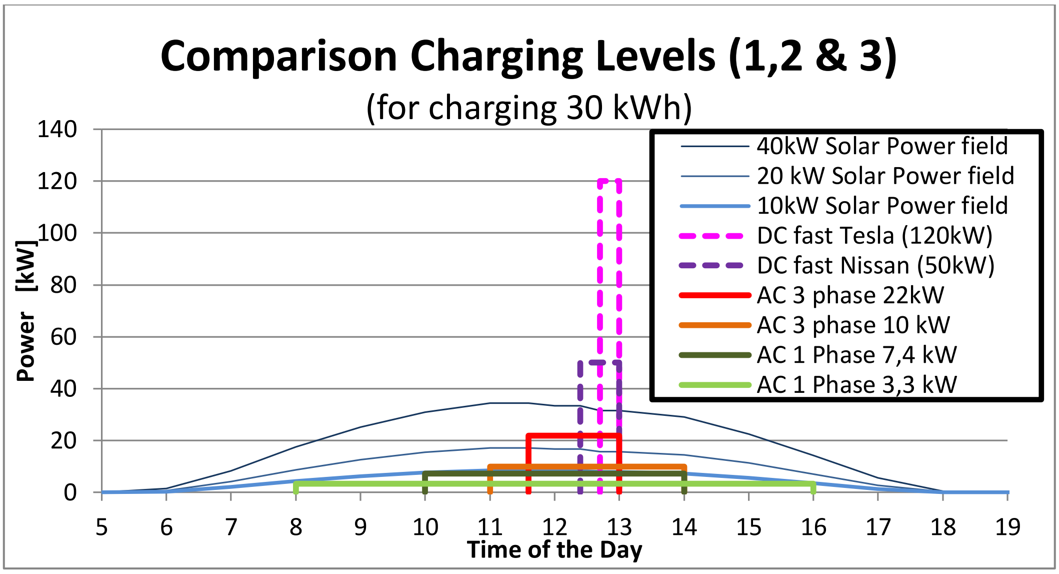


Fig. 11 Comparison Fast Charging Energy with Solar Energy Potential [Source: Own Figure]

Both dotted lines (fast level 3 DC charging) are in no relation with the actual availability of solar energy. Considering solar powered charging, DC – fast charging is not the best choice due to the low solar charging fraction.

The next diagram Fig. 12 shows the same solar energy production, but now focusing on level 1 and level 2 chargers. Green lines represent level 1, and red and orange level 2 charging.

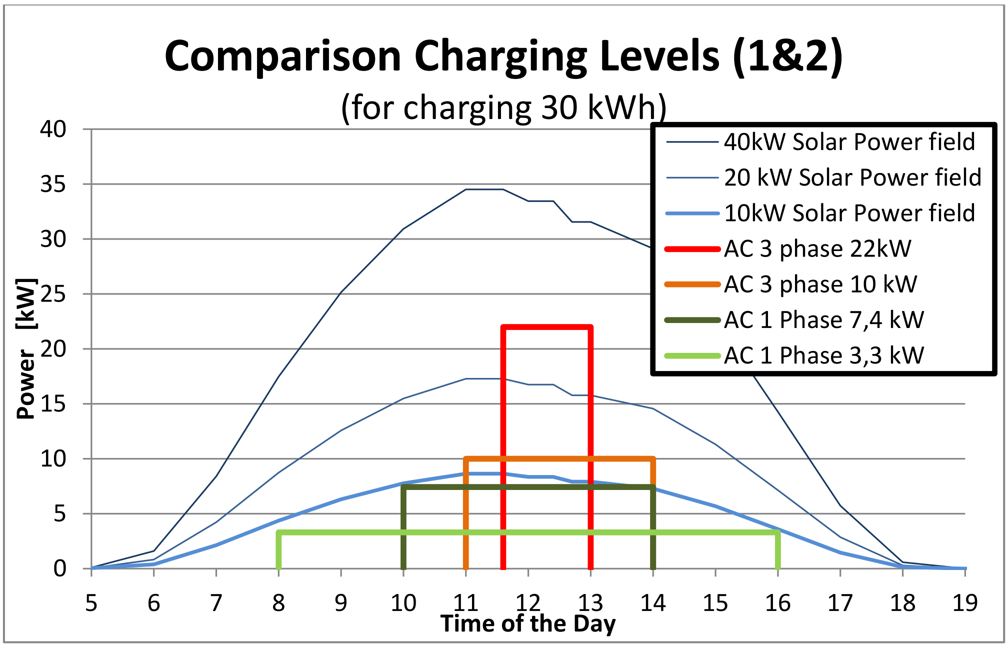


Fig. 12 Comparison Level 1 & 2 Charging with Solar Energy Potential [Source: Own Figure]

While level 1 charging requires long charging times, level 2 charging reduces the required charging time already significantly while still be in relation with available solar power.

Considering upfront cost and the solar charging fraction, level 3 charging can be seen to be unfeasible and therefore excluded from the further investigation.

2.7 Example Cities with Electric Vehicle Fleet Conversion

Following list shows cities and municipalities which already implemented Electric Vehicles into their operating fleet [cf. interv. Rafay 2016]:

- Houston,
- New York
- Seattle
- San Francisco
- Los Angeles
- Cobb County (Atlanta)

Cobb County is one of a handful of municipalities to incorporate plug in hybrids and battery electric vehicles in their fleet. Others such as Houston, New York, Seattle, San Francisco and Los Angeles serve as a testament of realizing the economic, social and environmental impact electric vehicles play within a fleet both in pool vehicle or assigned vehicle capacities [cf. interv. Rafay 2016].

Cobb County is one of the Counties of the city of Atlanta, and is therefore geographically located close to Savannah. The distance is only 400km (248 miles) [cf. Distance Online Tool, 2016], which lets assume same climate conditions, similar solar data, and since it is in the same State same national law and incentives apply.

This is the reason why the results of Cobb County are the most interesting for this thesis. It shall be used as the example city fleet conversion to look at in more details. The following section provides Cobb County's findings on electric vehicle benefits. For the further analysis the other cities are not in focus. However if the reader is further interested in the results provided by the other cities with fleet conversion, he or she is advised to conduct a quick internet research about the mentioned city names.

Cobb County started their electric vehicle project in July 2015. In total 16 Nissan Leaf EV's are leased by the County on a 3 years term for 259 $ / month and vehicle. The Cobb County Fleet Management calculated that this investment will save the county approximately 246,000 $ and displaces more than a million pounds (453.59 tons) of CO_2 emissions.

The leased vehicles will be used in different departments such as:

- tax assessor
- senior services
- juvenile court
- property management
- tax commissioner office

[cf. Government Fleet. 2015]

This calculations about financial benefits seem to be right, because in late August 2016 Cobb County started to widen their electric vehicle fleet by another 7 Nissan Leafs [cf. interv. Rafay 2016].

These 7 newly obtained electric vehicles will serve in the Fire and Emergency Services division. They are leased for 293 $ per month. An additional savings of 173,000 $ and displace of another 445,200 lbs (201.9 tons) of CO_2 is forecasted [cf. AJC, 2016].

Interesting to mention is that the offer to lease the vehicles instead of purchasing new vehicles helped the County to "exchange more of our older vehicles than we would have been able to through normal purchasing processes", states a city official [AJC, 2016].

2.8 Existing Tools for Fleet Conversion Assessment

There are several different tools existing for calculating the benefits of fleet conversion. Some of them are looked at in this chapter.

2.8.1 AFDC - Petrol Reduction Planning Tool

From the US - energy department initialized tool for a first brief and simple analysis about the possible benefits of

- Reducing idling
- Raising efficiency of car fleets
- Completely exchanging cars to hybrid cars
- Completely exchanging cars to electric vehicles

[cf. AFDC V, 2016].

The last option is of interest for the analysis of electric vehicle benefits in city fleet operations. Using this option shows results for gasoline savings and CO_2 emission reduction for a set of replacements hence a number of ICEV´s being replaced by EV´s. The results of this tool is only shown on a yearly basis, no further specifications are possible for the analysis [cf. AFDC V, 2016].

Fig. 13 represents the input field of the AFDC program.

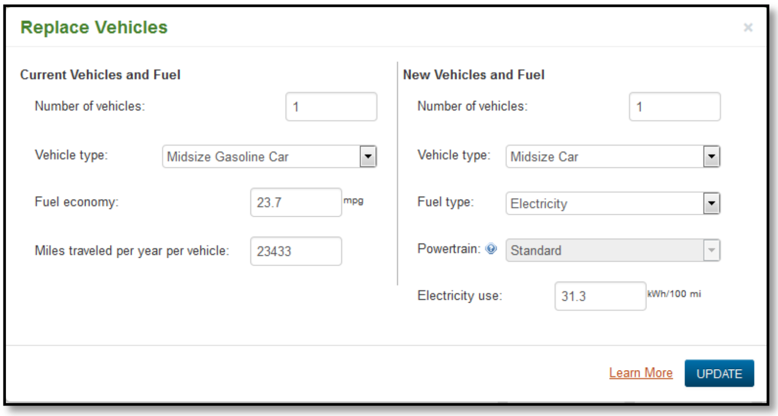


Fig. 13 Input Field of Fleet Calculaton tool AFDC [AFDC V, August 2016]

It comprises possible set ups for the current vehicle and the new vehicle it shall be exchanged with. The input for the current vehicle is number of vehicles of this type, vehicle type, the fuel economy, the yearly travelled distance.

For the new vehicle the possible input fields are number of vehicles, vehicle type, fuel type, power train, and electricity use per 100 miles [cf. AFDC V, 2016].

If the same 10 midsize gasoline vehicles are exchanged by 10 midsize electric vehicles as done later on with the own calculation tool , the results can be compared (see chapter Results). The Fig. 14 shows the result of this investigation in exchanging 10 gasoline cars by 10 electric vehicles.

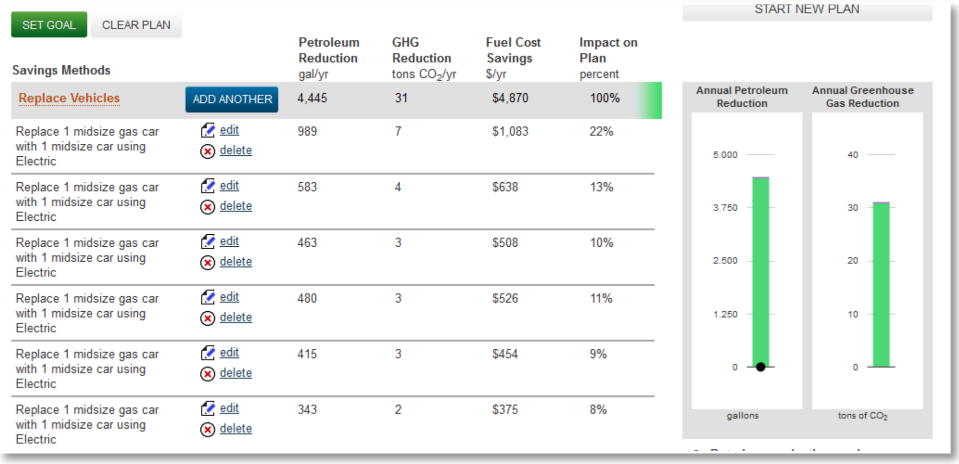


Fig. 14 Output Field of Fleet Calculation tool AFDC [AFDC V, August 2016]

The output field shows gasoline savings and CO_2 emission reduction both per car and as overall yearly saving [cf. AFDC V, 2016].

2.8.2 Propane Clean American Energy

This tool delivers valuable results for exchanging conventional cars to more fuel efficient solutions. It also has the option of not changing the total car but rather reequipping the car with better combustion systems. The tool includes propane and natural gas propulsion, however it is limited to combustion solutions thus does not include Electric Vehicles [cf. Propane Calculator, 2016].

2.8.3 Fleet Greenhouse gases in Washington State

Another quick but useful investigation into the benefits of implementing electric vehicles into the city fleet. This tool does not only give a statement about green house gas emissions during use phase, but also shows life cycle emission benefits. However also this tool does not show hourly values, and there is no option to calculate with Georgia specific values or even with USA values. The program was designed for the State of Washington only [cf. Westcoast Electric Fleets, 2016].

2.8.4 Alternative Fuel Life-Cycle Environmental and Economic Transportation – (AFLEET)

This tool gives profound possibilities to analyze. Among other things the user can calculate

- CO_2 emissions
- Other air emissions
- Life Cycle Assessment
- Payback time in years
- Payback time in miles of use

Also this tool however provides only yearly values and no option for more precise analysis [cf. AFLEET Tool, 2016].

2.8.5 GREET

This is a tool published by the research institution Argonne National Laboratory. As the previous tools also this one lacks the investigation on an hourly basis or the inclusion of solar power. It does have a life cycle module installed however. In general it is a nice tool for more detailed analyses than the previously mentioned ones [cf. GREET Tool, 2016].

To sum up, some of the fleet conversion tools do not provide:

- Sufficient emission analysis (only CO_2 but no CO_2e or other emissions)
- Life Cycle assessments
- Costs and Payback times
- General US-values for electricity grid emissions

2.8.6 Comparison of Fleet Conversion Tools

For better illustration a table (Table 2) is created, showing the advantages and disadvantages of the different tools. A – means that a certain feature is not available, a +

means that it is available and a double ++ means that it is available and on a very detailed level. For the tool Clean Propane gas certain assessments were not possible, because this tool focuses only on gas powered vehicles and not electricity. Sources for this Table 2 derive from the literature mentioned in the chapters above [cf. GREET Tool, 2016], [cf. AFLEET Tool, 2016], [cf. Westcoast Electric Fleets, 2016], [cf. Propane Calculator, 2016], [cf. AFDC V, 2016].

.

Table 2 Comparison Table of selected Fleet Conversion Tools [Source: own Table]

Tool Name	Fast Access and Calculation	Supports EV and electricity	Costs and Paypack time	Ecological Results	Applica-ble for general US Grid	Applicable for Savannah Grid	Hourly Basis of Caclulation	Inclusion of Solar Charging Possible	LCA Anal-ysis
AFCD	++	++	-	+	+	-	-	-	-
Propane Clean	+	-	**N/A**	**N/A**	**N/A**	**N/A**	-	-	-
Greenhouse Washington	+	++	-	+	-	-	-	-	+
AFLEET	-	++	++	++	+	-	-	-	++
GREET	-	++	+	++	+	-	-	-	+
Savannah Tool	-	++	++	++	++	++	+	+	++

As can be seen in the Table 2, none of the other analyzed tools provide:

- Hourly calculation
- Hourly results
- Possibility to include solar power for charging the EV´s.
- Savannah specific settings (electricity grid emissions, climate, etc.)
- Possibility to choose from Savannah city fleet car pool

[cf. GREET Tool, 2016], [cf. AFLEET Tool, 2016], [cf. Westcoast Electric Fleets, 2016], [cf. Propane Calculator, 2016], [cf. AFDC V, 2016].

3 Specific Goals

The chapter specific goals comprises aims, exclusions and the resulting scientific question.

3.1 Aims

The specific goals of this project can be split into two major groups.

The first part of the thesis is to develop an excel tool for the cost- benefit analysis of electric vehicle city fleet conversion. This tool shall be designed in a way that relevant input data can be easily accessed and changed if necessary. This approach allows the tool to be run for

- Different driving behavior
- Different current gasoline vehicles to exchange
- Different new electric vehicles to change to
- Different amounts of solar power
- Other locations (sun data and climate data can be changed if required)
- Future Use (if the gasoline price changed or EV purchase prices drop, etc.)

With this universal approach not only different locations can in theory be analyzed but also future investigations shall be easy to conduct (once the correct parameters are filled in).

In order to enable this amount of options, the user interface has to be comprehensive and easy to use. The main calculation process happens without being noticed by the user. It happens on a detailed level, while still maintaining a wide variety of different system settings. For a holistic set of possible input variables, the program then shall give output in form of charts and diagrams for following categories:

- Energy Consumption, Energy Efficiency
- CO_2 Emission, CO_2 reduction

- Costs reduction.

The second goal of the thesis is to feed this program with specific data for the location of Savannah (climate data, sun irradiation, etc.) and with data of the city fleet of the city of Savannah (yearly range, working hours, purchase and maintenance costs of existing fleet vehicles, etc.).

With the help of the tool and the precise input data, different scenarios shall be analyzed.

Scenarios, regarding energy efficiency and ecological impacts are:

- ICEV: Analyzing the energy and ecology impact of conventional vehicles (current city fleet cars). This Scenario is used as a comparison scenario to all electric scenarios.
- EV_Grid: Analyzing the energy and ecology impact of electric vehicles that are charged only by the local grid.
- EV_Solar: Analyzing the energy and ecology impact of electric vehicles that are charged by the local grid and by solar power.

On the basis of these three main scenarios various financial scenarios are analyzed in order to show the influence of certain cost parameter. Following financial scenarios are included:

- Solar power plant with a feed in tariff
- Solar power plant without a feed in tariff
- Purchase of vehicles
- Federal Tax Credit granted
- Federal Tax Credit not granted
- Leasing of vehicles
- Different energy price development scenarios (both for gasoline and electricity)
- Different electricity tariffs (standard contract vs. night and day tariff).

Finally statements regarding the benefits of EV-implementation for the city fleet of the city of Savannah shall be made. Statements will comprise the sectors energy reduction, CO_2 emission reduction and cost reduction.

With this two-step approach it is guaranteed that both an independent tool for EV-investigation as well as a detailed investigation for the current market situation in Savannah is conducted.

3.2 Exclusions

Following points are excluded in the investigation and development of the tool.

- The analysis is based on hourly values. At no point it is analyzed on a more precise level.
- The analysis for Energy Consumption only ranges over the full course of a year, but not more than that. For the life cycle analysis the CO_2 values of this one year are multiplied with the expected life expectancy of the vehicles.
- Only 10 substitution cycles of ICEV's by EV's can be analyzed simultaneously. For a higher number of replacement vehicles the program simply has to be run again.
- In case of a larger amount of vehicles to convert, the program simply has to be run more than once. The results can be added to achieve the final overall result.

3.3 Scientific Question

How can the task "electric vehicle city fleet conversion" be performed with the help of generating a calculation tool.

What does this calculation tool have to cover in order to be able to display a detailed comparison between electric and conventional vehicles.

What are the results of this calculation tool, when performing the analysis for the city of Savannah.

4 CALCULATION TOOL – BASIC CONCEPT

This chapter intends to give a brief overview about the structure of the program. It shows how the different parts, which are explained in more details in the chapter methodology, are connected and how the overall program works.

The Basic Concept of the Calculation Tool, which is seen in Fig. 15, is to develop an assessment system which analyzes benefits and possible drawbacks that come along with the implementation of EV's into a city fleet. This tool shall be designed independently from local parameters, so that it can be adapted easily and changed to different locations and / or modified input data. The following flow chart displays the general layout of the program, including input data, extensive input data, the calculation process field itself and the area for outputs.

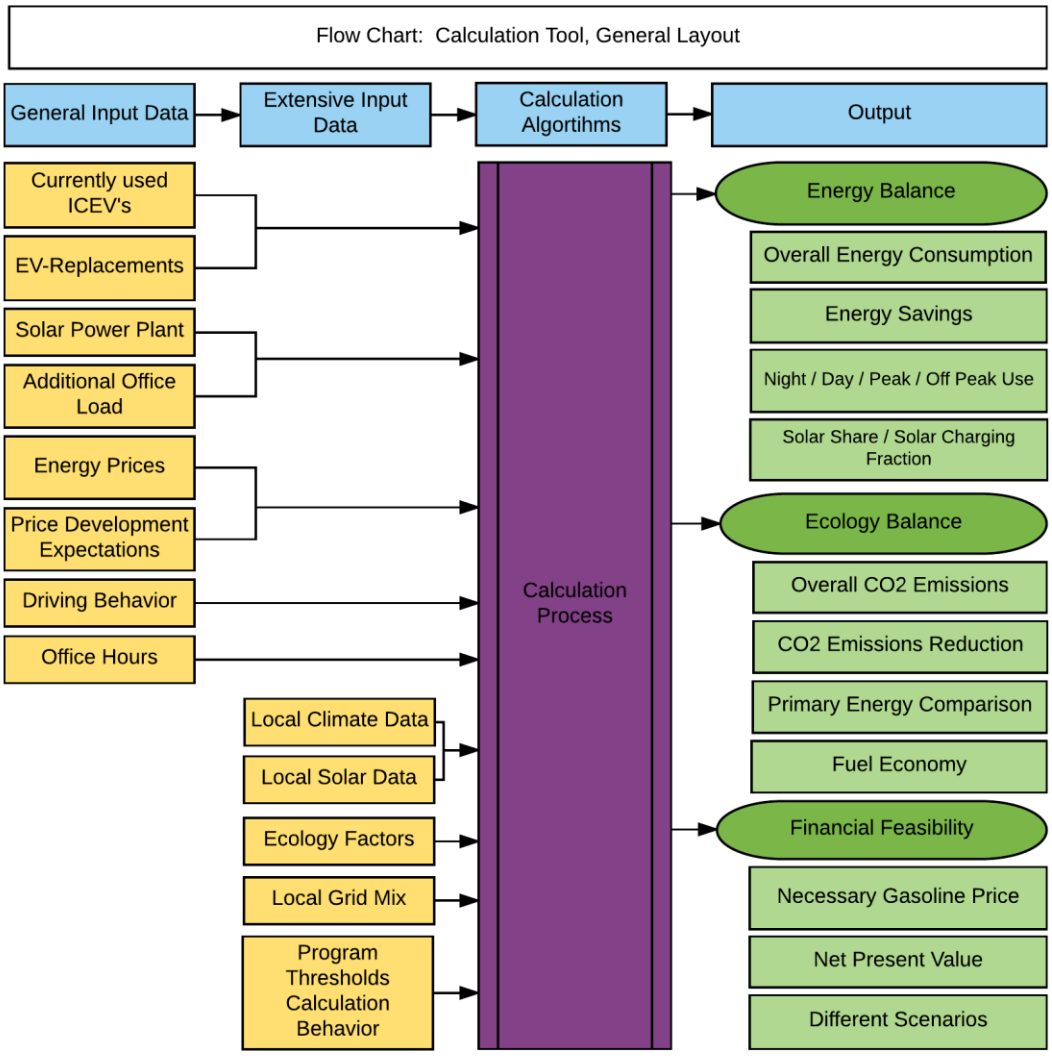


Fig. 15 Flow Chart: Calculation Tool Basic Concept [Source: Own Figure]

4.1 General Input Data

The General Input data comprises the basic input data. These data are essential in order to use the program. General inputs are data of high relevance, or those data that are likely to change frequently. It consists first of all of vehicle data that are subject to be exchanged. For both ICEV's and EV's all necessary data have to be acquired. Furthermore solar power and additional office loads are considered to be general input, likewise driving behavior and office hours. In addition data with highly fluctuating and unpredictable nature (e.g. gasoline price, energy price development, etc.) are set to be in the general input section, because chances are high they have to be adapted and changed often. The layout of the section general input data will be shown in the chapter Input Interface.

4.2 EXTENSIVE INPUT DATA

Whereas the section for general input data can be seen as basic input lines, extensive input data are additional input data that are more advanced and or data that are unlikely to change.

Extensive input data comprises calculation thresholds, constants, but also more stable background data that are less likely to change. As an example, the local electricity mix for Georgia will remain on a stable level for the next years with little or no changes. If the electricity mix stays the same, also ecology factors such as CO_2 factor for electricity, or primary energy factors for electricity remain the same. That is why these data will be kept in the section extensive input data.

Since these data has low fluctuational nature, they will have to be adapted rarely. Following this idea the extensive Input data section will be hidden in Excel. In case some extensive input data will change, it can be modified nonetheless with the button

<u>Display / Hide Advanced Settings</u> (see chapter Input Interface)

4.3 CALCULATION ALGORITHMS

The calculation processes and algorithms will be explained in the chapter methodology precisely, that is why here it is only mentioned briefly.

4.4 OUTPUT DATA

The investigation of exchanging existing ICEV's with EV's comprises mainly three output topics. For all 3 sections an absolute and a relative comparison between ICEV's and EV's is shown.

4.4.1 ENERGY BALANCE

It shows the differences regarding energy consumption of EV's and ICEV's. Energy Balance comprises furthermore split diagrams for solar share, for Primary Energy Consumption, for Reduction of Grid Electricity due to the installed Solar Power and for off peak and peak energy consumption.

4.4.2 ECOLOGY BALANCE

Ecology Balance shows mainly a CO_2 – equivalents balancing between EV's and ICEV's. This is first of all done for the time of use, but also includes in an additional diagram the CO_2 impact of manufacturing the vehicle.

4.4.3 FINANCIAL FEASIBILITY

Financial Feasibility deals with Net Present Value (NPV) analyses for different scenarios to help assessing the sensitivity of changes in the market. Thus the best financial choice for replacement can be found.

All three output sections are explained further in the chapter methodology.

5 Calculation Tool – Basic Layout

To explain the program better it helps looking at the designed interface of it. Since the calculation tool was designed for the city of Savannah, their logo is embedded in the layout. The head part always consists of the sections seen in Fig. 16.

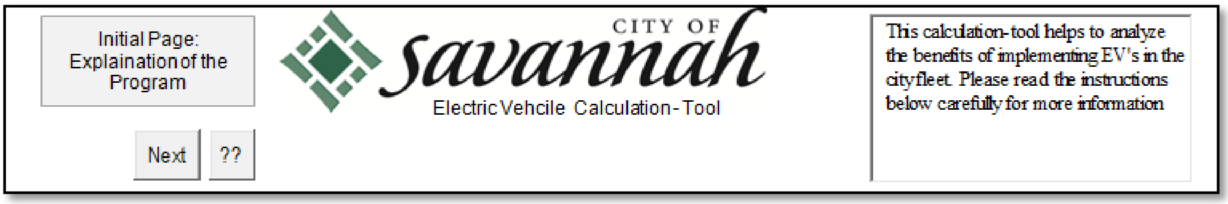


Fig. 16 Header of the Savannah Fleet Conversion Tool [Source: Own Figure]

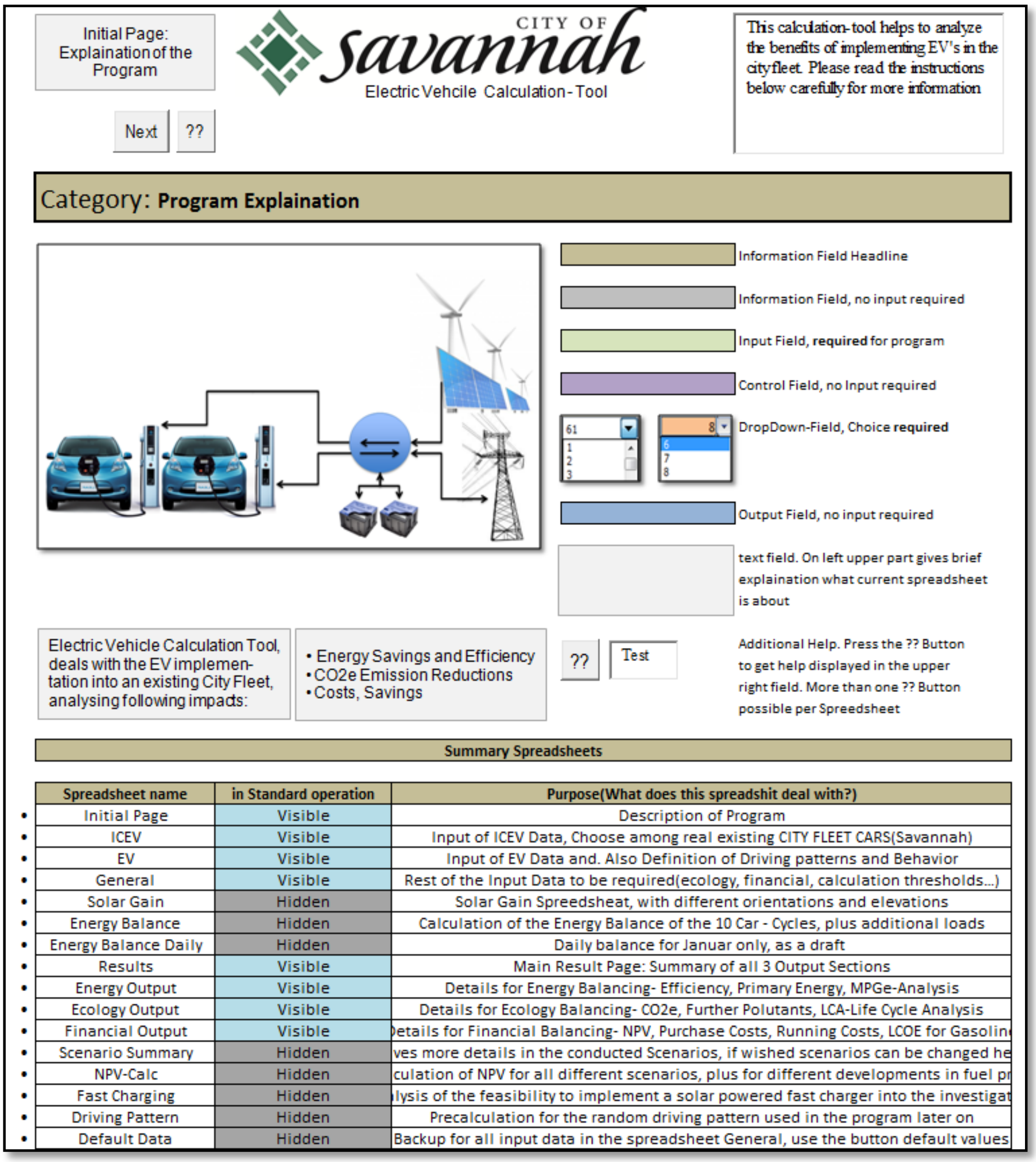
The left part includes a small info field showing the user where in the program he or she currently is. Below this info field there are buttons that can be used to navigate through the program. Button >>Next<< leaps to the next relevant page, while the button >>Previous<< shows you the previously seen page again to make further adaptations. The Button >>??<< can be used as a help if anything is unclear. By clicking on it the right up info field will be filled with information (in the image this button was clicked because the field is already filled, also the button >>Previous<< is not available because it represents the very first info sheet of the program and there is no previous spreadsheet).

The attempt of this chosen design was to make the program first easy to understand and second easy and fast to navigate through.

5.1 Initial Page

The initial page gives further information to the whole program. What is meant with the colors in the info fields, input fields and output fields? Which spreadsheets does the program comprise and what are they used for? Which spreadsheets are additionally available but hidden since rarely necessary to be used (They can be accessed if wanted though).

The advanced user can skip this page right away (with clicking the button >>Next<<), because it does not have any influence on the calculation process. The initial info page is shown in the following Fig. 17.



Spreadsheet name	in Standard operation	Purpose(What does this spreadshit deal with?)
Initial Page	Visible	Description of Program
ICEV	Visible	Input of ICEV Data, Choose among real existing CITY FLEET CARS(Savannah)
EV	Visible	Input of EV Data and. Also Definition of Driving patterns and Behavior
General	Visible	Rest of the Input Data to be required(ecology, financial, calculation thresholds...)
Solar Gain	Hidden	Solar Gain Spreedsheat, with different orientations and elevations
Energy Balance	Hidden	Calculation of the Energy Balance of the 10 Car - Cycles, plus additional loads
Energy Balance Daily	Hidden	Daily balance for Januar only, as a draft
Results	Visible	Main Result Page: Summary of all 3 Output Sections
Energy Output	Visible	Details for Energy Balancing- Efficiency, Primary Energy, MPGe-Analysis
Ecology Output	Visible	Details for Ecology Balancing- CO2e, Further Polutants, LCA-Life Cycle Analysis
Financial Output	Visible	etails for Financial Balancing- NPV, Purchase Costs, Running Costs, LCOE for Gasolin
Scenario Summary	Hidden	ves more details in the conducted Scenarios, if wished scenarios can be changed he
NPV-Calc	Hidden	culation of NPV for all different scenarios, plus for different developments in fuel p
Fast Charging	Hidden	lysis of the feasibility to implement a solar powered fast charger into the investigat
Driving Pattern	Hidden	Precalculation for the random driving pattern used in the program later on
Default Data	Hidden	Backup for all input data in the spreadsheet General, use the button default values

Fig. 17 Initial Page - Savannah Fleet Conversion Tool [Source: own Figure]

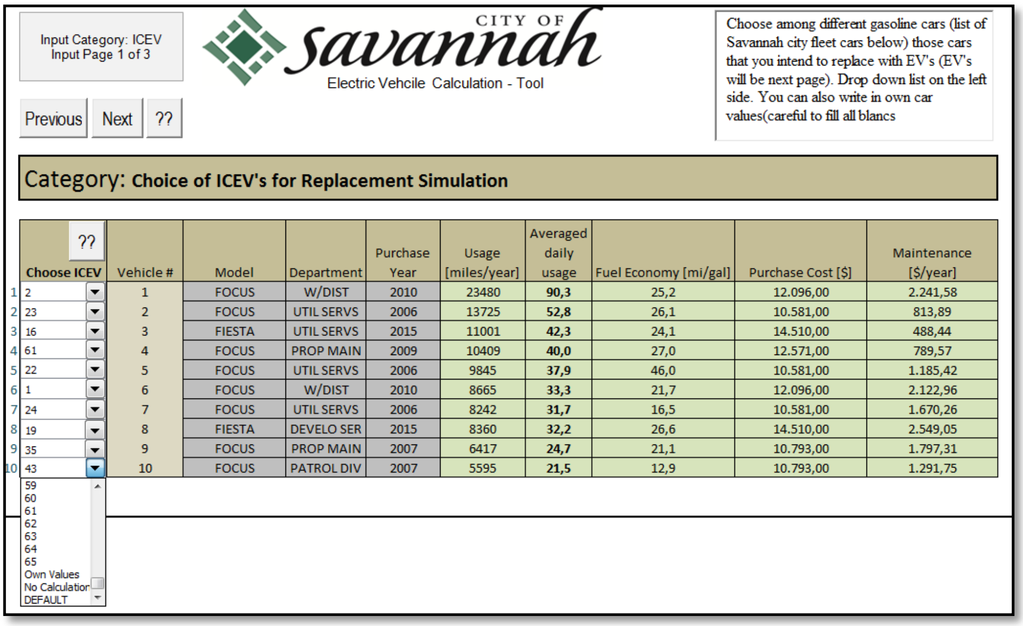
5.2 Input Interface

The input interface of the program is divided into 3 different spreadsheets:

- Current City Fleet Cars
- Electric Vehicles and Driving Behavior
- General Input, Program Start

5.2.1 Current City Fleet Cars

At this position the user can choose existing vehicles from a car pool provided from the city of Savannah [cf. interv. Fish, 2016]. This means real existing cars that are currently operating on the streets of Savannah can be used to compare with electric vehicles. The following Fig. 18 shows how the upper part of this spreadsheet looks like.



	Choose ICEV	Vehicle #	Model	Department	Purchase Year	Usage [miles/year]	Averaged daily usage	Fuel Economy [mi/gal]	Purchase Cost [$]	Maintenance [$/year]
1	2	1	FOCUS	W/DIST	2010	23480	**90,3**	25,2	12.096,00	2.241,58
2	23	2	FOCUS	UTIL SERVS	2006	13725	**52,8**	26,1	10.581,00	813,89
3	16	3	FIESTA	UTIL SERVS	2015	11001	**42,3**	24,1	14.510,00	488,44
4	61	4	FOCUS	PROP MAIN	2009	10409	**40,0**	27,0	12.571,00	789,57
5	22	5	FOCUS	UTIL SERVS	2006	9845	**37,9**	46,0	10.581,00	1.185,42
6	1	6	FOCUS	W/DIST	2010	8665	**33,3**	21,7	12.096,00	2.122,96
7	24	7	FOCUS	UTIL SERVS	2006	8242	**31,7**	16,5	10.581,00	1.670,26
8	19	8	FIESTA	DEVELO SER	2015	8360	**32,2**	26,6	14.510,00	2.549,05
9	35	9	FOCUS	PROP MAIN	2007	6417	**24,7**	21,1	10.793,00	1.797,31
10	43	10	FOCUS	PATROL DIV	2007	5595	**21,5**	12,9	10.793,00	1.291,75

Fig. 18 Input Page 1: ICEV - Savannah Fleet Conversion Tool [Source: own Figure]

There are 10 slots available for choosing a car to exchange. This means the maximum number of vehicles in the investigation can be 10, as further explained in the methodology part. The user has 4 options for each slot:

- DEFAULT: chooses a car with typical average US values for fuel consumption, yearly mileage and price

- No Calculation: This spot will not take part in the calculation (be aware that the same slot number is also for electric vehicles disabled then. (i.e. if gasoline car slot number 7 stays empty it cannot be compared to any electric car in slot 7 of electric cars)
- Own Values: The user can freely type values for a car, comprising all green input fields
- A number from 1 to 65: this chooses a car form the Savannah car pool, it is further described in the next image.

This Fig. 19 shows the same input spreadsheet again, but it shows explanations too for easier understanding. It furthermore shows the car pool of city fleet cars the user can choose cars from to exchange them with electric vehicles.

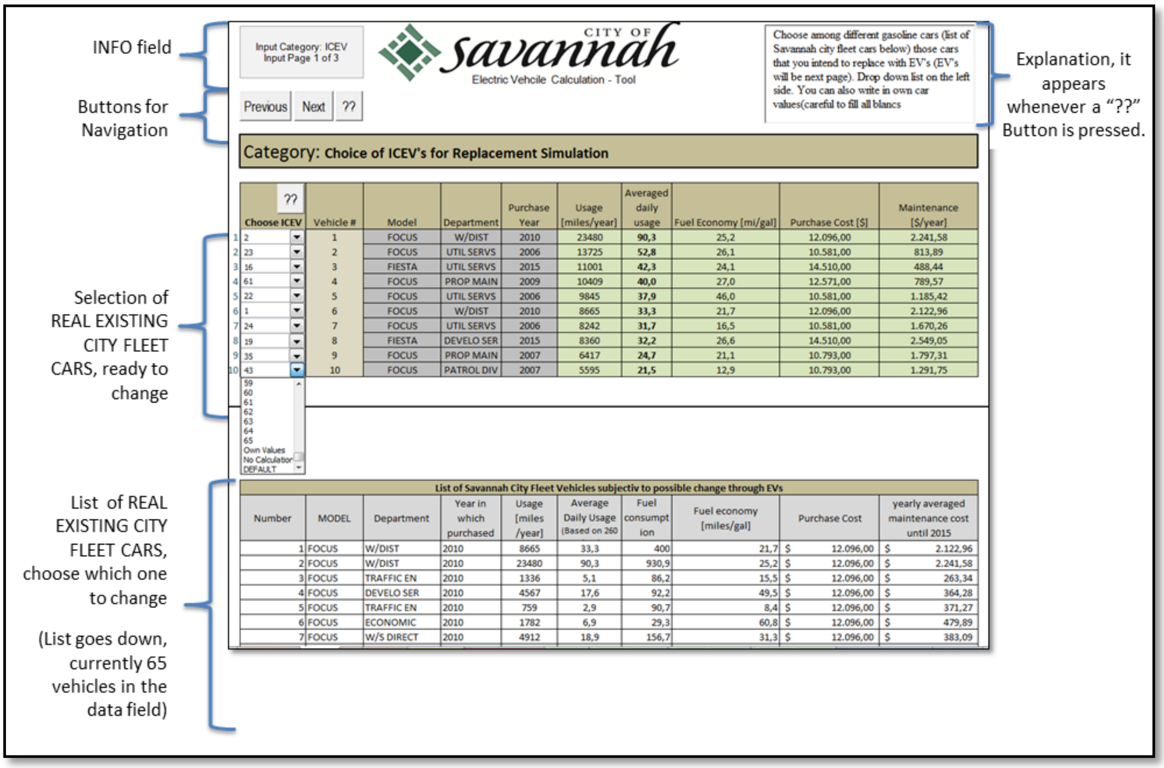
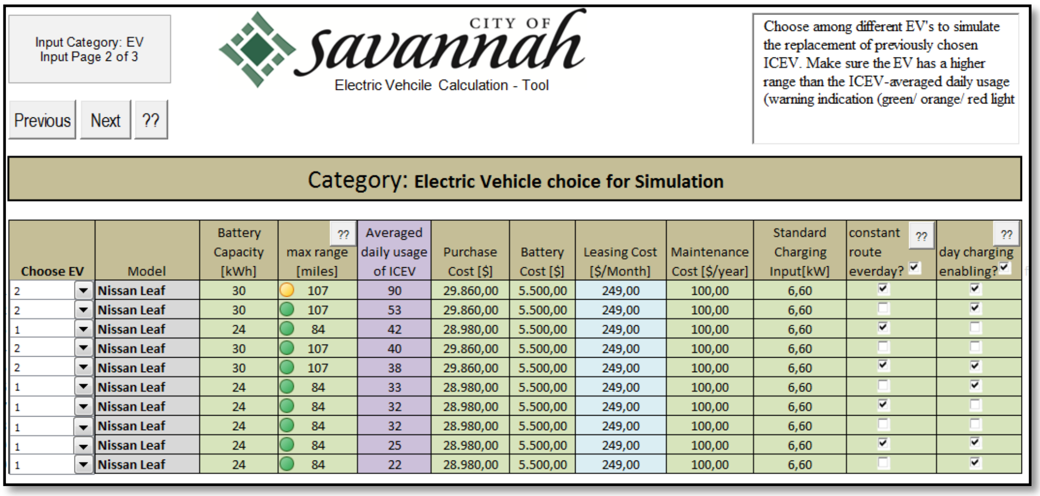


Fig. 19 Input Page 1: ICEV - Explanations - Savannah Fleet Conversion Tool [Source: own Figure]

Pressing the button >>Next<< will lead the user to the second input sheet.

5.2.2 ELECTRIC VEHICLES AND DRIVING BEHAVIOR

This input spreadsheet deals with both Electric Vehicles and with the driving behavior of the 10 different cycles. The Fig. 20 shows the general head part as on every input side. Underneath there is a place for 10 car spots. For each of them an electric vehicle can be chosen.



Choose EV	Model	Battery Capacity [kWh]	max range [miles]	Averaged daily usage of ICEV	Purchase Cost [$]	Battery Cost [$]	Leasing Cost [$/Month]	Maintenance Cost [$/year]	Standard Charging Input[kW]	constant route everday?	day charging enabling?
2	Nissan Leaf	30	107	90	29.860,00	5.500,00	249,00	100,00	6,60	✓	✓
2	Nissan Leaf	30	107	53	29.860,00	5.500,00	249,00	100,00	6,60		✓
1	Nissan Leaf	24	84	42	28.980,00	5.500,00	249,00	100,00	6,60	✓	
2	Nissan Leaf	30	107	40	29.860,00	5.500,00	249,00	100,00	6,60		
2	Nissan Leaf	30	107	38	29.860,00	5.500,00	249,00	100,00	6,60	✓	✓
1	Nissan Leaf	24	84	33	28.980,00	5.500,00	249,00	100,00	6,60		✓
1	Nissan Leaf	24	84	32	28.980,00	5.500,00	249,00	100,00	6,60	✓	
1	Nissan Leaf	24	84	32	28.980,00	5.500,00	249,00	100,00	6,60		
1	Nissan Leaf	24	84	25	28.980,00	5.500,00	249,00	100,00	6,60	✓	✓
1	Nissan Leaf	24	84	22	28.980,00	5.500,00	249,00	100,00	6,60		✓

Fig. 20 Input Page 2: EV - Savannah Fleet Conversion Tool [Source: own Figure]

Similar to gasoline cars, for electric vehicles there is a list provided of cars to choose from. This list comprises most common electric car models, such as Nissan Leaf Models, Tesla Models, Chevy Models, etc. Each of these electric vehicles will be directly compared to the one Savannah city fleet car that is on the same spot as the electric car.

The following Fig. 21 shows the explanation for each section. Everything in the red area has to deal with the selected electric vehicle. The yellow area deals with the driving behavior of each individual cycle.

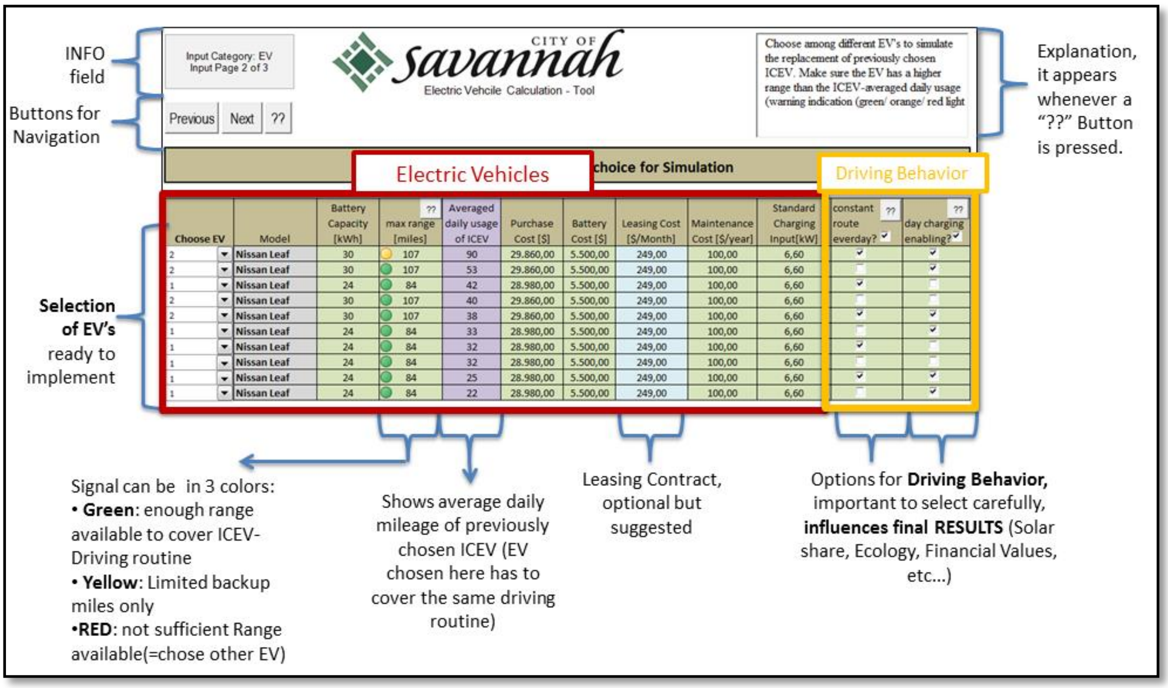


Fig. 21 Input Page 2: EV - Explanations - Savannah Fleet Conversion Tool [Source: own Figure]

Since each chosen electric vehicle is compared directly to the previously chosen gasoline car, it is worth displaying again the average daily mileage of the gasoline car (shown in the image as the purple column). This helps the user to choose an electric vehicle that has enough battery capacity to cover the expected daily travel distance.

Left of this purple column there is the maximum mileage of the chosen electric vehicles displayed. This one should be over the expected average mileage of the now used gasoline car. Furthermore there should be a significant margin between these 2 values in order to account for the possibility that the electric car has to go in unregularly patterns, i.e. has to go further on some days than on others.

To make it as easy as possible for the user of the program to choose the right electric vehicle, a 3 color signal is implemented showing the user one of 3 things:

- Green color: The electric vehicle can easily cover the expected daily driving distance, this is a good choice

- Yellow color: The electric vehicle can cover the average daily driving distance. However there is not much energy left to account for additional travels. Risky choice.
- Red color: The battery storage of the electric vehicle is not big enough to cover for the average miles the gasoline car currently drives per day. Choose another electric vehicle.

In a next step the driving behavior has to be defined for each of the 10 cycles. It is recommended to look at the currently operating car to find out in what pattern it really drives. In this way the analysis can be closer to reality. The Fig. 22 shows the driving behavior choices.

The user has 2 buttons to select the desired driving behavior for each of the cars (there is also a general button to (de)select all of the 10 cycles). This can be seen in the following image.

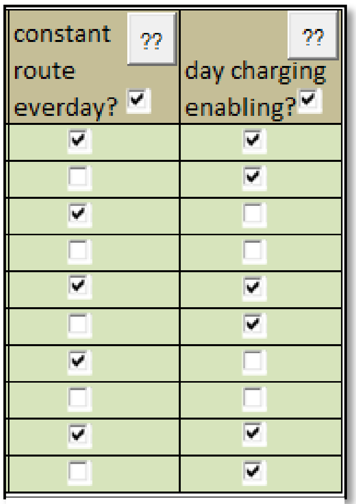


Fig. 22 Driving Behavior - Savannah Fleet Conversion Tool [Source: own Figure]

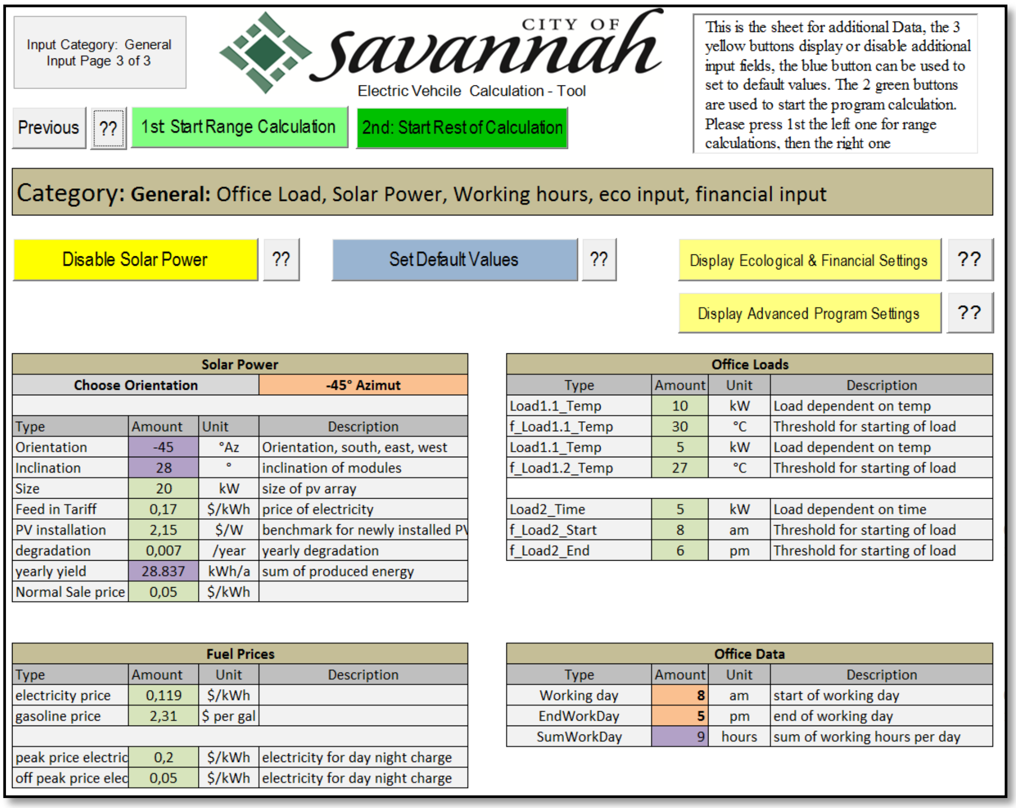
Due to this 2 buttons there are basically 4 different options for the driving behavior.

- Constant Route Every day is enabled: this means the car will drive on a daily routine with very similar mileage each day (in this case a yellow signal of the before described warning signal is acceptable)
- Constant Route Every day is disabled: The car will not follow a similar pattern each day but will drive in a randomized way. The calculation is done with the randomize mileage calculator (see methodology)
- Day Charging is enabled: in this case the car can be charged also during the day, whenever it is not used.
- Day Charging is disabled: in this case the car cannot be charged during working hours, even when it is not used.

For further information about driving behavior please read the chapter methodology.

5.2.3 General Input, Program Start

The 3rd input sheet shows all the additional variables necessary for the calculation. The following Fig. 23 shows this general input spreadsheet.



Solar Power			
Choose Orientation		-45° Azimut	
Type	Amount	Unit	Description
Orientation	-45	°Az	Orientation, south, east, west
Inclination	28	°	inclination of modules
Size	20	kW	size of pv array
Feed in Tariff	0,17	$/kWh	price of electricity
PV installation	2,15	$/W	benchmark for newly installed PV
degradation	0,007	/year	yearly degradation
yearly yield	28.837	kWh/a	sum of produced energy
Normal Sale price	0,05	$/kWh	

Office Loads			
Type	Amount	Unit	Description
Load1.1_Temp	10	kW	Load dependent on temp
f_Load1.1_Temp	30	°C	Threshold for starting of load
Load1.1_Temp	5	kW	Load dependent on temp
f_Load1.2_Temp	27	°C	Threshold for starting of load
Load2_Time	5	kW	Load dependent on time
f_Load2_Start	8	am	Threshold for starting of load
f_Load2_End	6	pm	Threshold for starting of load

Fuel Prices			
Type	Amount	Unit	Description
electricity price	0,119	$/kWh	
gasoline price	2,31	$ per gal	
peak price electric	0,2	$/kWh	electricity for day night charge
off peak price elec	0,05	$/kWh	electricity for day night charge

Office Data			
Type	Amount	Unit	Description
Working day	8	am	start of working day
EndWorkDay	5	pm	end of working day
SumWorkDay	9	hours	sum of working hours per day

Fig. 23 Input Page 3: General - Savannah Fleet Conversion Tool [Source: own Figure]

The spreadsheet comprises:

- Solar power aspects
- Office loads
- Ecological Factors
- Fuel Prices
- Financial Values
- Advanced Program Settings
- Default values for ICEV's and EV's

Not all of these options are necessary for each investigation, some of them most likely never have to be changed and therefore not looked at. Following this thought there is the possibility to hide input categories that are not required. The following image shows the explanation for all additional buttons available on this 3^{rd} input spreadsheet, comprising

- Activate/Disable Solar Power: This button hides or activates solar power. If activated also additional office loads will be activated, because those options are only required for solar power investigations.
- Set Default Values: When pressing this button every input field on this side will be reset to the default value. Default values are values that were true to the time of carrying out this project. For future use some of the default values might have to be handled with care.
- Display/Hide Ecological and Financial Settings: This button hides or displays ecological Settings. It is unlikely that these settings have to be changed since ecological factors stay the same.
- Display/Hide Advanced Program Settings: This button hides or displays advanced program settings. It is very unlikely that the user needs to change anything here, unless the program is changed profoundly.
- 1^{st} Start Range Calculation: This button generates the range patterns according to the inserted driving behavior on the page before. It has to be calculated before the actual calculation, thus it is denoted with a >>1^{st}<<.
- 2^{nd} Start Rest of Calculation: This button starts the actual calculation of energy balance, ecology balance and financial feasibility. It is denoted with a >>2^{nd}<< in order to press it after the range calculation.

The following image, Fig. 24, shows brief explanation to the displayed parts, which in this case is only (because the rest is disabled by the hide buttons):

- Solar Power
- Office Loads

- Fuel Prices (always visible)
- Office Data (always visible)

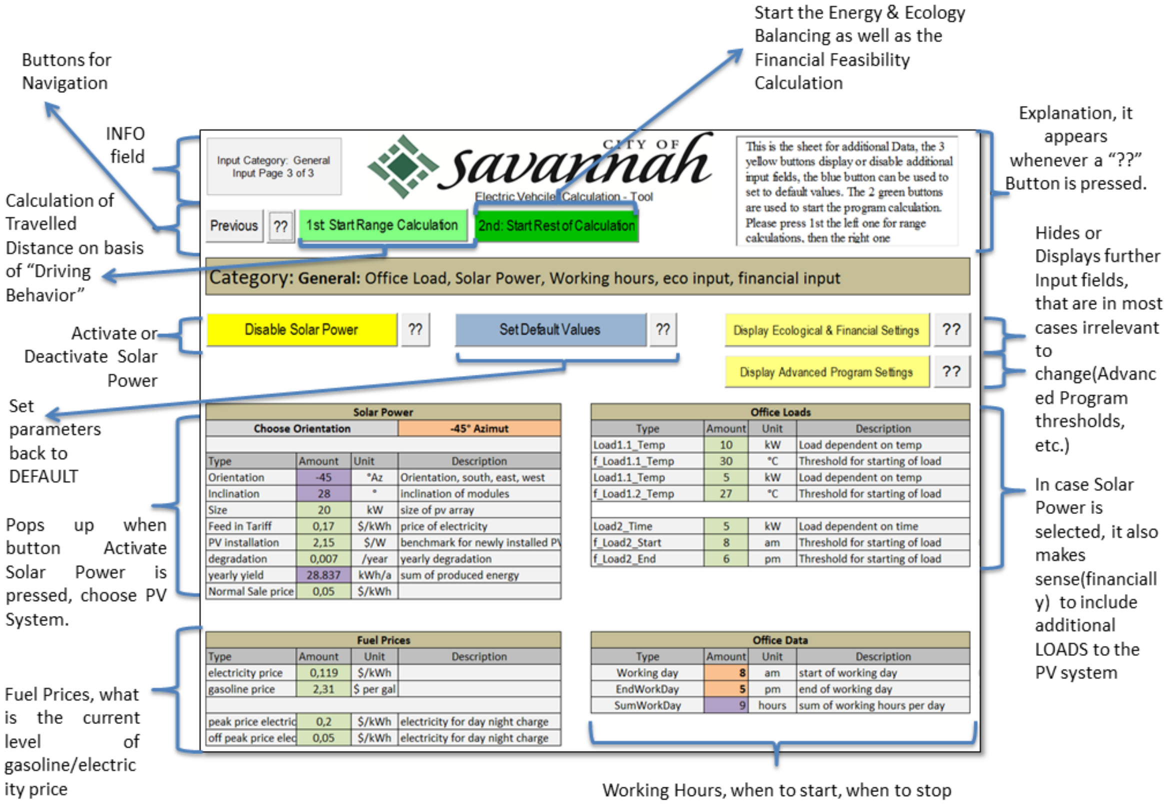


Fig. 24 Input Page 3: General - Explanations - Savannah Fleet Conversion Tool [Source: own Figure]

This means that the buttons Hide Ecological and Financial Settings and Hide Advanced Program Settings were pressed in order to facilitate the first impression of this page. This 2 buttons however can most of the time be in hide mode, since data there is unlikely to change (local electricity grid mix, years of investigation, thresholds of the program itself, etc.).

Furthermore there is a backup data base generated with good default values. If the user does not know what to insert, he or she can simply call the default data with the button >>Restore default values<<. Again the default values were correct at the time of production. However some time sensitive data like fuel price will vary and have to be handled with care if this tool is used in the future.

The selection of default data and the sources for them can be seen in the chapter Data Acquisition.

5.3 Output Interface

Also the output section is separated into different spreadsheets:

- General Output
- Energy Balance
- Ecology Balance
- Financial Feasibility

The page general output (Fig. 25) gives a short summary over the benefits regarding all 3 categories, however it does not go into detail of them. If the user wants to know more about Energy Efficiency, Ecological impacts or costs, he or she has to open the respective sheet. The following image shows the general output page, for a closer look on the other 3 spreadsheets see the attachment.

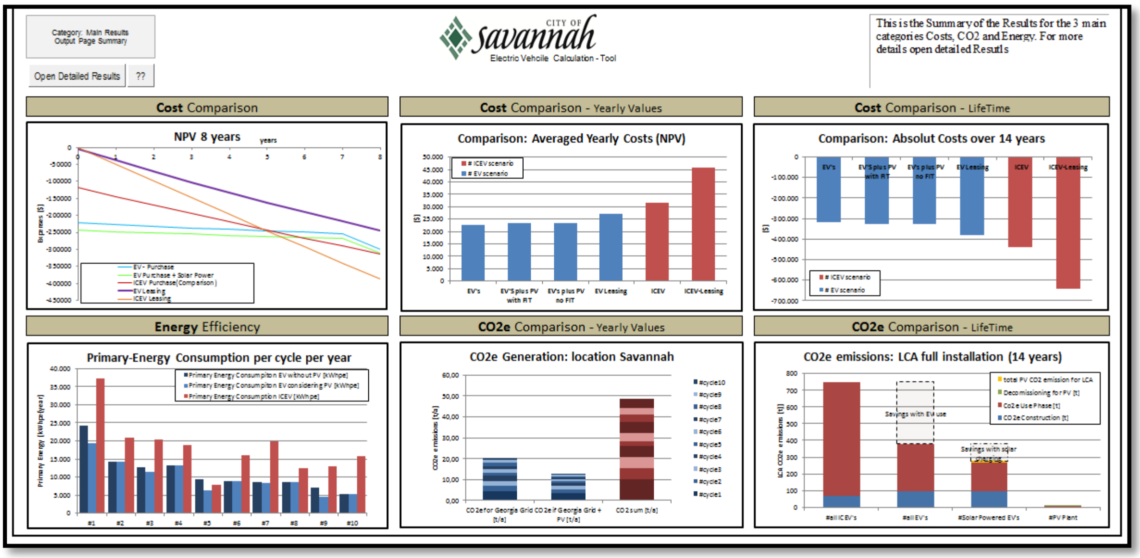


Fig. 25 Output Summary - Savannah Fleet Conversion Tool [source: own Figure]

6 METHODOLOGY

The following chapter shows the methodology of the program, comprising calculation processes, algorithms and formulas used in the different sections of the program. The chapter comprises following sections.

- Driving Behavior
- Calculation Energy Balance
- Path for Charging
- Path for Discharging
- Solar Power
- Renewable Energies
- Calculation Additional Office Loads
- Calculation Ecology
- Calculation Financial Feasibility
- Sensitivity Analysis

The energy balance is done on an hourly basis in order to be able to investigate energy consumption, share of solar energy use, peak load electricity, simultaneously charging of EV’s etc. on a precise level.

To be able to carry out this investigation, first the driving behavior has to be defined on an equally precise level.

6.1 DRIVING BEHAVIOR

Depending on how the Electric Vehicles are used, the final energy consumption can vary. With driving behavior not the acceleration behavior or driving speed is meant. This investigation focuses more on when the vehicles are used and to what extent (distance per hour). The driving cycle has to be on an hourly basis, because later on the energy balance calculation will be on this level of precision too.

For a good analysis, it is very important to get either real driving data of existing city fleet vehicles, or to develop good driving patterns that are reasonably close to reality.

Real driving data on an hourly basis would require to type in 8,760 fields (for a year-long analysis) for every single vehicle. If data can be procured on this level of detail it can be typed in manually into the calculation tool. However it is unlikely to have travel data on this level of accuracy. Furthermore it is unpractical for fast investigations (The program will finally be good for up to 10 vehicles, which leads to 87,600 fields of input just for the driving behavior, in short impossible for any fast analysis).

Thus simplifications were necessarily made. These simplifications intend to make the input easier and most of all quicker, while still guaranteeing a high level of precision. In addition to the yearly mileage per vehicle of investigation, the user can choose between 2 different options in the input section of the EV's:

- Enabling / Disabling Constant Route Everyday
- Enabling / Disabling Day Charging

With these two options in total four different driving modes can be selected. Furthermore the user can choose the driving behavior for each of the vehicles used in the analysis individually (vehicles subjected to change can be from different departments and might have totally different driving behavior). These 4 different driving behavior options guarantee for a fast and precise analysis. They are described in more detail now.

6.1.1 CONSTANT ROUTE EVERYDAY

For constant route every day following query (Fig. 26) is in operation.

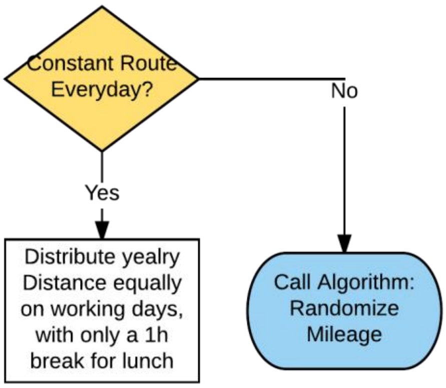


Fig. 26 Flow Chart: Driving Behavior 1 - Savannah Fleet Conversion Tool [Source: own Figure]

If the user of the program decides to choose a constant route every day, the route of the vehicle will have the same driving pattern every day. Many city fleet operated cars have this cycle.

As an example the parking meter enforcement is shown. The city is divided into specific sections, each of them is covered by one parking meter officer. The parking officer will cover this area every working day, using the same car every day. Thus this car will move the same way at the same time, every day.

Vehicles that are used in this mode – with a constant route or nearly constant route everyday – may occur in, but are not limited to, the following departments of a city (information provided by the city of Savannah fleet management):

- parking enforcement
- tax assessor
- senior services
- juvenile court
- property management
- tax commissioner office

If constant route every day is chosen, the yearly travel distance of a specific car is divided by the working days of a year (260). Along the day, the result is equally distributed to all hours, except for one hour lunch break.

If the real driving behavior is not following a constant route, the option constant route has to be disabled. This will open the Randomize Mileage algorithm.

6.1.2 Randomize Mileage

The basic structure of the algorithm Randomize Mileage can be seen in the flow chart in Fig. 27.

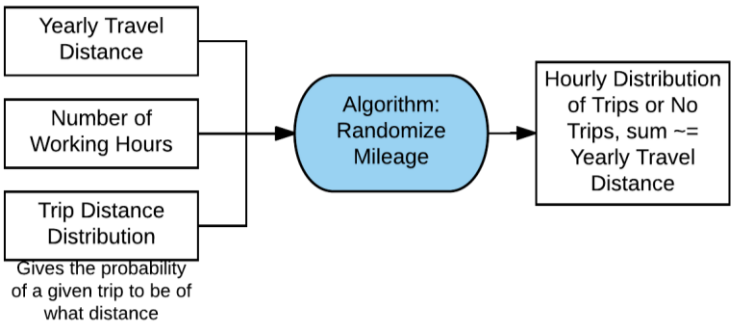


Fig. 27 Flow Chart: Randomize Mileage - Savannah Fleet Conversion Tool [Source: Own Figure]

With the help of the input variables

- Yearly travel distance
- Number of working hours per day
- Number of working days per year

and under consideration of a trip distance distribution function (see in the following) the randomized travel pattern for every working hour can be generated.

6.1.2.1 Trip Distance Distribution

The following trip distance distribution diagram gives the probability of a trip to be of a certain distance. It is shown in Fig. 28.

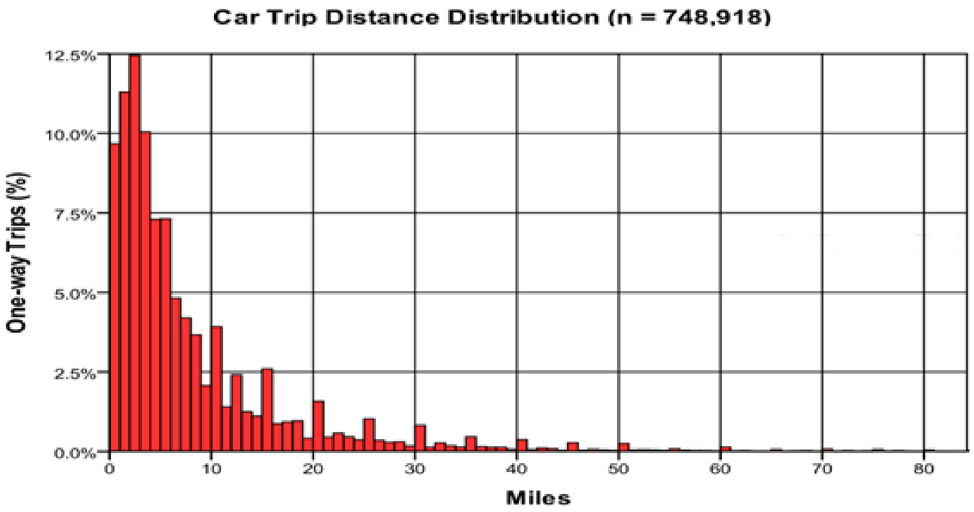


Fig. 28 Car Trip Distance Distribution [Van Haaren, 2011 p.26]

As apparent in the diagram, chances are high that trips are of rather short distance (left columns), and only rarely really long trips take place (right side of the diagram). The significant amount of trips is no longer than of 30 miles distance. [cf. Rob van Haaren, 2011 p.26]

For the randomize mileage generator following cumulated density function (CDF) was approximated out of the previously shown diagram and presented in Fig. 29. The specific lengths of trips were cumulated to fewer steps for simplicity reasons. Furthermore X and Y axis are inverted in the displayed diagram for demonstrational purpose.

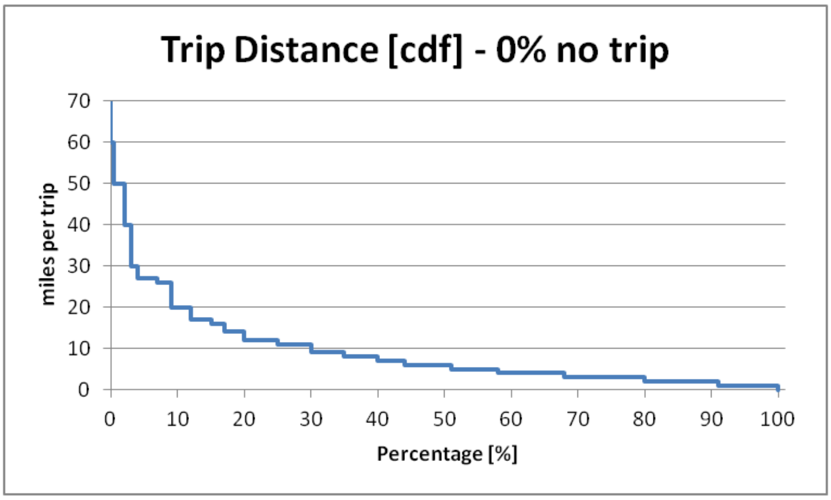


Fig. 29 Trip Distance Cumulated Density Function [Source: own Figure]

In this CDF it can be seen that only 10% of all trips reach a distance of or above 20 miles (32km), contrary 70% or all trips are below 10 miles (16km) of distance.

6.1.2.2 PROBABILITY FOR NO TRIP

This distribution function only showed the probability of a trip to be of a certain length, but not the chances of a trip to take place or not in the first place. However to stick close to reality, it has to be considered that at some working hours over the year the car will not be used, thus 0 distance is traveled at some hours of the year.

Since the probability of a trip to be of a certain length is known from the above mentioned diagram, the probability of no trip to take place can be calculated with consideration of the required travel distance of a year and the sum of all active hours in a year (number of all working hours in a year, not of a day). In other words the probability for 0 distance movements is used as an addition to the base travel distance distribution to finally reach the required yearly distance the car shall move.

Including the chances of o – trip possibilities obviously the percentages displayed before of the CDF change. Normalizing it again to 0 to 100% it is possible to show the space for 0 trip possibility.

In case yearly travel distance is low and there are a lot of working hours to divide this travel distance to, there is a high number of hours with no trip taking place, i.e. a high number of 0 trips (in the example it is 33% chance of no movement). This 0 distance movements are required to finally reach the required travel distance over the course of a year (if the car moves every hour with the given CDF, the distance accumulated would be too high). The CDF for a 33 % chance of no movement is presented if Fig. 30.

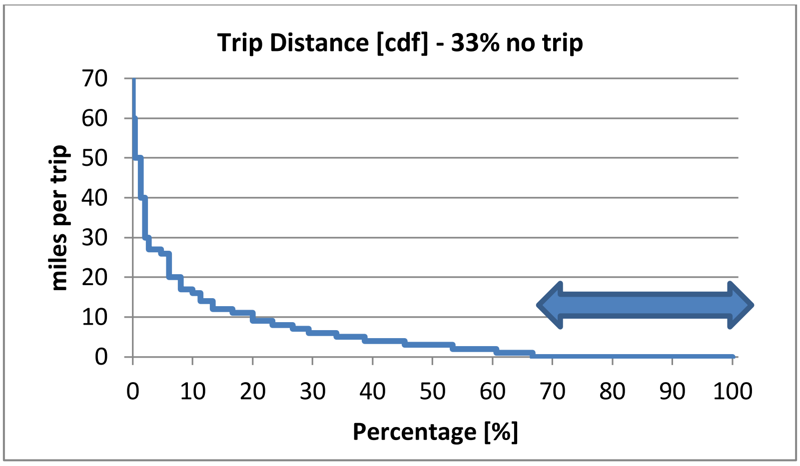


Fig. 30 Trip Distance CDF for 33 % Change of No Trip [Source: own Figure]

The next example (Fig. 31) shows a 20 % stand still time, which means 20 % of all working hours the car is not moving. This includes lunch breaks, but also business meetings (the car moves to get there, but then is simply parked for the time of the meeting), or other events. This 20 % stand still time helps to reach the final requested travel distance over the course of a year, while still using the CDF of trip distance probability.

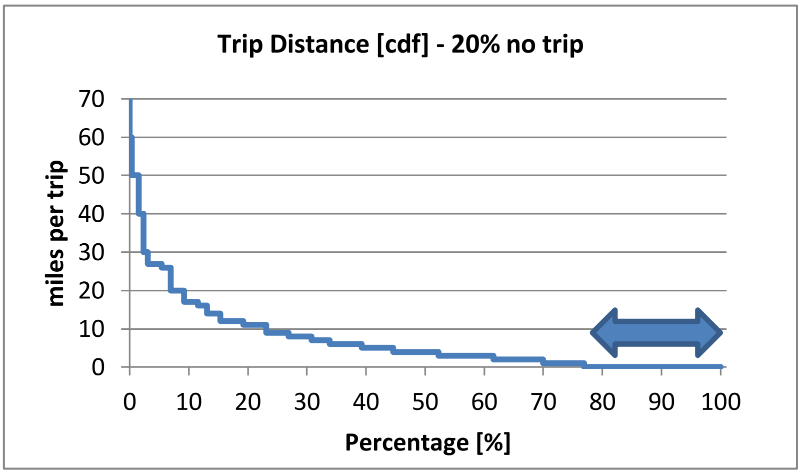


Fig. 31 Trip Distance CDF for 20% Cahnge of No Trip [Source: Own Figure]

In case the yearly travel distance is relatively high and the amount of working hours is limited (short working days), there will be limited time when the car is in stand still. This can go up to values of almost no stand-still, which means the car is constantly moving. If the car is constantly moving, although a 100% moving time is unlikely, it would look again like the trip distance distribution that was mentioned at first (Fig. 29).

6.1.2.3 FORMULAS USED FOR RANDOMIZED MILEAGE GENERATOR

The algorithm used in VBA for generating the randomized mileage is rather complex, and is only explained briefly here. In case of interest it will be displayed again in more details in the annex.

First the yearly required travel distance is assessed. Depending on the height of it a specific Probability-Number is assorted to it. This Number ranges from lowest 100 up to close to 175.

Now a randomize number generator is used to generate a Random Number from 0 up to the before defined Probability Number (so from 0 to max 175). This Number is then checked and set to the right distance. For example if the number is below 10 (equals a 10 % chance), it is set to a 1 km distance trip. If the number is however above 100, the number is randomized for numbers from 27 to 60. This means all random numbers above 100 are finally converted into long trips (between 27 and 60 km length). The algorithm tries to keep close to the initially shown Car Trip Distance Distribution curve, Fig. 28. The full algorithm code is attached in the end of the thesis.

The mentioned process is done for every working hour throughout the year. As it can be seen now, for low Probability Numbers (only slightly higher than 100), there is almost no chance for a 0 trip to occur, thus the final yearly distance will be high. Contrary if the Probability Number reaches its highest values, a high chance for no trip to occur is given.

Since the algorithm works with probabilities for certain trip lengths, the final result in travel distance over a year might vary from the originally inserted miles. However it is tried to limit this offset. If the user of the program is nevertheless unsatisfied with the results of this automated range algorithm, there is always the option to insert driving behavior automatically on the spread sheet Energy Balance.

6.1.3 Day Charging

The 2nd choice the user has is to enable or disable Day Charging (Charging during office hours). The query is shown in the flow chart Fig. 32, offering 2 different options.

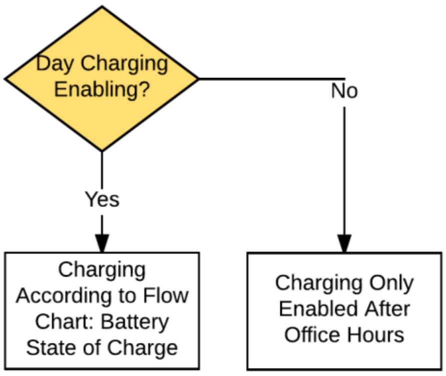


Fig. 32 Flow Chart: Driving Behavior 2 - Savannah Fleet Conversion Tool [Source: own Figure]

6.1.3.1 Day Charging is Disabled

In Case Day Charging is disabled, the EV will only be charged after Office hours. This happens independently from whether the car could be charged during the day or not. If day charging is disabled, only after work hours are subjective to charging process.

6.1.3.2 Day Charging is Enabled

If Day Charging is enabled, the EV can be charged according to the flow chart Battery State of Charge at any time, also during the working hours. Additional requirements for charging beside the driving behavior can be seen in the chapter Charging Suggestions.

6.1.4 Ecologic Choice of Driving Behavior

Obviously it cannot be freely chosen in what driving behavior a car is operated. However for a better understanding of how the chosen driving behavior options influences the ecology output (mainly share of renewables for charging purposes) following setups are closer looked at.

6.1.4.1 Day Charging is Enabled and Constant Route Everyday is Enabled

Since the constant route every day has a certain mileage on every working hour except for the lunch break, there is only 1 hour during office hours for charging with a high share of solar power. After working hours there is still solar power available, but maybe not in a sufficient amount to charge much with PV.

6.1.4.2 Day Charging is Enabled and Constant Route Everyday is Disabled

Constant route every day is disabled means that the randomize mileage algorithm is in place. Depending on the yearly traveled distance this could mean there are hours of no travel available. In these hours the share of renewables for charging will be higher than after work. However if the yearly traveled distance is high almost no hours with no movement are existing thus almost no solar charging is possible.

6.1.5 Algorithm for Charging Suggestions

Due to the previous chapter it is known that the possibility depends first of all on whether the car is moving or not. Thus it strongly depends from the driving behavior and the times of no movement.

However only because the Electric Vehicle is not moving, it does not necessarily mean that charging it is of interest too. It can be that it is already totally full or almost fully charged, and there is no solar energy available to charge it at the moment. So why charge it now?

The following flow chart (Fig. 33) shows the query for charging suggestions. It shall present a reasonable analysis for finding out good moments for charging the vehicles, beyond the simple query for whether the vehicle is currently moving or not. As an addition to these automated charging decisions, the decision can be reviewed and also modified and changed manually in the spreadsheet Energy Balance, if desired (Note that manual manipulation might be a lot of work to do, since there are many working hours over the course of a year).

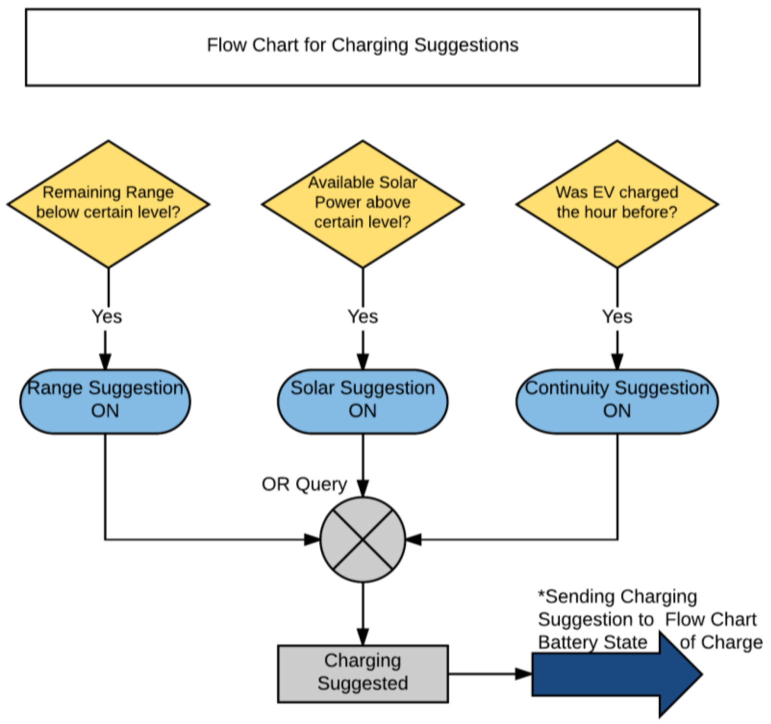


Fig. 33 Flow Chart: Charging Suggestions - Savannah Fleet Conversion Tool [Source: own Figure]

Any of these 3 charging suggestions can only be active if the currently investigated EV is not moving, thus has a 0 movement at the current hour. As it can be seen in the flow chart, there is an OR query. This means if only one of the charging suggestions is on, the charging suggestion is set to be on. The 3 different charging suggestions are further described now.

6.1.5.1 Range Charging Suggestion

Probably the most obvious suggestion derives from the remaining range. If the battery is empty, charging makes quite sense. Also if the battery reaches low or critical levels, charging is of importance. However if the car is moving, charging is impossible. Thus this charging suggestion is only active in times where the EV is not moving.

The precise threshold of range remaining to give out a charging suggestion can be defined in the advanced settings on the input page (and should be chosen in consideration of the daily travel distance).

6.1.5.2 SOLAR CHARGING SUGGESTION

In case a solar power plant is installed, the produced energy should also be used. Solar power has a priority over grid electricity to charge the electric vehicles. Considering this, when solar energy is available, there shall be a charging suggestion. Again the charging suggestion can only be available in times where the car is not moving.

The precise threshold of solar energy available to give a charging suggestion can be defined in the advanced settings on the input page.

6.1.5.3 CONTINUITY SUGGESTION

Third suggestion is due to continuity. The idea is: If the car is already charging, it should be continued for as long as possible or until it is full. Obviously the car cannot always be charged until it is full, because it can be that the EV is charged during working time, and the car has to be used again later on. However if charging is started already, it shall be continued for as long as possible or until the battery is full. Also this charging suggestion only activates in times where the car is not moving.

If either one of the charging suggestions is set to be on, the charging decision is sent to the next flow chart (Battery state of Charge). This flow chart calculates the battery state of charge on an hourly basis, thus includes discharging and charging of the EV's. If the previously mentioned charging decision is sent to the flowchart, charging is possible. The charging process is described in more details in the next flow chart, which can be seen in the next chapter.

6.2 ENERGY BALANCE

Due to the previously mentioned algorithms for driving behavior and charging suggestions there is now a precise structure available for the calculation of the energy balance. For each EV there is a certain driving pattern on an hourly basis available, with furthermore charging decisions at specific times (when either solar power is available, remaining range is low or due to continuity reasons).

Important to mention is that for the charging process there are simplifications assumed. Both charging and discharging is assumed to be linear for all energy calculations. With this approach the equations for calculating the energy can be simplified significantly. Because the main focus of the thesis is not to show the charging process in details and all its correctness but to show the overall energy consumption and efficiency of EV's compared to ICEV's, the simplification approach is legit. This topic is discussed further in the chapter Path for Charging.

The following flow chart (Fig. 34) represents the algorithm used for simulating the charging or discharging process of each EV's battery, using the previously described charging suggestions. This pattern is run on an hourly basis throughout a year, for each investigated EV.

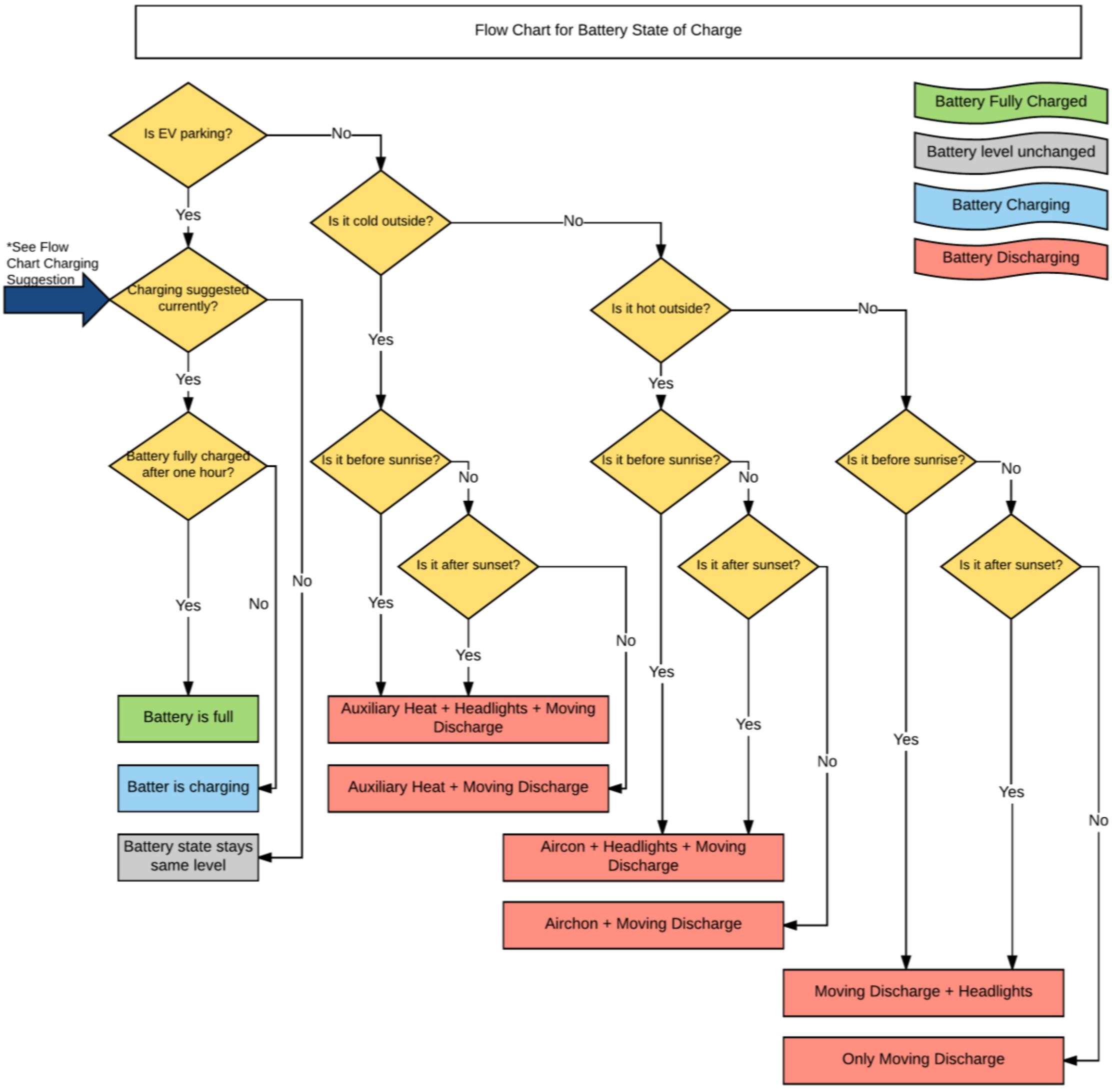


Fig. 34 Flow Chart: Battery State of Charge - Savannah City Fleet Conversion Tool [Source: Own Figure]

6.2.1 Path for Charging

As apparent in the flow chart, the electric vehicle can only be charged if the query “Is EV parking” and the query “Charging suggested currently” are fulfilled. First one asks if the EV is currently in a standstill position. But even if the vehicle does not move, it doesn’t necessarily mean that charging is of interest at this time. For this the second query is here, which gives a suggestion about charging. The algorithm for charging suggestions is based on internal calculations about the level of solar power available, the remaining range of the EV and the history of charging. The algorithm for charging suggestion can be obtained from the next flow chart.

If there is no charging suggestion apparent, even though the vehicle does not move and could in theory be charged, no charging will be applied and the current battery state of charge remains the same as before, displayed in following formula:

$$\boldsymbol{Ci} = \boldsymbol{C_{i-1}} \qquad [6.1]$$

[Source: own Equation]

Whereas the denotations mean:
C_i…….…….Battery State of Charge at current hour
i…………….Current hour.
C_{i-1}…………Battery State of Charge at previous hour

If the charging suggestion is on, the battery will be charged for one hour and the battery load is increased by the charging energy of one hour. The correct charging equation for batteries of electric vehicles can be obtained from the equation [6.2].

$$\boldsymbol{P_{b-in} = \frac{\alpha V}{\mu_t \mu_m}\left(Mg(f_r + i) + \frac{1}{2}\rho_a C_D A_f V^2 + M\delta \frac{dV}{dt}\right.} \qquad [6.2]$$

[Ehsani, Yimin, Ali, 2010, p.121]

This equation includes all the parameters required to calculate the real energy amount possible to charge within a certain time period. The equation considers among other parameters the voltage level, amperage, efficiency factors and losses of certain gear, the capacity of the battery and its initial charging value. Both μ_t and μ_m stand for efficiency values for the power transmission and the motor drive. The amount of energy charged can be calculated by integrating over the time of charge. [cf. Ehsani, Yimin, Ali, 2010, p.121].

However as mentioned at the beginning of the chapter >>Energy Balance<< it is important to mention that the charging process is assumed to be linear for the calculations of this tool (because the main focus of this thesis is not in showing the charging process on this precise level). With doing so the equations can be simplified significantly. All further charging equations in the chapter energy derive from the above mentioned precise charging formula, but are simplifications of it. The following equation sources are therefore denoted with [own source]

Following equation is used to approximate the battery charging process:

$$Ci = C_{i-1} + C_{1h} \qquad [6.3]$$

[Source: own Equation]

Whereas the denotations mean:

C_i…….…….Battery State of Charge at current hour

i…………….Current hour.

C_{i-1}…………Battery State of Charge at previous hour

C_{1h}…………Charging input per hour

C_{1h} is the energy amount that can be stored into the battery in 1 hour. The amount that can be charged in one hour depends on the charging efficiency of the battery charging system, but most of all on the power input. The available power input is dependent from the chosen Electric Vehicle. Some of them are equipped by default with fast charging devices. Most of them range by default at 3 to 6 kW. The formula for the C_{1h} is following:

$$C_{1h} = P_{Charging}\, t \qquad [6.4]$$

[Source: own Equation]

Whereas

C_{1h}………………… Charging input per hour

$P_{Charging}$……………..level of power the battery is charged with

t...........………………time interval of 1 hour

It can be seen, for the sake of simplification, a linear charging process is assumed.

If the additional energy C_{1h} already exceeds the maximum battery capacity, the battery level of charge C_i is set to be full and charging stops, displayed in following formula:

$$\boldsymbol{C_i = C_{max}} \qquad [6.5]$$

[Source: own Equation]

Whereas

C_i……..…….Battery State of Charge at current hour

C_{max}………..maximum Battery Capacity

The missing energy is calculated that is required for the full charging of the battery.

The real amount of electricity required for the charging process is increased finally by the efficiency value for charging, which is analyzed in the chapter data acquisition.

6.2.2 PATH FOR DISCHARGING

As apparent in the flow chart, the battery discharges as soon as the vehicle is moving. There are several paths for discharging depending on outdoor conditions. The detailed discharge equation is:

$$\boldsymbol{P_{b-out} = \frac{V}{\mu_t \mu_m}(Mg(f_r + i) + \frac{1}{2}\rho_a C_D A_f V^2 + M\delta \frac{dV}{dt}} \qquad [6.6]$$

[Ehsani, Yimin, Ali, 2010, p.121]

This equation contains all the parameters required to calculate the real discharge rate over a certain time period. The equation considers among other parameters the voltage level, amperage, battery capacity, losses and efficiency factors such as μ_t and μ_m for transmission and drive. The amount of energy discharged can be calculated by integrating over the time of use [cf. Ehsani, Yimin, Ali, 2010, p.121].

Again the discharge formula is simplified by assuming linear discharge rates.

All further equations for discharging in the chapter energy derive from the above mentioned precise discharge formula, but are simplifications of it. The following equation sources are therefore denoted with [own source].

The equation [6.7] shows the simplified discharge rate.

$$\boldsymbol{C_i = C_{i-1} - f_{fe} d_i} \qquad [6.7]$$

[Source: own Equation]

Whereas

C_i……………Battery State of Charge at the current hour.

i……………...Current hour.

C_{i-1}…………..Battery State of Charge at previous hour

f_{fe}……………Fuel Economy factor, shows the consumption of electricity per mile or km, measure of efficiency of the EV [kWh/mile]

d_i……………Distance the EV is moving in the current hour in [mi/hour]

In addition to this basic discharge formula, other factors have influence.

- Low ambient temperature
- High ambient temperature
- Night time

6.2.3 DISCHARGING RATE AT LOW AMBIENT TEMPERATURE

At low outside temperatures, the discharge speed of the EV is higher, mainly due to auxiliary energy needed to keep the EV at operational temperature. This is expressed in the program with following formula.

$$\boldsymbol{C_i = C_{i-1} - f_{fe} d_i f_{T1}} \qquad [6.8]$$

[Source: own Equation]

Whereas

C_i……………..Battery State of Charge at the current hour.

i………………Current hour.

C_{i-1}……………Battery State of Charge at previous hour

f_{fe}……………..Fuel Economy factor, shows the consumption of electricity per mile or km [kWh/mile]

d_i……………Distance the EV is moved in the current hour [mi/hour]

f_{T1}…………..Additional discharge factor for low Temperatures

6.2.4 DISCHARGING RATE AT HIGH AMBIENT TEMPERATURES

At high outside temperatures, the discharge speed of the EV is higher, mainly due to the use of air condition. This is considered in the program with following formula.

$$\boldsymbol{C_i = C_{i-1} - f_{fe} d_i f_{T2}} \qquad [6.9]$$

[Source: own Equation]

Whereas

C_i……………Battery State of Charge at the current hour.

i………………Current hour.

C_{i-1}…………..Battery State of Charge at previous hour

f_{fe}…………….Fuel Economy factor, shows the consumption of electricity per mile or km [kWh/mile]

d_i…………….Distance the EV is moved in the current hour [mi/hour]

f_{T2}……………Additional discharge factor for high Temperatures

6.2.5 DISCHARGING AT NIGHT TIME

If the Electric Vehicle is used at night time, the additional use of headlights will also lead to a different result in discharge level, as represented in following formula.

$$C_i = C_{i-1} - f_{fe} d_i f_{Night} \qquad [6.10]$$

[Source: own Equation]

Whereas

C_i…………..……Battery State of Charge at the current hour.

i………………Current hour.

C_{i-1}…………..Battery State of Charge at previous hour

f_{fe}…………….Fuel Economy factor, shows the consumption of electricity per mile or km [kWh/mile]

d_i…………….Distance the EV is moved in the current hour [mi/hour]

f_{Night}………..Additional discharge factor use at night.

Since the impact of a city fleet car is analyzed, and the normal working hours are during the day, night discharge will not occur very frequently, thus the sensitivity of the definition of night hours (the exact start and end time) is of low importance.

6.2.6 COMBINED LEVELS OF DISCHARGE

As visualized in the flow chart, these additional factors can occur combined as well, if the case is given.

As example, cold ambient temperature and night use can occur:

$$C_i = C_{i-1} - f_{fe} d_i f_{T1} f_{Night} \qquad [6.11]$$

[Source: own Equation]

Hot temperature and night use lead to following discharge formula:

$$C_i = C_{i-1} - f_{fe} d_i f_{T2} f_{Night} \qquad [6.12]$$

[Source: own Equation]

Finally once the current battery state is calculated, the remaining range R_i of the EV at the particular hour can be calculated on the basis of the battery state C_i.

$$R_i = \frac{R_{max}}{C_{max}} C_i \qquad [6.13]$$

[Source: own Equation]

Whereas

R_i…………..…..Range remaining at current hour

R_{max} ……….max Range of the electric vehicle when fully charged

C_i……. ..…..Battery State of Charge

i…………….Current hour.

C_{max}………..Maximum Battery Capacity of the electric vehicle in observation.

6.2.7 Balancing over a Year

The obtained information about energy consumption on an hourly basis can now be further analyzed and summed up regarding different sections for:

- Day Electricity
- Night Electricity
- Peak energy
- Solar Power Usable
- Solar Share for Office Loads

Finally the energy consumption of every investigated EV is summed up and displayed together. It is then compared with the energy consumption of the previously chosen ICEV vehicles on a mutual basis (comparing Electricity with Gallons of Gasoline (or generated heat) does not directly make sense). Thus following 2 comparisons are chosen:

- Primary energy: Conversion of both Electricity and heat energy of gasoline back to a primary energy level)
- Miles per gallon equivalents with miles per gallon (see chapter literature research)

This chapter showed that it is not only important to assess the overall mileage and overall energy consumption over a year, but to analyze energy consumption on a higher level of detail. Discharge levels and amount of solar energy available vary, depending on the chosen driving cycle, the time of the day and the outside conditions.

For a good analysis of energy consumption of EV's the energy balance has to be done on an hourly basis throughout the course of one year.

6.3 Renewable Energy and Local Climate

In the next chapter the implementation of renewable energies is dealt with. The program is mostly designed to implement solar power, however if another electricity source is available (e.g. wind power), it can be inserted too (see Additional Renewables). In the spread sheet Energy Balance there is a section for renewable energy, on an hourly basis for one full year. This is the sum of the available solar power, plus any additional renewable energy, if available. The insert for both solar power and any other renewable energy is in the spread sheet solar gain.

6.3.1 Solar Power

In the spread sheet solar gains there is a list of solar yields on an hourly basis over the course of a year. One of them can be chosen to be implemented into the analysis of the program. The list comprises produced electricity for certain selected angles of azimuth and inclination. The investigation is carried out with PVSol for a 10 kW power plant for the location of Savannah. The coordinates of Savannah are obtained from an online geographic tool [cf. LatLong, 2016].

DMS Lat: 32° 4' 34.2336" N

DMS Long: 81° 5' 18.1356" W
[LatLong, 2016]

The analyzed solar power plant consists of following main components:

- PV modules: 44 modules type Solar World 230W poly crystalline
- Inverter: Fronius USA, 11.4 kW single string inverter 277V input
- Array: 1 Array with 4 strings of 11 modules
- Installed Capacity: 10.1 kW

The general arrangement of the solar power plant can be obtained from Fig. 35.

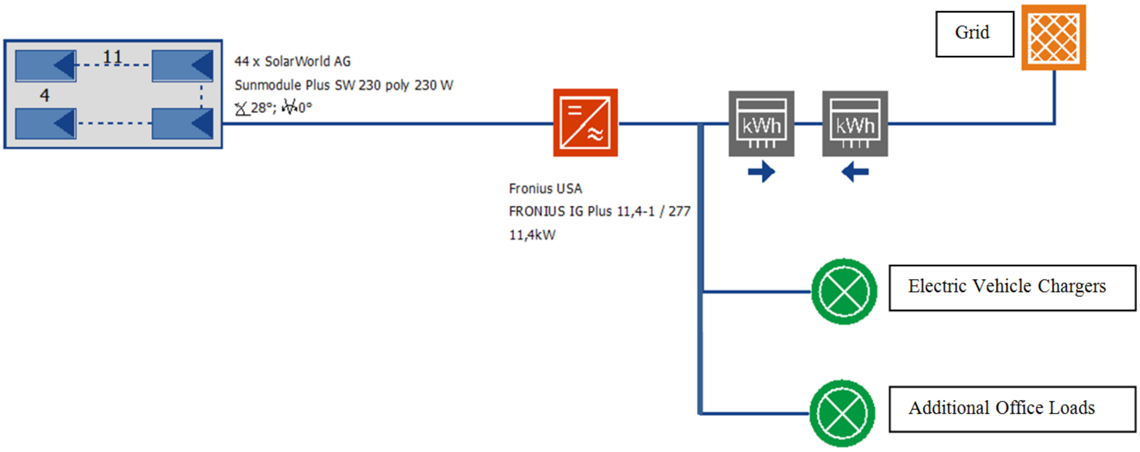


Fig. 35 Solar Module Layout [Source: PVSol]

The standard orientation setting is chosen to be

- Azimuth: 0°
- Elevation: 28°

This orientation is chosen because it leads to highest solar production over the course of a year. The maximum result in solar production can be seen in the following 2 chapters.

6.3.1.1 Energy Production on a sunny summer day

The Fig. 36 shows the produced energy on the 5th of May.

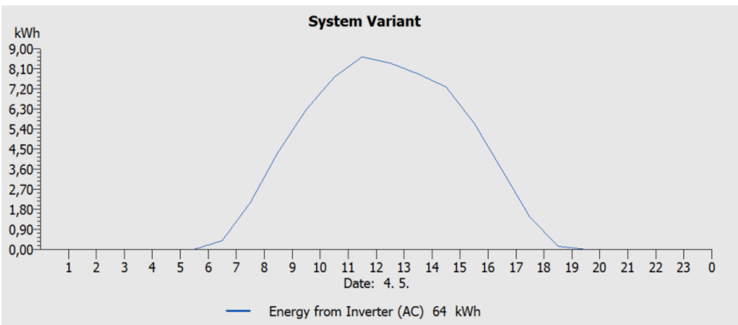


Fig. 36 Solar Energy Production with standard plant arrangement -5/5/15 [Source: PVSol]

It is found that this day shows one of the highest solar energy production curves of all the analyzed year. It is not surprising that this day is in the summer period. The precise hourly values for the Fig. 36 can be obtained from the appendix.

6.3.1.2 Energy Production on sunny winter day

The following Fig. 37 shows the produced energy on the 12th of December.

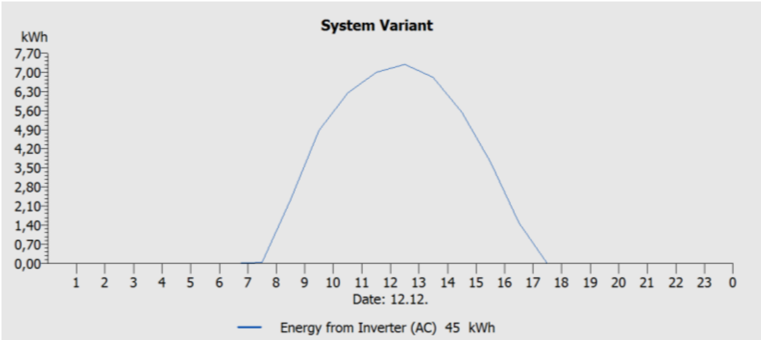


Fig. 37 Solar Energy Production with standard plant arrangement -12/12/15 [Source: PVSol]

This value represents one of the days in the winter period with the highest solar energy production. The precise hourly values for the Fig. 37 can be obtained from the appendix.

As it can be seen in above displayed figures, the maximum irradiation is lower in winter months than in summer months. However this difference is not as extreme as it would be at locations further north. What is a bigger influence is the difference of available sun hours, which makes the overall energy production on a winter day lower than on a summer day.

Another important influence on the energy generation is the current weather situation, which can cause big fluctuations of the availability of solar energy. It is here not further shown how low solar potential can drop due to bad weather. If required the full database is available in the calculation tool (solar energy production on an hourly basis over the course of a full year, location Savannah).

6.3.1.3 ORIENTATION

The above mentioned basic layout for a 10kW PV-plant (same modules, same inverter, etc.) is used to model the energy output for different angles of azimuth and elevation. Following parameters are applicable in the program:

- Elevation: 0° or 28° or 35°
- Azimuth: 0°, 45°, 90°, -45°, or -90°

Elevation of 28° is used for the orientation of 0°, 45° and -45° azimuth, while elevation of 35° is used for 90° and -90° (sun at this angle of azimuth will be lower already, thus a higher elevation is of advantage). The orientation of -90° and 90° for azimuth is used to have high solar power at the morning or respectively at the evening hours (idea of high amount of solar energy for evenings and after work electric vehicle solar charging).

6.3.1.4 INDICATION OF SIZE

The energy calculation with PVSol is carried out only for the above mentioned 10kWp plant. If the size of the solar power plant shall be bigger or smaller than 10kW, the hourly values for the solar power can be up or downgraded within the calculation tool. This is achieved with following formula:

$$f_{PV,size} = \frac{P_{Real}}{P_{10kW}} \qquad [6.14]$$

[Source: Own Equation]

Whereas:

$f_{PV\ size}$..............................Sizing factor for the real PV system size

P_{Real} ....……..Real PV peak power installation chosen (in solar input field)

P_{10kW} ……………………………Comparison Power, always at 10kWp because the back ground data in the solar power spreadsheet is stored at 10 kWp.

The output of the solar power plant (which is calculated in PVSol before) is then multiplied with this factor on an hourly basis to get the new yield for the actually PV plant size chosen by the program user.

$$\boldsymbol{E_{i,sized}} = \boldsymbol{f_{PV,size}}\ \boldsymbol{E_i} \qquad [6.15]$$

[Source: Own Equation]

Whereas:

E_i……………………the energy output at the current hour of the initially PV installation (10 kWp installation)

$E_{i,sized}$………………the energy output at the current hour after being up or downgraded by the actual installation size.

$f_{PV,size}$………………Sizing factor for the real PV system size.

6.3.1.5 SENSITIVITY OF SOLAR POWER

The program is limited to certain orientations, certain elevations, 1 predefined solar module type and 1 inverter for a system of 10kW. Furthermore shading is not considered in the investigation. However if a specific PV setup, which is not part of the predefined choices, is wanted it can always be calculated manually with any available solar power tool. Later on the result of energy production can be typed in on an hourly basis into this calculation tool. The same process has to be done if the analysis shall be carried out for another geographic location (because values for irradiation and outside temperature change and therefore the solar production too).

It can be seen that certain simplifications were made with respect to accuracy of solar power production. However the main approach is to generate a fast yet rather accurate calculation tool that investigates many different fields. Solar power is only one of them. With the described simplifications the impact of solar power can be analyzed sufficiently accurate and still without high complexity. If the result of the calculation eventually shows that solar power is really of interest for a certain scenario, it is suggested that the solar power production analysis is carried out again on a higher level of details.

6.3.2 ADDITIONAL RENEWABLES

In case another source of renewable energy shall be considered for the calculation, this can be done in the spread sheet solar energy. For this section there is no input help however. If another energy source shall be considered, the energy data has to be obtained independently (from measurements, wind power tools, etc.) and typed in manually (hourly basis 8760 fields for the full year). In doing it this way any kind of additional energy can be considered and not just one type of renewable energy like wind.

6.3.3 CLIMATE INPUT

Climate data for is present on the spreadsheet solar energy. It considers as standard values a set for Savannah ambient temperature values on an hourly basis for one year. The used climate data derives from the program PVSol.

If the calculation tool is intended to be used for another location, it is easily possible. First the user has to find ambient temperature data on an hourly basis for the new location. Many Solar Power tools offer this, including but not limited to PVSol, PVSyst or Meteonorm. The climate data in the spread sheet solar gain has to be overwritten in a second step. Now the calculation tool can be run for a new climate set.

However the previously mentioned solar energy values are also for the location of Savannah, thus also these values have to be modified if a consideration at another location is carried out.

Furthermore, if the location is significantly different (i.e. not another city in Georgia but another State or even country), also ecological factors, tax incentives, electricity and gasoline prices, and even price development expectations have to be reinvestigated again.

6.4 Additional Office Loads

In case of considering solar energy, there are several aspects of importance.

First it has to be known if there is a special feed in tariff or another financial benefit that helps making the PV-System feasible. A feed in tariff means that the produced electricity can be sold at price level that is higher than the normal market price.

If there is no additional financial benefit available, the logical financial conclusion is to try to consume as much of the produced power as possible rather than feeding it into the grid with low sale rates and buying it back at another time for a more expensive price. Charging the EV's will consume part of the produced electricity, but hardly all of it. For trying to raise the share of own consumption, it is of interest to add additional loads in addition to the EV-charging load to the investigation.

Following additional loads can be of interest for the investigation in the program.

Imagining the EV charging stations to be part of a parking garage, the installed solar power on the rooftop can be used to first charge the cars, but with excess energy also light the garage.

In case the charging stations and PV panels are attached to an office building, additional loads for the solar panels can be office air condition and or office illumination.

The program therefore offers slots for additional loads, with either the thresholds for outside temperature (for air condition loads), or time of the day (for illumination loads).

- Additional Load 1.1: Dependent to the ambient temperature, it is seen as base load air condition load. As soon as outside temperature rises over a certain level, this load will be on, given that it is during the office hours. Starts at a lower temperature than Additional Load 1.2 and only during office hours.

- Additional Load 1.2: Dependent from ambient temperature as well. It is used as a peak load for air condition. Starts to work at a higher temperature than Additional Load 1.1 and if active it replaces the Additional Load 1.1. Again this load is only in operation during office hours.
- Additional Load 2: This load is not dependent from the outside temperature or the office hours. It is only dependent from time of the day, which can be varied with 2 input fields (start time and end time). The load shall represent the additional energy consumption due to illumination, which can co-occur with office hours (if the illumination of an office building is used) but could also be on 24/7 (at a parking garage for example)

Additional loads in the investigation are of importance for the latter on financial analysis (feed in versus own consumption). For the ecologic investigation it is of no concern however, as discussed in the next chapter.

6.5 Calculation Ecology – CO_2

After the last chapter, the energy balance for both gasoline cars and electric vehicles is done. It is now known how much gasoline and how much electricity is required over a year. Furthermore the electricity consumption is split into grid energy and own produced one (solar power).

This is the first relevant information for calculating direct emission values. The ecology balance will also include life cycle assessment on a later stage. But first focus lies on the use stage alone. Following 3 main scenarios are possible to analyze with the program:

- The impact of ICEV’s
- The impact of EV’s charged with grid electricity only
- The impact of EV’s charged partly by solar power

These 3 basic scenarios regard only energy and ecology. As can be seen in the chapter Calculation Financial Feasibility, these 3 main scenarios will be further divided into different financing methods, which can be looked at in details in the chapter scenarios.

For environmental calculations the homepage of the environmental protection agency (EPA) shows valuable information and presents formulas for various calculations [cf. EPA, 2016].

6.5.1 Use Stage CO_2e Emissions

Keeping in mind the chapter literature research we know that in use stage there are direct tailpipe emissions, but also upstream / indirect emissions. Just a brief recall, upstream for ICEV's derives from gasoline refinement and transport, for EV's it is the production of electricity.

The CO_2 emission of burning one liter (or gallon) of gasoline can be calculated straightforward, because the amount of carbon in the fuel is known.

Thus it is easy to formulate a factor of CO_2 emission that can be multiplied with the amount of consumed fuel. In this way the overall tailpipe emissions can be calculated. For upstream emissions it depends on the efficiency of the whole supply chain, however the process usually adds between 24 to 28 % [Cowart, Pesinova, Saile. 2003, p.10f].

For the calculation the more conservative value of 25% (more conservative in the sense of seeing less ecological benefits of EV's) is chosen.

For a real ecologic analysis, not only CO_2 emissions are of interest. The real interest lies in global warming potential or greenhouse gas emissions. This is presented in CO_2 equivalents, or short CO_2e. This measuring system sums up all global warming relevant missions of a certain process (combustion of gasoline, production of electricity, etc.), and calculates out of all of them one unit, the CO_2e.

There are CO_2e factors existing not just for gasoline combustion, but for each source of energy (solar power, electricity from hydropower, from wind power, from coal power plants, or the grid electricity mix (varies from state to state due to different shares of power plant types).

To obtain the emission result the correct factors simply have to be multiplied with the correct amount of energy consumption (solar power, grid electricity or gasoline consumption). The formulas in the following are obtained from emission calculation report guidelines from the Environmental Protection Agency [cf. EPA. 2016].

For gasoline, the factors can be seen in following formula:

$$\boldsymbol{CO_{2-ICEV-direct}} = \boldsymbol{f_{CO_2\_Gas} V_{Gas}} \qquad [6.16]$$

[cf. EPA. 2016]

Wheras:

$CO_{2\text{-ICEV-direct}}$ ……	Sum of direct emissions of an ICEV due to gasoline combustion
f_{CO2_Gas} …………	Factor that accounts for released amount of CO_2 per amount of gasoline burnt
V_{Gas} ….. …………	Amount of consumed gasoline fuel in volume (liters or gallons)

For gasoline the factor of direct emission is 2.35 kgCO_2e/l (19.640 lbs CO_2e/gal), Diesel would be higher with 2.86 kgCO_2e/l (22.38 lbs CO_2e/gal) [cf. EIA IV, 2016].

Alternative Fuels Data Center uses a 2.82 kgCO_2e / l (23.5 lbs of CO_2e/gal) for the emissions of burning gasoline [cf. AFDC II, 2016].

For the sake of conservancy the first source is used for further analyses.

$$\boldsymbol{CO_{2-ICEV-Upstream}} = \boldsymbol{f_{CO_2\_Upstream} V_{Gas}} \qquad [6.17]$$

[cf. EPA. 2016]

Wheras:

$CO_{2\text{-ICEV-upstream}}$ …	Sum of indirect emissions due to refinement of gasoline

$f_{CO2\_Upstream}$ …….. Factor that accounts for the released amount of CO_2 per amount of gasoline produced / refined.

V_{Gas} ….. … Amount of consumed gasoline fuel in volume (liters or gallons)

The full use emissions is the sum of direct and indirect emissions, hence the sum of [6.16] and [6.17].

For electric cars the direct tailpipe emissions are zero, thus

$$f_{CO_2\_EV\_direct} = 0$$

$$\boldsymbol{CO_{2\_EV\_direct}} = \boldsymbol{f_{CO2\_EV\_direct} d_{EV}} = 0 \qquad [6.18]$$

[cf. EPA. 2016]

Wheras:

$CO_{2\_EV\_direct}$ … Sum of direct emissions due to driving an EV

$f_{CO2\_EV\_direct}$ …… Factor showing the released tailpipe CO_2e emissions of an EV

d_{EV} ….. distance, shows travelled amount of EV (miles or km)

However indirect emissions or upstream emissions account with following formula:

$$\boldsymbol{CO_{2-EV-Up}} = \boldsymbol{f_{CO_2\_Grid} E_{total}} \qquad [6.19]$$

[cf. EPA. 2016]

Wheras:

$CO_{2\text{-}EV\text{-}Up}$… Sum of upstream emissions due to generation of electricity

f_{CO2_Grid} ……... Factor that accounts for the released amount of CO_2e for the generation of 1 unit of electricity CO_2e/kWh) at local grid mix

E_{total}….. Electricity amount that is consumed by the EV, all from local grid in this case.

The CO_2e factor for grid electricity depends strongly on the geographic position, since the grid mix(share of different power plants for producing energy) is different among the states of the US. Values range from 0.5 lbs / kWh in Upstate New York (high share of hydropower) to the coal intense Middle West with 1.825 lbs / kWh (For Grid factors [cf. Diem, Quiroz, 2012]. See a full list in the attachment.

Much like the emission factors for grid electricity also solar power has an emission factor. This is important for the scenario where EV's are charged partly with solar power. Depending on how much solar power an electric vehicle consumes for charging (depends on the frequency of driving, and the driving behavior. This is further analyzed in the chapter energy balance), the overall CO_2e emissions can be reduced thanks to the solar charging fraction.

$$\boldsymbol{CO_{2\_EV\_Solar\_Up}} = \boldsymbol{f_{CO_2\_Grid} E_{Grid}} + \boldsymbol{f_{CO_2\_Solar}\, E_{Solar}} \qquad [6.20]$$

With:

$$\boldsymbol{E_{total}} = \boldsymbol{E_{Solar}} + \boldsymbol{E_{Grid}} \qquad [6.21]$$

[cf. EPA. 2016]

Wheras:

$CO_{2\_EV\_Soolar\_Up}$……	Sum of upstream / indirect emissions due to generation of electricity, in this formula electricity derives partly from the grid and partly from a solar power plant.
f_{CO2_Grid}….	Factor that accounts for the emitted amount of CO_2e for the generation of 1 unit of electricity (CO_2e/kWh) at local grid mix
f_{CO2_Solar}…..	Factor that accounts for the released amount of CO_2e for the generation of 1 unit of electricity (CO_2e/kWh) from Solar Power
$E_{\_Grid}$……	Grid share of total energy consumption of the EV
$E_{\_Solar}$ ……	Solar power share for charging of EV, part of total energy consumption of the EV

$E_{\_total}$ Sum of grid share and solar power share, accounts for total energy consumption of the EV

For the use phase analysis only the share of solar power that can be used for charging the vehicles is considered, and not the full production of the solar power plant.
The total CO_2 emissions during the use phase are equal to either [6.19] in case no solar power is used for charging, or [6.20] in chase the EV is partly charged by solar power. This is because the tailpipe emissions are zero and thus [6.18] does not have to be considered.

6.5.2 USE STAGE ADDITIONAL EMISSIONS

Also other emissions can be calculated in the same manner as above mentioned. Following emissions is looked at:

- NOx: Nitrogen Oxides
- SOx: Sulfur Oxides
- PM10: Particulate Matter: Fine particles with a diameter of 10 µm or less
- PM2.5: Particulate Matter: Fine particles with diameters of 2.5 µm or less
- OC: Organic Compounds
- CO: Carbon monoxide
- VOC: Volatile organic Compounds

This emission factors are given in g / mile, and are displayed in the chapter data acquisition.

Since the emission factors are in grams per mile, the following formula [6.22] has to be used for analyzing the emission values of an electric vehicle:

$$\boldsymbol{NOx_{\_EV}} = \boldsymbol{f_{Elec\_NOx} d_{EV}} \qquad [6.22]$$

[cf. EPA. 2016]

Whereas:

$NOx_{\_EV}$……	Sum of NOx emissions due to driving an EV
f_{Elec_NOx} ……	Emission factor for NOx that is emitted due to the local electricity mix.
d_{EV} ….…	distance, shows travelled amount of EV (miles or km).

It works the same way for other emission factors of electricity production. Hence the missions for SOx is a multiplication of the factor for SOx emissions (f_{Elec_SOx}) times the distance of the EV.

For gasoline cars and its emissions following formula is used:

$$\boldsymbol{NOx_{\_ICEV}} = \boldsymbol{f_{Gas\_NOx} d_{ICEV}} \qquad [6.23]$$

[cf. EPA. 2016]

Wheras:

$NOx_{\_ICEV}$ ……	Sum of NOx emissions due to driving an ICEV
f_{Gaso_NOx} ……...	Emission factor for NOx that is emitted with the combustion of gasoline.
d_{ICEV} ….………	Distance, distance, shows travelled amount of EV (miles or km)

6.5.3 LIFE CYCLE CO_2E EMISSIONS

Life cycle analysis looks at the whole life of the vehicle. It does not state the CO_2 emissons per year, but over the full lifetime of 14 years. It also comprises CO_2 emissions that hold account for the manufacturing intensity of both EV's and ICEV's. Furthermore the additional manufacturing of an exchange battery has to be taken consideration of, since 14 years of life is too long for 1 battery pack (at least with current technologies). Finally, as already mentioned in the chapter literature research, there is no decommissioning included of either ICEV’s or EV’s in most common life cycle analyses [cf. Nealer ,Reichmuth ,Anair. 2015] and [cf.Wilson. 2013].

For the third scenario, which is the one that includes solar power in the investigation too, there is a life cycle analysis for a solar power plant included.

For the life cycle analysis the full impact of solar power is considered and not only the share that can be used directly for charging. The next paragraph explains why.

For the use phase analysis only the share of solar power that can be used directly for charging the vehicles was considered, and not the full energy production of the solar power plant. This is because the analysis directly focuses on the individual vehicle cycles and not on the total overall output. In theory the impact of solar power is bigger, if all of the produced energy could be used to minimize the required grid electricity and hence reduce emissions from electricity.

For a life cycle analysis this is ok however to include. If the whole installation (i.e. 10 EV’s plus a solar power plant) is at focus, it does not matter if the solar electricity is used directly or fed into the grid first, the ecologic benefit of green energy is apparent, because the produced solar energy is used no matter what, just at one place or another.

Thus only the absolute amount of produced solar energy and the absolute amount of still necessary grid electricity are of interest for the further ecologic calculation, while for the direct share of solar consumption is decided to be irrelevant for the life cycle assessment.

For the life cycle analysis following further emission factors are relevant:

- fCO_2_EV_production: Shows the CO_2 intensity of production, it includes furthermore the emission intensity of a new battery pack, which will be necessary to change over one full lifetime. Factor is in absolute value, thus CO_2 / Vehicle

- fCO_2_ICEV_production: Shows the CO_2 intensity of producing a conventional car. Factor is in absolute value, thus lbs of CO_2 / vehicle.
- fCO_2_PV_production Shows the CO_2 intensity of producing a solar power plant. Factor is in CO_2 per kWh produced.
- fCO_2_PV_decomissioning Shows the CO_2 intensity for decommissioning a solar power plant. Factor is again in lbs CO_2 / kWh produced.

The chosen emission factors for the program can again be obtained in the chapter data acquisition.

The final lifecycle emissions are presented once in the full emissions over the life time of the vehicles (in metric tons for the full installation over 14 years), as well as in grams per mile driven with the including part for manufacturing (and battery exchange).

The following formula, [**6.24]**, shows the calculation of the full Gasoline Car LCA emissions. Both **[6.16]** and **[6.17]** are required to calculate first.

$$LCA_{\_CO_2-ICEV} = (CO_{2\_ICEV\_direct} + CO_{2\_ICEV\_upstream})t_{LCA} + f_{CO_2-ICEV\_prod}$$

[6.24**]**

[cf. Nealer ,Reichmuth ,Anair. 2015, et al]

Whereas:

$LCA_{-CO2-ICEV}$......	Sum of all Emissions over the Lifetime of an ICEV
$CO_{2\_ICEV\_direct}$......	Yearly direct emissions of an ICEV
$CO_{2\_ICEV\_upstream}$......	Yearly indirect / upstream emissions of an ICEV
t_{LCA}.................	Life time in LCA analysis, t = 14 years

$f_{CO2\_ICEV\_prod}$…… Production factor of manufacturing one unit of a gasoline car. Factor is in lbs CO_2 / vehicle.

For evaluating the full electric vehicle LCA emissions for only grid electricity (NO Solar power). Formula **[6.19]** is necessary to calculate first.

$$LCA_{\_CO_2\_EV} = CO_{2\_EV\_Upstream} t_{LCA} + f_{CO_2 EV\_prod} \qquad [6.25]$$

[cf. Nealer ,Reichmuth ,Anair. 2015, et al]

Whereas:

$LCA_{\_CO2\_EV}$…… Sum of all Emissions over the Lifetime of an EV

$CO_{2\_EV\_Upstream}$… Yearly indirect emissions of an EV (direct emissions are 0.)

t_{LCA}…… Life time in LCA analysis, t = 14 years

$f_{CO2\_EV\_prod}$…… Production factor of manufacturing one unit of an electric car. Includes also the necessary battery exchange after 8 years. Factor is in lbs CO_2 / vehicle.

The following section deals with the calculation of the full electric vehicle LCA emissions for being partly charged by solar power). For this first the LCA emissions of the solar power plant are calculated (including only production and decommissioning factors, because the use factor is already included in the calculation **[6.20]**

$$LCA_{\_PV} = \mathbf{Q_{PV} t_{LCA}} (\mathbf{f_{PV-prod}} + \mathbf{f_{PV-decom}}) \qquad [6.26]$$

[cf. Nealer ,Reichmuth ,Anair. 2015, et al]

Whereas:

$LCA_{\_PV}$….. Sum of all Emissions over the Lifetime of an EV that is partly charged by solar power.

$f_{CO2\_PV\text{-}prod}$…… .Emission factor of manufacturing a solar power- plant. Factor is in lbs of CO_2 per produced kWh.

$f_{CO2\_PV\text{-}Decom}$… Emission factor of decommissioning a solar power plant. Factor is in lbs of CO_2 per produced kWh.

Q_{PV}…… Solar yield per year in kWh to match with the PV- manufacturing and decommissioning factors.

The full electric vehicle LCA emissions for being partly charged by solar power can be seen in the following formula **[6.27].**

$$LCA_{CO_2-EV-Solar} = CO_{2\_EV\_Solar\_Up} t_{LCA} + f_{CO_2 prod} + LCA_{PV} \qquad \textbf{[6.27]}$$

[cf. Nealer ,Reichmuth ,Anair. 2015, et al]

Whereas:

$LCA_{\_CO2\_EV\ Solar}$….. Sum of all Emissions over the Lifetime of an EV that is partly charged by solar power.

$CO_{2\_EV\_Solar\_Up}$……… Yearly indirect emissions of an EV (direct emissions are 0.)

t_{LCA}………… Life time in LCA analysis, t = 14 years

$LCA_{\_PV}$….. Sum of all Emissions over the Lifetime of an EV that is partly charged by solar power.

Since the final LCA is also presented in emissions per km (or mile), each of the 3 above calculated LCA values (3 scenarios) has to be divided by the travelled distance over a lifetime, as visible in equation [6.28].

$$LCA_{\_CO_2-ICEV-mile} = \frac{LCA_{\_CO2\_ICEV}}{d_{year}\, t_{LCA}}$$

$$LCA_{\_CO_2-EV-mile} = \frac{LCA_{\_CO2\_EV}}{d_{year}\, t_{LCA}}$$

$$LCA_{\_CO_2-EV-solar-mile} = \frac{LCA_{\_CO2\_EV\_Solar}}{d_{year}\, t_{LCA}}$$

[6.28]

[cf. Nealer ,Reichmuth ,Anair. 2015, et al]

Whereas:

$LCA_{\_CO2\_ICEV\_mile}$………	Averaged LCA Emissions per mile of an ICEV
$LCA_{\_CO2\_EV\_mile}$………	Averaged LCA Emissions per mile of an EV
$LCA_{\_CO2\_EV\_Solar\_ mile}$…	Averaged LCA Emissions per mile of an EV charged partly by solar power.
$LCA_{\_CO2\_ICEV}$………	Sum of all Emissions over the Lifetime of an ICEV
$LCA_{\_CO2\_EV}$…………	Sum of all Emissions over the Lifetime of an EV
$LCA_{\_CO2\_EV\ Solar}$………	Sum of all Emissions over the Lifetime of an EV, that is charged partly by solar power.
d_{year}…………	Travelled distance per year (miles / year)
t_{LCA}………	Life time in LCA analysis, P = 14 years

6.6 Calculation Financial Feasibility

For comparison of different investments like the purchase 10 gasoline cars versus purchase of 10 electric vehicles versus the purchase of 10 electric vehicles plus solar power installation, it makes sense do to a Net Present Value (NPV) Analysis. In this way different scenarios can be compared with each other.

6.6.1 Net Present Value

The Net Present Value (NPV) is used for capital budgeting. It helps to analyze the profitability of a projected investment or a project. The NPV shows the difference between the present value of cash outflows and the present value of cash inflows [cf. Short, Packey, Daniel, Holt, 1995, et al].

Following formula is used for calculating the NPV:

$$\boldsymbol{NPV = \sum_{t=1}^{t} \frac{C_t}{(1+r)^t} - C_o} \qquad [6.29]$$

[Short, Packey, Daniel, Holt, 1995, p.13]

Whereas:

C_t ……………….net cash inflow during the period t

C_o ……………….total initial investment costs

r …………………hurdle rate

t …………………number time periods or years

For stepwise calculation of the NPV the interior part of the formula can be used to calculate all the present values of each time period.

$$\boldsymbol{Present\ Value = \frac{C_t}{(1+r)^t} - C_o} \qquad [6.30]$$

[Short, Packey, Daniel, Holt, 1995, p.12]

This present values have to be summed up to achieve the final NPV(of a certain time period) [cf. Short, Packey, Daniel, Holt, 1995, p.12].

The time period t is obviously in years for the use of vehicles. It is common to use 14 years for the lifetime of new vehicles, as it can be seen both in the life cycle analysis of Shades of Green [cf. Wilson. 2013, et al] and [cf. Nealer ,Reichmuth ,Anair. 2015, et al].

For the city of Savannah however a maximum time period of 8 years is of interest, because this is the current time of keeping cars in the fleet [cf. interv. Fish, 2016]. This is why both time periods are conducted. One can show the general cost impact over a full vehicle lifetime, and one can show the effect for serving as a city fleet car.

- t= 8 years
- t= 14 years

The hurdle rate is defined to be 3%, which is agreed on by the City of Savannah [cf. interv. Fish, 2016]. The present value of cash inflows and the present value of cash outflows depend on the scenario that is looked at. Financial Scenarios are described in the chapter scenarios.

When the NPV reaches positive values it means that the project's earnings are greater than the investment and accumulated running costs. A project is profitable if the NPV reaches positive levels after a reasonable short amount of time. A NPV with a negative value results in a net loss [cf. Short, Packey, Daniel, Holt, 1995, et al].

For the here conducted investigation a net loss for all scenarios is anticipated, because the purchase of several vehicles, no matter if electric or gasoline cannot reach positive levels. Especially because there are continuously further expenses (maintenance, gasoline price or electricity) and there is no further income expected, except for the earnings in the scenario with solar power feed in tariff.

What is important here is not the point of return of investment (NPV graphs reach 0), but simply the comparison between the different NPV graphs. The NPV line that is the least negative is the most profitable acquisition scenario. If for example the NPV line for the purchase of electric vehicles is higher (less negative value) than the line for purchasing conventional cars, this means that electric vehicles are more feasible.

On basis of the above mentioned formula following Table 3 can be calculated (one for each financial scenario). The here given example is for the purchase of 10 electric vehicles with an additional installation of solar power.

Table 3 Net Present Value Calculation for Electric Vehicle Purchase [Source: own Table]

Year	Investment $	Costs $	Revenue $	Cash Flow $	Present Value $	Accumulated NPV $
0	244230.0	0.0	0.0	-244230.0	-244230.0	-244230.0
1	0	5096.4	1337.2	-3759.2	-3646.4	-247876.4
2	0	5091.3	1327.8	-3763.5	-3537.7	-251414.1
3	0	5086.2	1318.4	-3767.8	-3428.7	-254842.9
4	0	5081.1	1309.0	-3772.2	-3319.5	-258162.4
5	0	5076.0	1299.5	-3776.5	-3210.0	-261372.4
6	0	5070.9	1290.1	-3780.8	-3100.3	-264472.7
7	0	5065.8	1280.7	-3785.1	-2990.3	-267462.9
8	55000.0	5060.7	1271.3	-58789.5	-44680.0	-312142.9
9	0	5055.6	1261.8	-3793.8	-2769.5	-314912.4
10	0	5050.5	1252.4	-3798.1	-2658.7	-317571.1
11	0	5045.4	1243.0	-3802.4	-2547.6	-320118.7
12	0	5040.3	1233.6	-3806.8	-2436.3	-322555.1
13	0	5035.2	1224.1	-3811.1	-2324.8	-324879.9
14	0	5030.1	1214.7	-3815.4	-2212.9	-327092.8

- The first column represents the year of operation. The analysis here is for 14 years.
- The column investment shows the initial investment (=purchase), as well as other investments necessary (=battery exchange after 8 years).
- The column Costs shows the running costs of each year. Due to price developments in electricity this numbers change slightly over the year.
- The column Revenue shows net incomes. At this scenario with solar power, the net income derives from an expected Feed in Tariff for green electricity. Due to degradation the expected net income over the years decreases slightly.
- Next column is Cash flow. It is the sum of the current flows in this year (both expenses and incomes).

- The present value uses the interior part of the above mentioned formula to calculate all the single present value parts, that later on can be accumulated (=summed up to the NPV)
- NPV, accumulation of the single present values (of t). The NPV is calculated here for up to 14 years.

6.6.2 Costs per Mile – Running Costs

A good observation unit is to show the running costs in costs per mile ($cent/mile) or in kilometer ($cent/km). This gives a good idea about how efficient or how expensive it is to run the purchased vehicle.

Fuel costs, maintenance costs, operating costs and insurance costs are the most important factors of running costs [cf. Ehow, 2016].

These values are normally known in costs per year. Thus they can simply be summed up and divided by the yearly amount of traveled miles to reach the costs per mile.

$$C_{per\ mile} = \frac{C_m + C_f + C_o + C_i}{d} \qquad [6.31]$$

[Business Con, 2016 et al]

Whereas:

$C_{per\ mile}$……	Running costs in cost per mile
C_m…………	Maintenance costs per year
C_f …………	Fuel costs per year
C_o…………	Operation costs per year
C_i…………	Insurance costs per year
d …………	traveled distance per year in miles

Since insurance is necessary either way, for ICEV's or EV's, this part is not include in the analysis. Operation costs are thought to be 0 too. However if the car is not purchased but leased this is presented in the operation costs.

Although the costs per mile is a good way of showing the running costs of a vehicle, leaving out the initial investment costs shows only part of the whole picture.

6.6.3 LEVELIZED COST OF GASOLINE

Considering the idea of fluctuating and rising gasoline prices, it is also of interest to show a cost comparison with the method for levelized cost of energy (here gasoline). The question is how expensive has gasoline to become in order to make alternative options (for example the purchase and use of electric vehicles) feasible. For this method the payback time is not the result, but the input [cf. US.-Department of Energy III, 2016, p.5].

For example, if a payback time after 4, 6 or 8 years shall be achieved, what is the necessary price of gasoline to achieve this. The calculation is done in $ per barrel of gasoline (or $/liter). The comparison is done between the scenario of purchasing ICEV's and EV's with grid connection only and another comparison is done between ICEV's and EV's that are partly charged by solar power.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad [6.32]$$

[US.-Department of Energy III, 2016, p.5]

Whereas:

I_t ……………..	Investment expenditures in year t (including financing)
M_t……………	Operations and maintenance expenditures in year t
F_t ……………	Fuel expenditures in year t
E_t …………….	Energy production in year t (in this case energy use)

r……………… Discount rate

n ……………. Life of the system

The similarity to the previously introduced NPV formula is apparent. This is why it is also possible to use goal seek in VBA. The 2 scenarios that shall be evaluated can be to be equal for 4,6 or 8 years, and the variable cell is the gasoline price. VBA then calculates the necessary gasoline price to reach a breakeven point (after 4, 6 or 8 years).

For any of the mentioned cost calculation, it is important to first gather carefully all the required costs, before starting to calculate. This is shown in the chapter data acquisition.

6.7 Sensitivity Analysis Program Structure

The here presented calculation tool characterizes itself with high individualism of input and the attempt of a very holistic approach. Thus this the tool comprises many different fields of investigation, including but not limited to an extensive energy balance on an hourly basis, a profound ecologic impact analysis including not only CO_2e emissions, but also other emitters of EV's and also ICEV's, a life cycle analysis comparison, a well-grounded estimation of driving behavior of the car users, and finally a cost estimation including Net Present Values and Levelized Costs of Electricity.

All this makes the program a very extensive tool. Considering all these different sections it can be apparent that the main focus did not lie into making each of these sectors the most precise to the very last extent. The main approach was to create a holistic tool that covers many different sections of EV's, and to show the overall performance of them. Therefore each section of the analysis is carried out on a good and sufficient level of details.

However where necessary and possible, this complex matter was facilitated. For the awareness of the future tool users, following facilitating steps were done, which may generate following sources for eventual inaccuracies in the tool:

- Charging Process: The charging process of electric vehicles follows the same charging curve as for any other chargeable device (cell phones, notebooks, conventional car batteries and accumulators of all kind. In the here presented calculation tool the charging curve is assumed to be linear instead of following the real charging behavior. The reason for this is simplicity.
- Solar Input: The above presented investigation in solar power is on sufficient details for the here relevant purpose, however it does not claim to be a fully detailed analysis into solar power potential and solar power feasibility for the location of Savannah, Georgia.
- Hourly Investigation: Other encountered software tools for fleet conversion investigation analyze only on a yearly basis, whereas this software analyzes on an hourly basis. Despite the fact that this already a significant higher level of details, the hourly investigation still encounters its limits, most notably:
    - If working hours are not on an hourly interval (example values that might cause inaccuracies: working hours start at 8.30am, lunchbreak is 45 min, work ends on 3.50pm.
    - The charging process can only be portrayed in full hour intervals. Even if for example the battery is fully charged after 20 minutes, the whole hour interval is displayed as charging time in the tool (the real energy consumption however is calculated accordingly to the real time of charging, following as previously mentioned the linear charging curve).
    - Solar data does not change on hourly intervals but constantly. The irradiation value on an hourly basis is only an average (however a sufficient enough for the here seen purpose).
    - Driving Behavior: Not each trip takes exactly one hour. Most of them take shorter time, some might even take more than one hour. In the tool trips are always displayed as one hour long. This means if in one specific hour the car moves (i.e. makes a trip), the charging possibility is disabled for the full hour(regardless of how far thus how long the trip is).

- Driving Behavior: No real driving cycles are used as an input (with 8760 input fields per vehicle of observation this was too bulky for fast investigations. Thus a facilitation method had to be used.
- Driving Behavior: Despite the fact that driving behavior is based on well-grounded information about trip length distribution function, which analyzed for typical car users the probability for a trip to be of a certain distance (see methodology part). The developed algorithm for randomized trip distance values can show inaccuracies. This is because:
  - > The algorithm is based on the information provided by this average trip length distribution function. Starting from this it randomizes values within a certain deviation range to this curve. This deviation is necessary to provide randomized distance values, but it also gives space for errors.
  - > The scientific research was done for average car users and not for city fleet specific uses.
- Default Values: The program includes a default value button to restore initial input values. Despite these values were obtained from literature research, carefully selected and stored into the database, it can still be that some data is inaccurate, because:
  - > The fluctuating nature of input parameters such as gasoline. Always update the tool with latest information before use.
  - > General purchase price changes of EV. There are frequently sales or special offers from local salesmen. A general statement about the purchase price is therefore delicate to state.
  - > Battery replacement costs. Prices for battery replacement are current applicable ones. However if an EV is purchased now the estimated battery exchange would only happen in approximately 8 years, which gives room for further price reductions of the battery system.

> If another location is chosen for the investigation not all the data does apply for it. Carefully change all relevant data to a new location if the analysis is done for another spot.

- Emission Values: Emission values are only for gasoline vehicles in the database for now. This is because the current fleet of Savannah city fleet vehicles, or at least the part that is in consideration for EV – substitution, runs on gasoline. If Diesel vehicles shall be analyzed the emission factor can be changed in the input section.
- Discharge: Although the program provides input for different levels of discharge, depending on the surrounding climate (for cold or hot weather, as well as for night or day use), the program's default value is set to an equal discharge. This is done because:

  > According to Cobb County (Atlanta), the standard US rating for EV's is very accurate to what they experience with their vehicles. The distance between Cobb County and Savannah is with only 400km (248 miles) [cf. Distance Online Tool, 2016] short enough to assume similar climate conditions, and since both institutions use the EV's as city fleet cars also similar driving behavior thus similar levels of discharge can be assumed.

- There is only one set of environmental data included in the calculation tool.

  > Solar data over the course of a year: There is a detailed set of solar data provided for one full year, however not beyond. The life expectancy of a vehicle can be assumed to be up to 14 years, thus significantly longer than the one year spectrum of solar data. However this facilitation can be done without causing high inaccuracies, since both extremes (highest and lowest irradiation are presented).

  > Whether data is also only provided for one full year. However this covers both extremes of hot and cold weather, thus it is sufficient accurate.

7 DATA ACQUISITION

After finalizing the methodology of the program, also the correct input data has to be found in order to make a meaningful calculation. As the program itself is structured in 3 big parts, also the data acquisition is split in energy input, ecology input and cost input. In addition a small section for general data required is added too. The in the following mentioned data function as default values for the program. If the user wants to change them, this is possible in the input sections of the program.

7.1 ENERGY

Required information about energy efficiency for the program, as stated in the chapter methodology, are:

- Fuel efficiency rating: in kWh per mile, or in MPGe, or in miles per kWh
- Maximum Range in miles or km
- Battery Capacity in kWh
- Charging Rate in kW input
- Charging Efficiency in % or in another power value (i.e. input versus output charging power)
- Primary/ Source Energy Factors in kWh primary energy /kWh final energy

If the maximum range and the battery size of a car are given, the fuel efficiency can be calculated by dividing the miles by the battery size.

For obtaining the required information regarding energy performance, there are several reports and platforms existing dealing with the comparison of electric vehicles and their energy values. For example Clean Cities 2016 Vehicle Buyer's Guide [cf. US.-Department of Energy IV, 2016] or Green car reports [cf. Green Car Reports, 2016].

Also many car manufacturers provide relevant information on their homepages, such as the example for different Nissan Leaf models [cf. Nissan USA, 2016]. See also attachment.

7.1.1 Charging Efficiency

The charging efficiency depends on the charging equipment, but also on the energy level of charging and the ambient temperature. Table 4 shows the charging efficiencies for level 1 and level 2 charging for different charging energy amounts [cf. Forward, Glitman, Roberts, 2013 p.9ff]

Table 4 Charging Efficiency of Electric Vehicles, Effect of Energy [Forward, Glitman, Roberts, 2013 p.9]

Charge event dataset	Average Level 2 Charge Efficiency	Average Level 1 Charge Efficiency	Efficiency gain of Level 2 charging
Total combined	86.4 %	83.7 %	2.7 %
High energy only (>2kWh)	86.5 %	84.2 %	2.3 %
Low energy only (<2 kWh)	83.5 %	70.7 %	12.8 %

Table 5 shows the charging efficiencies for level 1 and level 2 charging at different ambient temperatures.

Table 5 Charging Efficiency of Electric Vehicles, Effect of Temperature [Forward, Glitman, Roberts, 2013 p.10]

Charge event dataset	Average Level 2 Charge Efficiency	Average Level 1 Charge Efficiency	Efficiency gain of Level 2 charging
Temperature > 53°F <70°F	86.4 %	83.7 %	2.7 %
Temperature < 53°F	86.5 %	84.2 %	2.3 %
Temperature > 70°F	83.5 %	70.7 %	12.8 %

Considering Table 4 and Table 5 for the further calculation process, a standard value of 85 % charging efficiency is chosen for the Savannah Fleet conversion tool.

7.1.2 Source Energy Factors

The primary or source energy comparison is used to compare the real energy effort and not only the final provided energy (i.e. site vs. source energy). Source energy includes all the relevant steps of conversions and their efficiency values. Thus source energy is a possibility to compare different forms of energy with each other [cf. Ueno, Straube, 2010]. This is necessary because the program intends to compare different forms of energy, electricity and heat energy of the combustion of gasoline, with each other.
Electricity has a higher primary energy factor than gasoline [cf. Deru, Torcellini, 2007, p.6 and p.9], thus it is interesting to compare if EV's show also on primary energy level advantages over gasoline cars.

The used conversion factors are displayed in the Table 6.

Table 6 Source Energy Factors [Deru, Torcellini, 2007, p.6 and p.9]

Program related data			
Type	Amount	Unit	Description
Gasoline Energy Content	33,7	kWh/gal	used for MPGe
Diesel Energy Content	38,656	kJ/l	Energy Content of Diesel
Gasoline Energy Content	27,870	kJ/l	Energy Content of Gasoline
fpe_Diesel	1.158	kWhpe/kWh	Source Energy Factor for Diesel
fpe_Gasoline	1.187	kWhpe/kWh	Source Energy Factor for Gasoline
fpe_Electricity	3.443	kWhpe/kWh	For eastern US grid
fpe_PV	0.122	kWhpe/kWh	For renewable energy

7.2 Ecology

For emissions due to combustion of fuel the Energy Infromation Administration provides a list of various fuel types [cf. EIA VII, 2016]. This list can be found also in the attachment.

As stated before many electric vehicle manufactures provide information about energy efficiency and also ecologic benefits. However about the ecologic impact car manufacturers tend to focus on tank to wheel analysis, because here 0 % emissions can be claimed as the example page of Nissan shows [cf. Nissan Global, 2016] However for a higher level of details the whole process of electricity generation has to be included too. This is however independent from the vehicle manufacturer, and depend merely on the grid ecology of where the vehicle is used.

The research focus therefore is into the local grid emissions of the city of Savannah. Following emission factors are used, using the formulas mentioned in the chapter methodology in order to calculate the ecological impact of EV use.

The Table 7 gives examples about emission factors within zones of the USA. These zones are defined along areas with similar emissions derived from power production (thus similar shares of certain power plant types) [cf. Diem, Quiroz. 2012 p.8].
The zones can be seen in Fig. 38. The region for Georgia is mentioned as SRSO.

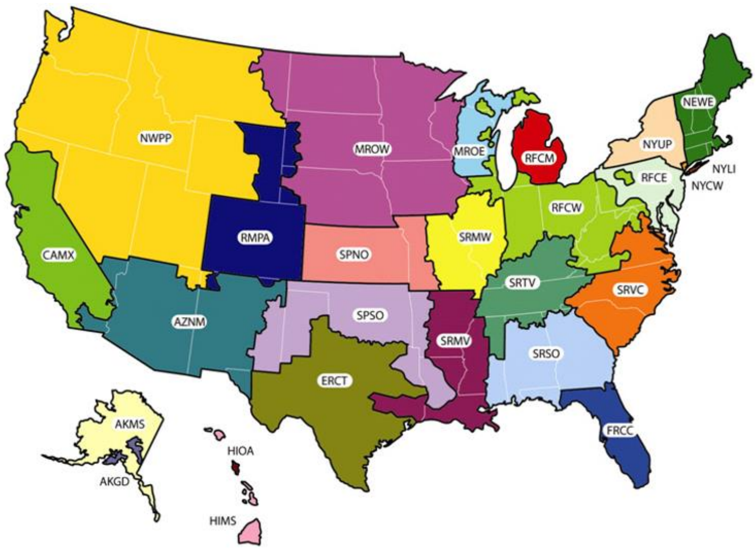


Fig. 38 Grid sections with same split of power plants [Diem, Quiroz 2012. p.8]

A list of some regions and their subsequent emission factors are used in the calculation tool in order to see ecological grid differences, i.e. how ecologic or not ecologic the local electricity grid is compared to other regions. The list in Table 7 is used in the program, the full list of all regions can be found in the attachment.

Table 7 CO_2e emissions for various US locations [Diem, Quiroz,2012 p.11] [NREL, 2012 p.2]

CO_2e Factors		
Type	Amount	Unit
fCO_2mix USA	1.222	lbs/kWh
fCO_2mix Savannah (local grid)	1.333	lbs/kWh
fCO_2mix WestCoast	0.823	lbs/kWh
fCO_2mix MiddleWest	1.825	lbs/kWh
fCO_2NewYork Upstate	0.500	lbs/kWh
fCO_2_Solar Power USE-phase	0.023	lbs/kWh

The emission factors for both local electricity grid and gasoline combustion can be obtained from the Table 8:

Table 8 Emission Values for EV and ICEV [GREET, 2015]

Further Emission factors		
Type	**Amount**	**unit**
fElec_NOx	0.127	g/mi
fGaso_NOx	0.301	g/mi
fElec_SOx	0.377	g/mi
fGaso_SOx	0.159	g/mi
fElec_PM10	0.046	g/mi
fGaso_PM10	0.038	g/mi
fElec_PM2.5	0.016	g/mi
fGaso_PM2.5	0.019	g/mi
fElec_OC	0.003	g/mi
fGaso_OC	0.006	g/mi
fElec_CO	0.053	g/mi
fGaso_CO	2.789	g/mi
fElec_VOC	0.020	g/mi
fGaso_VOC	0.367	g/mi

The next table, Table 9, shows the factors relevant for the life cycle emissions. For vehicles this includes factors for the production stage (and for solar power also in the decommissioning stage). The production of an EV furthermore already includes the necessity of battery pack exchange, which currently has to happen after around 8 years [cf. Nealer, Reichmuth, Anair, 2015 p.16ff], or [cf. Wilson, 2013 p.15ff].

Table 9 CO_2e emission factors for LCA [Nealer, Reichmuth, Anair, 2015 p.16ff] [NREL, 2012 p.2]

CO_2e Factors		
Type	**Amount**	**Unit**
fCO_2_EV_production	20718.0	lbs CO_2eq
fCO_2_ICEV_production	14694.0	lbs CO_2eq
fCO_2_PV_production	0.062	Lbs CO_2eq /kWh
fCO_2_PV_decomissioning	0.035	Lbs CO_2eq /kWh

7.3 Costs

Costs of going into electric transportation originate from different sections. The following list shows the possible cost positions of electric vehicles and for the comparison also the costs of conventional vehicles:

- Initial purchase costs
- OR Leasing costs
- Purchase and installation of charging stations
- Federal Tax Credit
- Other subsidies
- Electricity price
- Gasoline price
- Price Developments
- Battery exchange costs
- Maintenance Costs for EV's
- Maintenance Costs for ICEV's (more moving parts)
- Solar Power purchase and installation costs
- Solar Power incentives (Feed in tariff or normal sales)

7.3.1 COSTS OF EXISTING ICEV

After a meeting with the city fleet management of the city of Savannah , a excel sheet with plenty of key data for parts of their city car fleet (light duty vehicles, those that can be thought of to exchange by electric vehicles) was provided [cf. interv. Fish, 2016]

This list (also possible to observe in the program, 1st input spreadsheet) comprises:

- Vehicle model
- Department of use
- Purchase year
- Fuel economy
- Fuel consumption
- Costs for fuel (historically)
- Maintenance class
- Individual yearly maintenance costs
- Driven miles per year

To get an idea about the price range a part of the list is shown here in Table 10.

Table 10 List of Savannah City Fleet Vehicles and their Characteristics [cf. interv. Heather Fish. 04/13/16]

List of Savannah City Fleet Vehicles subjective to possible change through EVs									
Number	MODEL	Depart-ment	Year in which purchased	Usage [miles /year]	Average Daily Usage	Fuel consumption [gal/year]	Fuel economy [miles/gal]	Purchase Cost	yearly averaged maintenance costs
1	FOCUS	W/DIST	2010	8665	33,3	400	21,7	$ 12.096,00	$ 2.122,96
2	FOCUS	W/DIST	2010	23480	90,3	930,9	25,2	$ 12.096,00	$ 2.241,58
3	FOCUS	TRAFFICEN	2010	1336	5,1	86,2	15,5	$ 12.096,00	$ 263,34
4	FOCUS	DEVELOSER	2010	4567	17,6	92,2	49,5	$ 12.096,00	$ 364,28
5	FOCUS	TRAFFICEN	2010	759	2,9	90,7	8,4	$ 12.096,00	$ 371,27
6	FOCUS	ECONOMIC	2010	1782	6,9	29,3	60,8	$ 12.096,00	$ 479,89

7	FOCUS	W/S DIRECT	2010	4912	18,9	156,7	31,3	$ 12.096,00	$ 383,09
8	FOCUS	RES REFUS	2010	3040	11,7	138,2	22,0	$ 12.096,00	$ 388,00
9	FOCUS	COMM SERV	2011	1282	4,9	82,9	15,5	$ 12.621,00	$ 412,04
10	FOCUS	ACM ADMIN	2011	815	3,1	35,1	23,2	$ 12.621,00	$ 423,53
11	FOCUS	DEVELO SER	2011	1790	6,9	77,1	23,2	$ 12.621,00	$ 291,57
12	CAVALIE R	REAL PROP	2003	4774	18,4	263	18,2	$ 10.599,00	$ 850,00
13	FIESTA	PROP MAIN	2014	6173	23,7	246,7	25,0	$ 14.669,00	$ 1.476,71
14	NEON	ATHLETIC S	2005	936	3,6	33,3	28,1	$ 10.624,00	$ 1.061,46
15	NEON	TOURIS M PA	2005	3768	14,5	229,8	16,4	$ 10.624,00	$ 1.174,52

Thus all the relevant cost factors for ICEV's are given. The only things that are missing are the current gasoline price and leasing costs for conventional vehicles. This is because so far the city of Savannah does not lease but purchase and own vehicles. Both missing price factors are covered in the next chapters.

7.3.2 Purchase Costs of EV

A good source for getting an idea about all different alternative fuel vehicle and their costs is the Vehicles Buyer's Guide, which is published yearly. [cf. US.-Department of Energy IV, 2016].

But there are many car portals in the internet claiming to have the correct and best price for any EV. For a first approach it is surely sufficient accurate. Green car reports and EVObsession are used in addition to the Vehicle Buyer's Guide to find EV purchase prices [cf. Green Car Reports II. 2016] and [cf. EV obsession, 2016].

The Nissan homepage reveals the Nissan Leaf for 29,010$ [cf. Nissan USA III, 2016]. The new arriving Chevy Bolt is expected to be launched at 30,000 $ per unit [cf. Chevrolet II, 2016].

As can be seen in the chapter local availability of EV's it is important for city officials to purchase eventual new electric vehicles locally. This is why, although the calculation tool offers more different electric cars (BMW i3, Audi, etc.), they are not relevant for the analysis for the city of Savannah.

For getting the right local offer the best way is to directly contact a local salesman and ask for offers and discounts.

7.3.3 Federal Tax Credit

An additional aspect while purchasing electric vehicles is that there are federal tax credits available. Also these credits have to be considered in the investigation. According to IRC, the tax credit is applicable for every electric vehicle purchased after December 31, 2009. For getting the full 7,500$, the capacity of the vehicle must be 16 kWh or beyond [cf. IRS, 2016].

A further limitation for the credit is the number of sold cars. It only holds true for cars that have not yet reached a sale number of 200,000 or above [cf. IRS, 2016].

This is why for the further investigation it still makes sense to look both at a scenario with tax credit granted and at one without it.

7.3.4 Leasing Costs

The following chapter shows the comparison in leasing costs of conventional and electrical vehicles.

7.3.4.1 EV Leasing

For getting an offer to lease a vehicle, the best option is to either access the homepage of the manufacturer, or to address directly a local car dealer. See attached a lease offer for a Nissan Leaf. Despite electric vehicles are still mostly more expensive in purchase than their conventional counterparts, the leasing offer for EV's can be very competitive.

This is because the leasing agent is granted the above mentioned federal tax credit for his or her car. And if he or she offers it to be leased the initial price discount also influences the leasing contract positively. This is why the Nissan Leaf can be found in the internet for a lease price of only 200$ per month [cf. Nissan USA III, 2016].

7.3.4.2 ICEV Leasing

The leasing costs for ICEV's can be equally obtained as for EV's. Addressing local salespersons and getting the most accurate offer. Currently often in use in the city fleet are Nissan Versa and Ford Focus [cf. interv. Fish, 2016]. Considering this a Nissan Versa was chosen to use for finding out the leasing costs, because it is from the same company as a Nissan Leaf, which makes it better to compare later on.

7.3.4.3 Comparison of Leasing Options

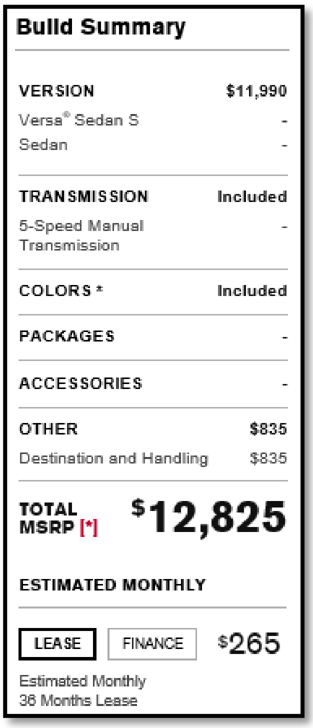


Fig. 40 Purchase and Leasing Cost Nissan Versa [Nissan USA, 2016]

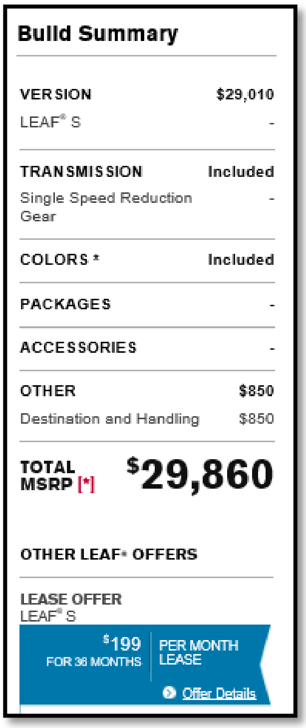


Fig. 39 Purchase and Leasing Cost Nissan Leaf [Nissan USA, 2016]

Fig. 39 shows the purchase and Leasing Costs of a Nissan Leaf, while Fig. 40 shows the purchase and leasing costs of a comparison model, the Nissan Versa.

Nissan Versa has a current purchase price of 11,990 $. The same car is offered to lease with a contract that costs 265 $ / month [cf. Nissan USA IV, 2016].

The Nissan Leaf however has a purchase price of 29,860 $, and it can be leased starting with offers from 199 $ / month [cf. Nissan

USA V, 2016].

Surprisingly, leasing an ICEV is equally expensive as leasing an EV, even though the purchase costs significantly more expensive of the electric vehicle.

7.3.5 Maintenance Costs of Electric Vehicles

Evaluating the real maintenance costs for electric vehicles, it is necessary to make a survey over several years with the electric vehicles already in use. Since this is not possible as there are not yet any EV’s owned, it was the cooperation with Cobb County (county of Atlanta, thus a local partner with similar climate conditions thus similar expected maintenance conditions). According to their fleet manager, the survey of their now 1.5 years old electric vehicles showed that maintenance costs for their EV’s are on an absolute minimum compared to the significantly higher maintenance costs for their gasoline cars [cf interv. Rafay, 2016].

For the survey a 200 $ maintenance costs for EV’s is chosen, which is a very conservative (which means high) value, since Cobb county did not do much more than cleaning and inflating the tires of their EV’s [cf interv. Rafay, 2016].

7.3.6 Charging Equipment Costs

If there is not a level 3 DC charging station required to install, additional purchase and installation costs to equip for EV’s can be kept to a minimum. After a short literature research a charging system for level 1 and level 2 charging is offered for only 399$ per charger for 1 car [cf. Charging Equipment Costs, 2016].

7.3.7 Charging Costs Electricity and Price Development

As in the chapter literature Research already covered, Georgia Power offers various tariffs for customers. For the further investigation following electricity prices are used.

- Standard price: 11.6 $cents/kWh
- Day and Night Tariff:
  - > 0.20 $cents / kWh at peak hours: 10 am until 5pm
  - > and 0.05 $cents / kWh at off peak hours: 5.01 pm until 9.59am

[cf. Georgia Power III, 2016].

This electricity prices are thought to be on a very constant level, looking at the history of prices. EIA actually shows even a decline of 1.5% for Georgia compared to the year 2015.

	June 2016	% change from June 2015
Total net generation *thousand megawatthours*	369,225	1.7%
Residential retail price *cents/kilowatthour*	12.73	-1.5%
Retail sales *thousand megawatthours*	325,562	0.7%
Natural gas consumption *million cubic feet*	1,011,265	9.1%
Coal consumption *thousand tons*	63,384	-8.4%
Cooling Degree-Days	269	5.1%

Source: Electricity Monthly Update

Fig. 41 Electricity Price for Georgia [Energy Information Agency V, 2016]

However due to talks with a Georgia Power representative the information is obtained that this company actually calculates with a slight price rise of 2% [cf. interv. Norman, 2016]. Thus 2 scenarios are carried out, one with constant electricity price and one with a rather steep increase rate:

- Price development 1: - 0.1 % per year
- Price development 2: +2 % per year

7.3.8 Fuel Costs Gasoline and Price Development

As mentioned the last local update for gasoline price was done in July, 20th 2016. The gasoline price was at 2.31$ per gallon [cf. Georgia Gas, 2016].

This is set as default value in the program. However for any further analysis it is recommended to update the program with the current gasoline price.

For the gasoline price trends the survey from the International Energy Agency is used, which predicts 3 different scenarios for fuel price, all of them predict a rise. According to the current available gasoline price, the price development of the IEA is following

- Minimum Gasoline price rise: + 0.8 % per year
- Moderate gasoline price rise: + 2.5 % per year
- Maximum gasoline price rise: + 4.3 % per year

[cf. .EIA III, 2016].

7.3.9 Solar Power Installation Costs and Degradation

For purchasing the solar modules alone around 0.5 to 0.7 $/watt installation size have to be calculated [cf. Sunelec, 2016]. For the whole installation (equipment purchase + installation and initiation) a 3.3$ per Wp can be assumed for residential installations in the USA. For commercial installations the price can be 2.6$ and lower. Utility scale reaches values slightly below 2 $/Wp [cf. NREL. 2012].

These prices were set for 2013, while recent years showed a price reduction of 30$cents per year [cf. Berkley Lab, 2016].

Considering this trend further for a current installation, a 2.3$ per Wp is assumed for an installation in the scale of big residential / small commercial.

Degradation of PV modules are usually be kept below 20% in 20 years. That is a degradation of 1 % per year. Newer modules perform far better than this. Sun power for example claims to achieve with their modules a degradation rate of only 0.25% per year [cf. Sunpower, 2016].

A 0.7% degradation per year can be assumed for this analysis to still be on the safe side.

7.3.10 SOLAR POWER BENEFITS

For the benefits of solar power it strongly depends on what sales options are available.

If there is a feed in tariff (FIT) available: All of the produced electricity is sold to the grid, the net benefit can be used to purchase the required energy for charging back. However it has to be pointed out that this feed in tariff is not granted. It might be that the owner of a PV- system gets the FIT, it might also be that he or she does not.

The second option is that there is no feed in tariff available. The idea then is to use as much of the produced electricity directly for charging the electric vehicles (or the additional office appliances), because if sold to the gird there is no or very revenue generated. Contrary every kWh of electricity that does not have to be bought saves the user the previously mentioned electricity price of 11.6 $cents.

Following price scenarios are available:

- FIT: 17 $cents / kWh, for 5 years. This offer is capped at 4.4 MW of installation size, and is therefore no longer available [cf. EIA VI, 2016].
- FIT: 13 $cents / kWh, for 20 years and small installations sizes below 100 kW. This FIT is also capped at a certain level. Excess capaci-

ty exceeding 45 MW / year installation costs is rolled over to the next year's application process [cf. EIA VI, 2016].

- NO FIT: Normal Sales price at around 5 $cent per kWh [cf. Georgia Power IV, 2016].

However the application alone for a FIT does not grant the applicant to also really get it. There is a lottery system by a 3rd party electing the winners that are than eligible for FIT. In 2013 & 2014 only 10 MW of installation capacity were nominated (Contrary to the original plan of awarding 45 MW / year as stated above). The application fee for the lottery is 25 $, and if won the system must be built within 6 months after the awarded Power Purchase Agreement (PPA) [cf. Georgia Power V, 2016].

Due to this fact for the further analysis it is wise to not only consider an option with a granted FIT, but also one without it (thus normal sales tariff instead).

7.4 General

There are some additional input values required. These are shown in the following chapter.

7.4.1 Solar Data

Solar data as used by the program derive from an analysis in PVSol, as further described in the chapter of Methodology. Considering the local situation (i.e. the roof top area of parking garages), the amount of solar power installation is limited.

Considering the fact, that the solar installation is meant to charge the electric vehicles (at least partly), and that the program is designed to investigate in a maximum of 10 vehicles, a suggested solar power capacity of 10 to 40 kW is suggested.

It is important that these values do not state a 100 % charging fraction. It is a value that leads to relatively high charging fractions with solar energy, while still not producing too much of excess solar electricity (try and error approach with the calculation tool).

Furthermore this is only meant as a guidance value. It depends on the investigation that is thought to carry out which value is finally a reasonable one.

7.4.2 Weather

Also the weather data derives from the program PVSol. Temperature has influence on the calculation process:

- Air condition of both electric vehicles and office load turns on above a certain temperature.
- Energy Consumption of EV’s is slightly higher at cold ambient temperatures.

For the user however this cannot be influenced, unless the whole meteorological dataset in the program is changed

7.4.3 EV – Local Availability

For the investigation locally available vehicles should be preferred, as stated by city officials form city of Savannah. Even though some car manufacturers are not locally present, they were still included in the electric vehicle pool, since for later analyses they might be of interest. The priority however lies on Nissan as a local partner. And on Chevrolet, as soon as they enter the electric vehicle market (expected to happen in 2017 as stated earlier).

7.4.4 Working Time

Although the working time is not equal of every person working for the city of Savannah, most people work at following 3 patterns, according to the city fleet management [cf. interv. Fish, 2016]:

- Standard working hours from 8 am to 5 pm, with a lunch break of one hour at 12pm
- Working hours form 7 am to 4 pm, with 1 hour lunch break.
- Special Work case: 7 am to 3:30 pm, with only half an hour of lunch break and 2 ten minutes breaks.

Either of these values can be used as an input in the calculation tool.

7.5 Values Chosen for the Analysis for the City of Savannah

To provide example information to the city of Savannah, and to be able to prove if the calculation tool works correctly, an example analysis is carried out. This analysis consists of exchanging 10 city fleet gasoline vehicles by 10 electric vehicles.

The chosen city fleet vehicles are chosen randomly and are presented in Table 11, which includes all relevant vehicle data.

Table 11 Chosen Savannah Vehicles for Analysis with Savannah Fleet Conversion Tool [interv. Fish, 2016].

Vehicle #	Model	Department	Purchase Year	Usage [miles/year]	Daily Average [mi/day]	Fuel Economy [mi/gal]	Purchase Cost [$]	Maintenance [$/year]
2	FOCUS	W/DIST	2010	23480	90.3	25.2	12,096	2,241.58
23	FOCUS	UTIL SERVS	2006	13725	52.8	26.1	10,581	813.88
16	FIESTA	UTIL SERVS	2015	11001	42.8	24.1	14,510	488.44
61	FOCUS	PROP MAIN	2009	10409	40.0	27.0	12,571	789.57
22	FOCUS	UTIL SERVS	2006	9845	37.9	46.0	10,581	1185.42
1	FOCUS	W/DIST	2010	8665	33.3	21.7	12,096	2,122.96

24	FO-CUS	UTIL SERVS	2006	8242	31.7	16.5	10,581	1,670.26
19	FIES-TA	DEVELO SER	2015	8360	32.2	26.6	14,510	2,549.05
35	FO-CUS	PROP MAIN	2007	6417	24.7	21.1	10,793	1,797.31
43	FO-CUS	PATROL DIV	2007	5595	21.5	12.9	10,793	1,291.75

These vehicles are compared with 10 electric vehicles. The choice of electric vehicles and their characteristics can be seen in the Table 12 below. The used data for this table is obtained throughout the chapter data acquisition.

Table 12 Choice of Electric Vehicles to Exchange ICEV with [Source: own Table]

#	Model	Battery Capaci-ty [kWh]	max range [miles]	Pur-chase Cost [$]	Bat-tery Cost [$]	Leas-ing Cost [$/Month]	Maintenance Cost [$/year]	Stan-dard Char-ging [kW]	Driving Behavior 1: Con-stant route?	Driving Behavior 2: Day charging enabling?
1	Nissan Leaf	30	107	34,200	5,500	249.0	200.0	6.60	x	x
2	Nissan Leaf	30	107	34,200	5,500	249.0	200.0	6.60	x	
3	Nissan Leaf	30	107	34,200	5,500	249.0	200.0	6.60		x
4	Nissan Leaf	30	107	34,200	5,500	249.0	200.0	6.60		
5	Nissan Leaf	30	107	34,200	5,500	249.0	200.0	6.60		x
6	Nissan Leaf	24	84	29,860	5,500	249.0	200.0	6.60	x	
7	Nissan Leaf	24	84	29,860	5,500	249.0	200.0	6.60	x	x
8	Nissan Leaf	24	84	29,860	5,500	249.0	200.0	6.60	x	
9	Nissan Leaf	24	84	29,860	5,500	249.0	200.0	6.60		x
10	Nissan Leaf	24	84	29,860	5,500	249.0	200.0	6.60		

As it can be seen, for electric vehicles only Nissan Leafs are chosen. This was done because Nissan is a local partner, as mentioned in the chapter data acquisition. However for later use the user is free to choose other electric vehicles as well and compare.

Both a 24 kWh and a 30 kWh Nissan Leaf version is included in the analysis, depending on the daily distance that has to be covered (See the Table 11 of conventional cars). The further specifications of the used Nissan Leaf can be obtained from the attachment.

Table 12 also shows the choices of driving behavior. Also this input was done randomly now, just to show results. For a future investigation, the cars that shall be exchanged should be combined with their real driving behavior.

A small solar power plant of 10 kWp, 0° azimuth, 28° elevation, with a yearly yield of 14,933 kWh (see PV Sol attachment), is chosen for the solar power scenarios.

Standard working hours are assumed (8am to 5 pm).

The main input data used in the program is mentioned here. The further used input data can be obtained from the attachment.

This information is used in the calculation tool to evaluate the results, using the different designed feasibility scenarios for a broad calculation. The designed scenarios can be seen in the next chapter Feasibility Scenarios for City of Savannah.

8 Feasibility Scenarios for City of Savannah

In the previous chapter of methodology it is seen that there are 3 different scenarios regarding energy efficiency and ecologic impacts. Considering financial aspects, these 3 main scenarios can be further split in different options. This is necessary, because there are different ways of financing, what electricity contract to use, there is the uncertainty of getting the federal tax credit or not, if a solar power plant is installed it could be that it is with or without federal tax credit, the energy prices both for electricity and for gasoline can develop differently, etc.

This chapter does not present any sources or data for the scenarios, because this is done in the previous chapter data acquisition.

The ecology scenarios, once again, are:

- SCN_ICEV The impact of ICEV's
- SCN_EV - Grid The impact of EV's charged with grid electricity only
- SCN_EV - Solar The impact of EV's charged partly by solar power

8.1 Main Financial Scenarios

On basis of these three main ecologic scenarios three main scenarios regarding financial feasibility are carried out. The following list shows the main scenarios:

- SCN_ICEV --- ICEV Purchase, moderate gasoline price development

The first main scenario is the comparison scenario. This scenario assesses the costs of conventional cars instead of electric vehicles. This makes it possible to compare the financial situation of electric vehicles with the one of conventional cars.

For this scenario the current gasoline price is the start value. From there a moderate price development is assumed, according to the EIA forecasts mentioned in the chapter data acquisition.

- SCN_EV - Grid --- EV Purchase, With Tax Credit, NO solar

The second scenario shows the benefits of electric vehicles when only charged with grid electricity. A Federal Tax credit is assumed furthermore. EV's are assumed to be purchased not leased. A federal tax credit is present.

- SCN_EV - Solar --- EV Purchase, With Tax Credit, Solar FIT

The third main scenario shows the benefits of electric cars when charged partly by solar power in addition to the grid supply. EV's are assumed to be purchased not leased. A federal tax credit is present. Furthermore a feed in tariff is assumed to be available.

8.2 Additional Financial Scenarios

Contrary to energy values or ecological factors, which stay the same, the financial aspects of electric vehicles implementation are more unsteady (firstly gasoline price, but also electricity price, price developments, eligibility for a FIT or not, etc.).

This is why in addition to the main three financial scenarios mentioned before, more cost scenarios are conducted (based on either one of the three ecologic base scenarios). This is done in order to cover a higher range of possibilities or chances in the initial financial situation. Following further scenarios are covered in the calculation tool.

8.2.1 ICEV based scenarios

Each of the following scenarios is based on the ICEV main scenario from the ecologic analysis.

- SCN_ICEV --- ICEV Purchase, low gasoline price development

This scenario is similar to the base scenario of conventional cars. The difference is that instead of a moderate gasoline price rise a lower one is assumed

- SCN_ICEV --- ICEV Purchase, high gasoline price development

This scenario is similar to the base scenario of conventional cars. The difference is that a step gasoline price rise is expected in this scenario.

- SCN_ICEV --- ICEV Lease, moderate gasoline price development

The same price expectations as in the main scenario for gasoline cars. However instead of purchasing cars, this scenario analyses the leasing option for conventional cars.

- SCN_ICEV --- ICEV Lease, low gasoline price development

This scenario presents the low gasoline price rise scenario for leasing of conventional cars.

- SCN_ICEV --- ICEV Lease, high gasoline price development

This scenario presents the high gasoline price rise scenario for leasing of conventional cars.

8.2.2 EV – Grid based scenarios

Each of the following scenarios is based on the EV grid scenario from the ecologic analysis.

- SCN_EV - Grid --- EV Purchase, NO Tax Credit, NO Solar

This scenario is similar to the main scenario of electric vehicle purchase without solar power installation. The difference is that in this scenario the federal tax credit is not granted.

- SCN_EV - Grid --- EV Purchase, With Tax Credit, NO Solar, Night Electricity Contract

This EV – purchase scenario analyses the impact of a different electricity contract. it is based on Off- and On-peak times with different sales prices. Furthermore this scenario assumes like before to get the federal tax credit.

- SCN_EV - Grid --- EV Lease, NO Solar

This scenario analyses the impact of leasing electric vehicles instead of buying them. No federal tax credit is apparent here, however it is already, at least to a certain extent, included in the leasing offer.

- SCN_EV - Grid --- EV Lease, NO Solar, Night Electricity Contract

Another scenario of leasing electric vehicles, however this time with the on- off- peak electricity price.

8.2.3 EV –Solar based scenarios

The following two scenarios are based on the main EV scenario with additional solar power for charging.

- SCN_EV - Solar --- EV Purchase, With Tax Credit, Solar Own Use, NO FIT

This scenario is similar to the EV – purchase plus solar power scenario. The difference is that this scenario assumes that no feed in tariff is available and solar power can only be sold to very cheap sales prices. For this scenario the own consumption of electricity is the most important. A federal tax credit is assumed to be eligible.

- SCN_EV - Solar --- EV Purchase, NO Tax Credit, Solar FIT

This scenario is similar to the EV – purchase plus solar power scenario. The difference is that this scenario assumes that no federal tax credit is available. Feed in tariff is again available in this scenario.

9 RESULTS

The chapter Results is divided in two main sections. Section one is the analysis for the electric vehicle implementation at the City of Savannah with the input data mentioned in the chapters Data Acquisition and Feasibility Scenarios for City of Savannah. The second part is a sensitivity analysis of the obtained results with other fleet conversion tools.

9.1 ELECTRIC VEHICLE IMPLEMENTATION AT CITY OF SAVANNAH

The results for the City of Savannah Analysis are ordered in three output sections, energy impact, ecologic impact and financial feasibility. For both energy impact and ecologic impact the three mentioned main scenarios are analyzed, which, are:

- SCN_ICEV The impact of ICEV's
- SCN_EV - Grid The impact of EV's charged with grid electricity only
- SCN_EV - Solar The impact of EV's charged partly by solar power

For each of these scenarios 10 vehicles are analyzed and compared respectively with their counterparts of the other two scenarios. The three vehicles that are directly compared with each o (one of each scenario) there are also called cycle in the following. Since 10 vehicles of each scenario are calculated 10 cycles exist.

9.1.1 ENERGY IMPACT

The Fig. 41shows the yearly primary energy consumption of gasoline cars and electric vehicles charged by grid or partly solar.

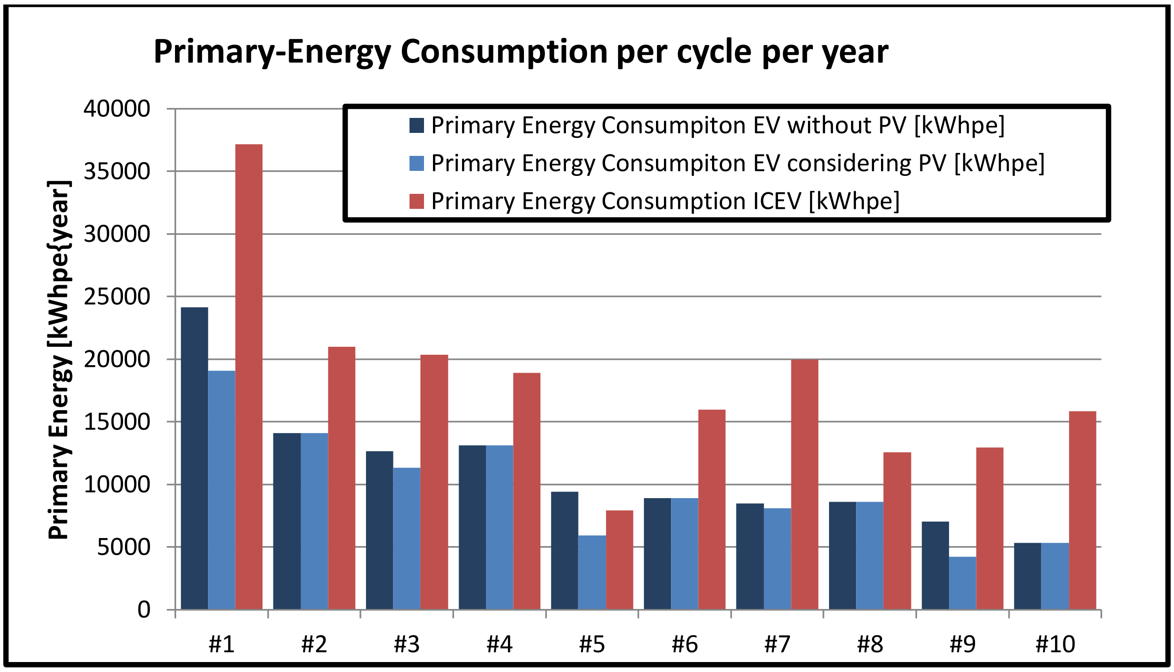


Fig. 42 Primary Energy Consumption of EV's and ICEV's [Source: own Figure]

Number #1 to number #10 represent the cycle number. Each cycle compares three vehicles, each from another scenario. The colors in the diagram represent the different scenarios.

- SCN_ICEV: Red
- SCN_EV – Grid: Dark Blue
- SCN_EV - Solar : Bright Blue

The diagram shows that the red column is always the highest, only in cycle #5 the dark blue column is slightly higher.

The diagram furthermore shows that the bright blue column varies between almost equal to the dark blue one to significantly lower.

The Fig. 43 shows the efficiency of electric vehicles compare the conventional vehicles in the analysis. The efficiency comparison is done in miles per gallons or miles per gallon equivalents.

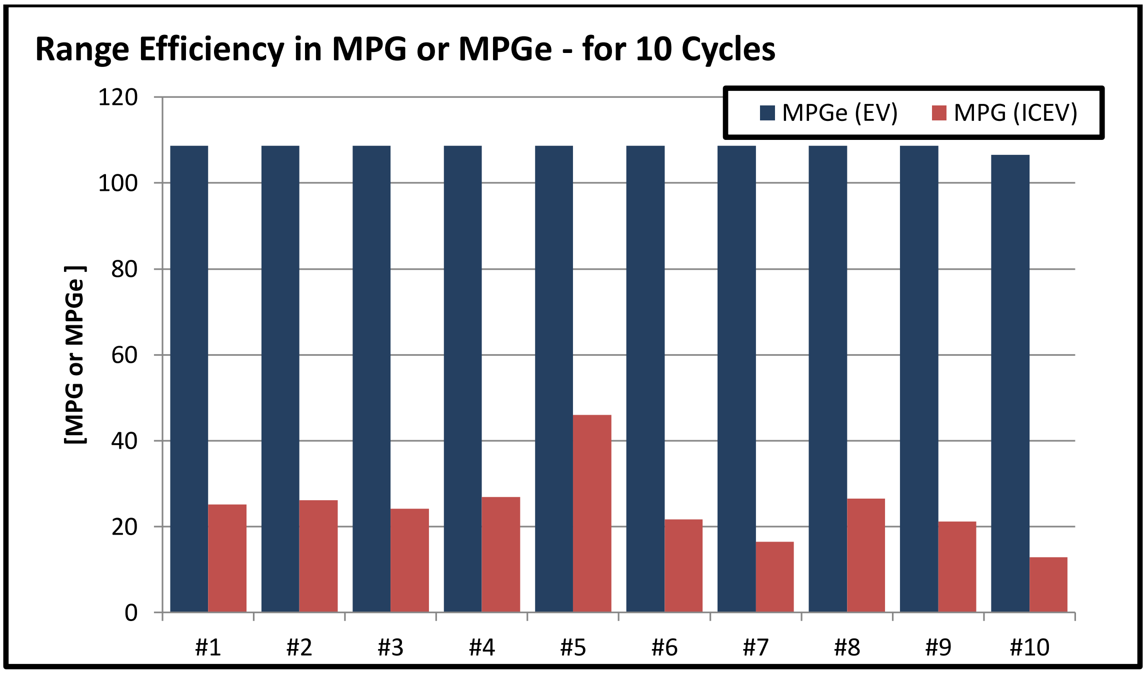


Fig. 43 Range Efficiency of EV's and ICEV's [Source: own Figure]

Number #1 to number #10 represent again the cycles of comparison. Electric vehicles that are charged partly by solar power are excluded from this Fig. 43.

- SCN_ICEV: Red
- SCN_EV – Grid: Dark Blue
- SCN_EV - Solar : N/A

The dark columns represent a theoretical distance of above 100 miles with one theoretical gallon, while conventional cars tend to have efficiency values of 10 to 25 miles per gallon. Cycle #5 presents again an exception where the efficiency of the gasoline car is with almost 50 MPG significantly higher.

The Fig. 44 shows the solar energy use of the production side. This means of all the produced energy, how much can be used directly or charging, how much has to be fed into the grid, how much can be used for additional appliances (such as office air condition or garage illumination, etc.).

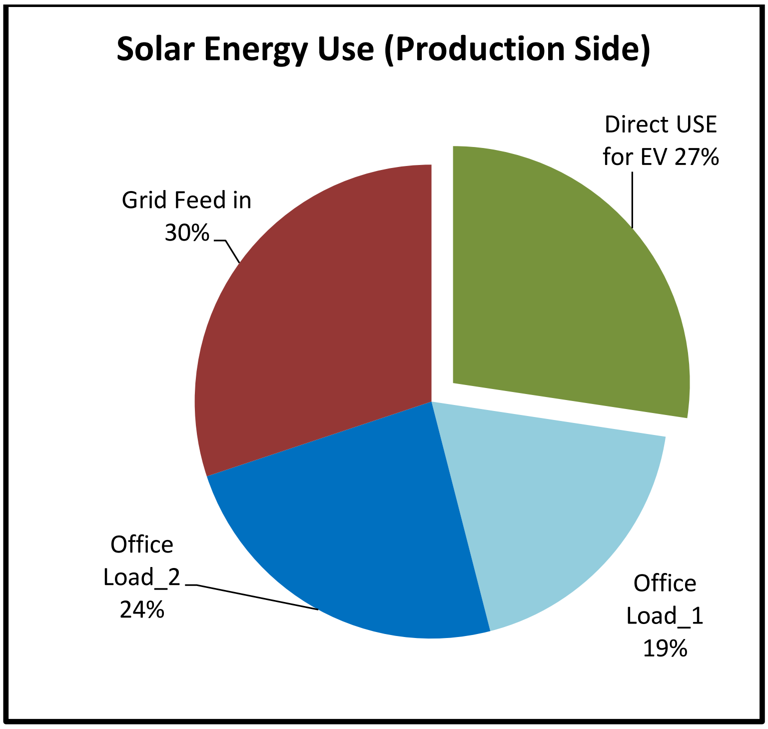


Fig. 44 Solar Energy Use Fraction (Production Side) [Source: Own Figure]

This Fig. 44 is done not for a single cylce or car but for the whole installation (thus 10 electric cars).

- Solar energy share for charging electric vehicles: Green
- Solar energy share for Office Load 1, Air Condition: Bright Blue
- Solar energy share for Office Load 2, Lighting: Dark Blue
- Excessive solar energy, that cannot be used: Red

The share for electric vehicle with 27 % means that 27 % of all the produced solar power can be used in the charging process. The rest of the energy is available at times where there is no charging process going on, thus it cannot be used.

The Fig. 44 shows further that although the included solar power installation with only 10 kWp is relatively small there is excess energy that cannot be used. If the solar power installation size is bigger, than the excessive energy share rises accordingly.

Fig. 45 shows the solar energy use at the load side. This means how much of all the required energy for charging and office appliances can be covered directly by solar power.

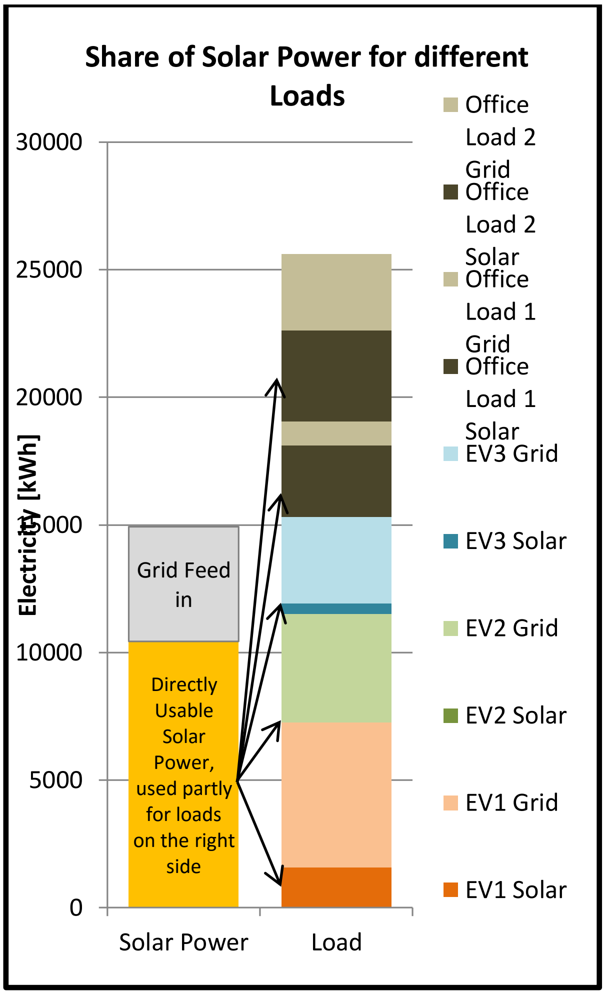


Fig. 45 Solar Energy Use Fraction (Load Side) [Source: Own Figure]

The right column represents the produced solar energy, which is separated into the part that can be directly used and the excessive part. The right column represents all the loads (i.e. electric vehicle 1 charging, electric vehicle 2 charging, electric vehicle 3 charging, office loads, etc.). The bright parts represent all the electricity that has to be covered by the grid. Only the dark sections can be covered by solar energy.

9.1.2 Ecologic Impact

The ecologic impact is divided into CO_2e emissions, other emissions and a life cycle analysis.

9.1.2.1 CO_2e Emissions

The Fig. 46 shows the yearly CO_2e emissions of either the refinement and combustion of gasoline or the emissions of electricity production. The three main scenarios are shown.

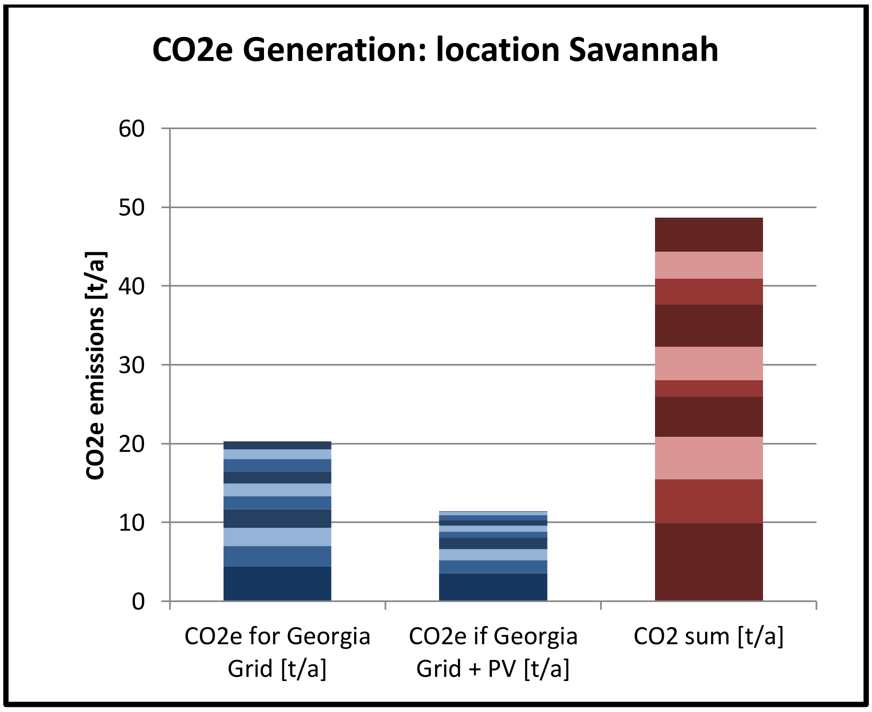


Fig. 46 CO_2e emissions of 3 main scenarios [Source: Own Figure]

This diagram shows the total output of the scenario (10 vehicles combined) and not the individual one like in the energy section. However the slight variation in colors in all three columns shows the different vehicles. The main focus here is however on the absolute height of these three columns, which are defined:

- SCN_EV – Grid: Blue tones, represented in the first column
- SCN_EV - Solar: Blue tones, represented in the second column
- SCN_ICEV: Red tones, represented in the third column

The Fig. 46 CO_2e emissions of 3 main scenarios [Source: Own Figure] shows that CO_2 emissions from gasoline vehicles are always higher than from electric vehicles, regardless if charged with solar power or not. Solar power shows a further ecologic benefit in the use stage.

For further interest the location Savannah can be compared with other locations in the United States. The comparison shows the ecological level of the respective grid.

Fig. 47 shows the CO_2 emissions of 10 electric vehicles over a year for different geographic positions and compares them with the emissions of 10 gasoline cars.

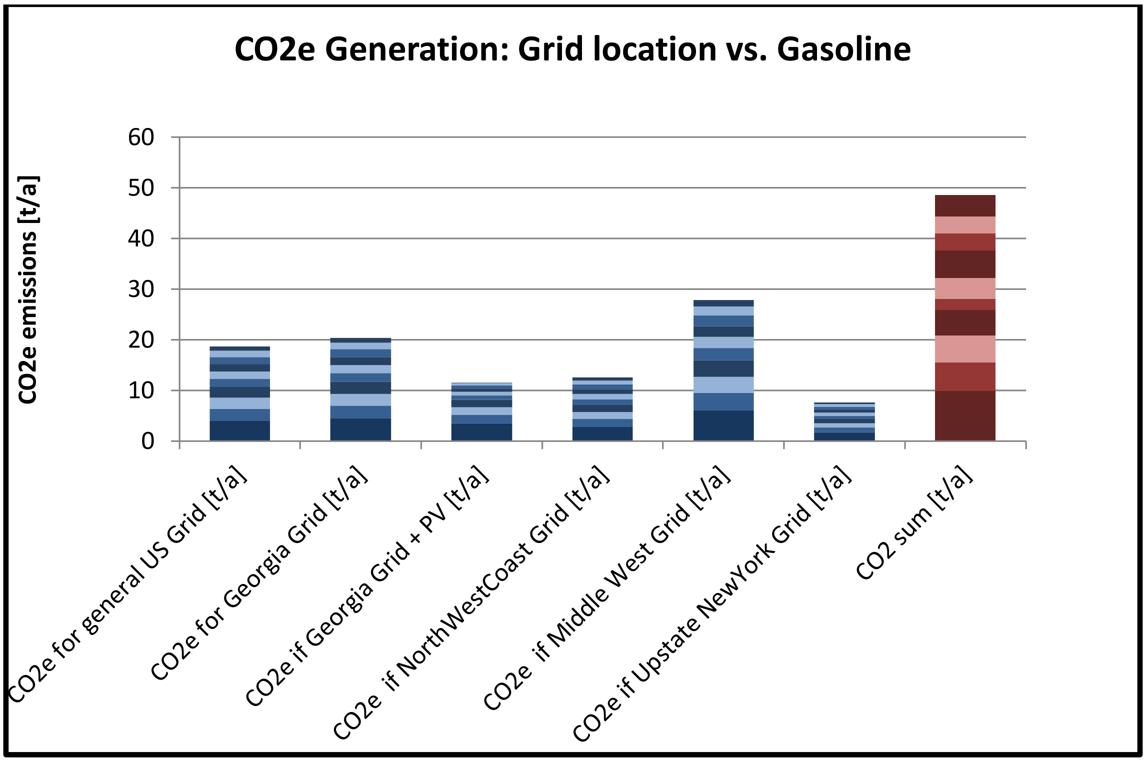


Fig. 47 Level of CO_2e emissions of different grid zones [Source: Own Figure]

The following locations are observed.

- Column 1: General US – Grid
- Column 2: Georgia Grid for comparison
- Column 3: Georgia grid with solar share, for comparison
- Column 4: Northwest coast of the USA.
- Column 5: Middle West area of the USA.
- Column 6: Upstate New York area of the USA.
- Column 7: Gasoline cars as a comparison.

The local grid of Georgia is not the most ecological one, however there are also worse zones in the USA existing. None of the analyzed regions in the US – grid reaches emission values of gasoline cars.

9.1.2.2 Further Emissions

Fig. 48 shows a comparison of further emissions between gasoline cars and electric vehicles. Emissions are emitted either by the electricity production or by the gasoline combustions. The comparison is done on the level of one average car (averaged by the 10 vehicles of each type).

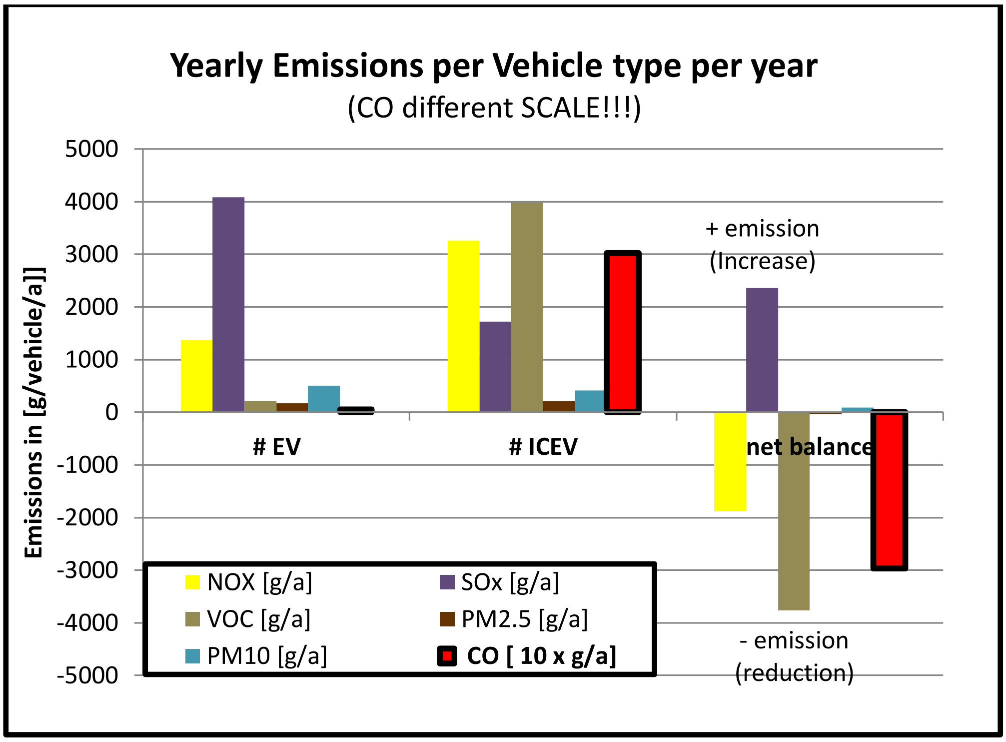


Fig. 48 Additional Emissions of EV's and ICEV's [Source: own Figure]

Please note: while NOX, VOC, SOX, PM2.5 and PM10 is in grams per vehicle and year, the CO emissions of gasoline vehicles are higher by the factor of 10. For the sake of comparison they were reduced by the factor of 10.

The comparison shows a significant reduction of NOX emissions, VOC emissions and CO emissions. The amount of particles is relatively constant and SOx values are increasing with electric vehicles.

9.1.2.3 Life Cycle CO_2 Emissions

Fig. 49 shows a life cycle comparison of CO_2 emissions in tons between the three scenarios. Included is manufacturing emissions, battery exchange emissions, emissions during the use phase, both direct emissions and indirect / upstream, and decommissioning emissions (however the last one only for the solar power plant). The use phase / life time is 14 years, as mentioned in the chapter methodology.

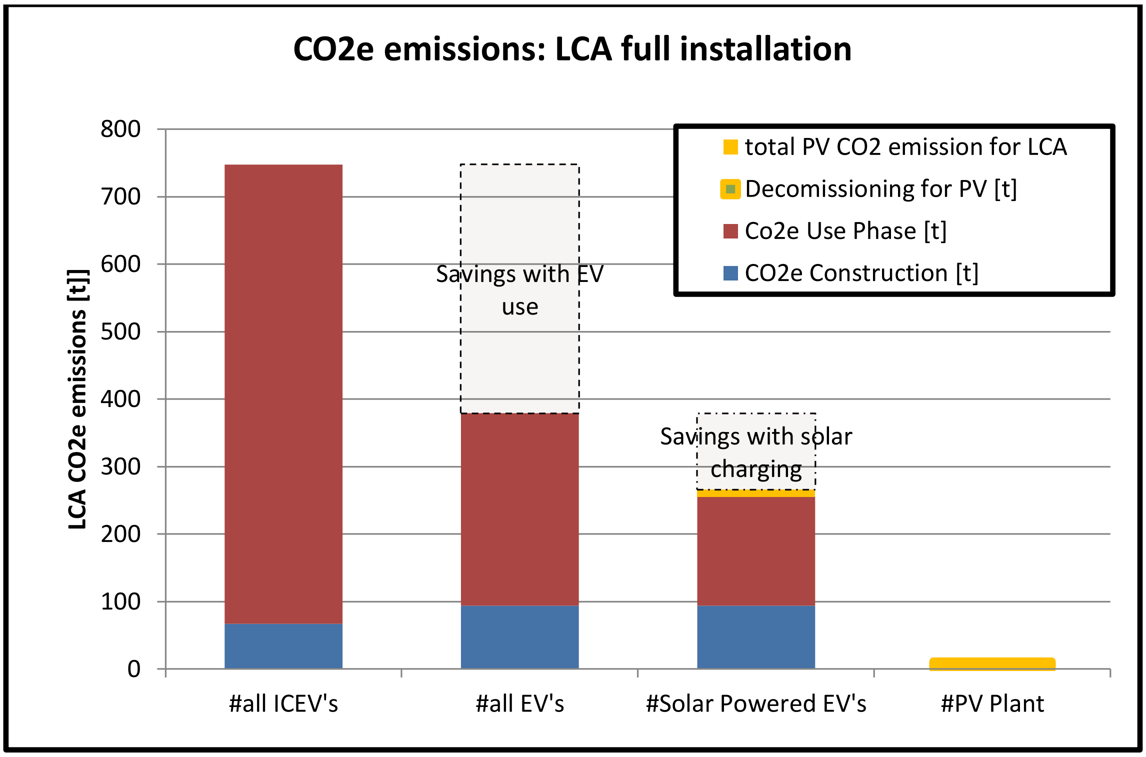


Fig. 49 CO_2e emissions: LCA full installation [Source: own Figure]

- SCN_ICEV: Is presented in the first column. It shows the life cycle emissions of 10 gasoline cars. The blue area shows the manufacturing emissions. Red is the amount of emissions during the lifetime.
- SCN_EV – Grid: Is presented in the column 2. The blue area shows the in tensity of manufacturing and the battery exchange after 8 year. The red emissions are indirect emisisons over the life
- SCN_EV - Solar: Is represented in the third column. It shows the additional benefits of solar power, even though the solar power installation, use and decomission emits additional CO_2.

The fourth column shows the CO_2 intensity of the solar power plant over its lifetime.

Fig. 50 shows again a life cycle comparison of CO_2. This time the comparison is in CO_2 emissions per driven mile. The before seen advantages from the Fig. 51 stay the same in this analysis method.

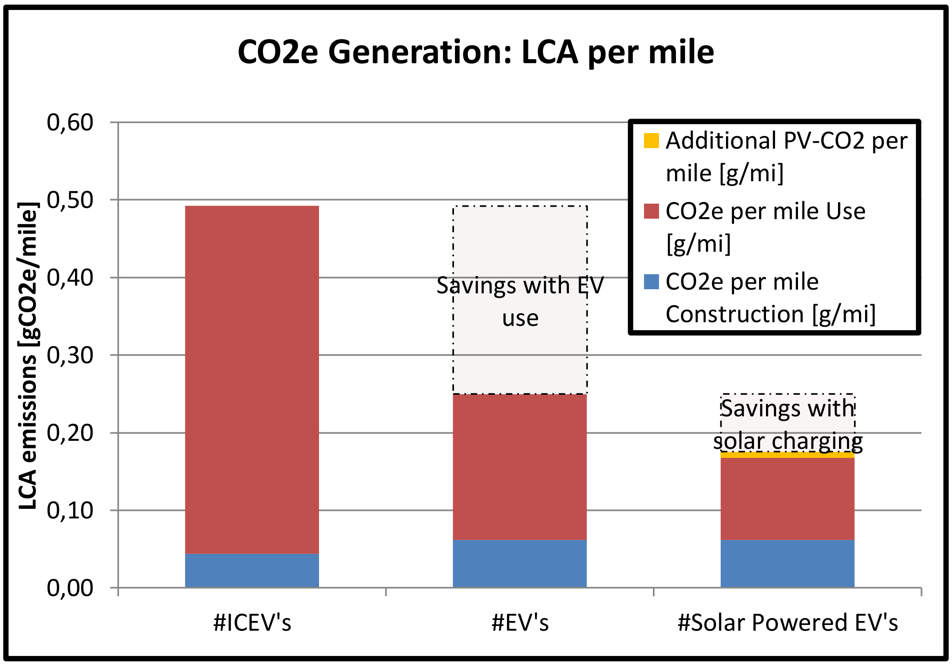


Fig. 50 CO_2e emissions: LCA per mile [Source: own Figure]

9.1.3 Financial Feasibiliy

For the chapter of financial feasibility there are more scenarios than the above mentioned three main scenarios. Thus figures and diagrams will show more than only 3 columns or lines.

9.1.3.1 Running Costs

The following Fig. 51 shows running costs for different financial scenarios. The low blue columns are all those scenarios with EV – purchase. The high blue columns represent EV leasing. The difference in running costs is big because the leasing price is included into the running costs. The red columns represent ICEV, the first is purchase scenario and the second red column is leasing of an ICEV.

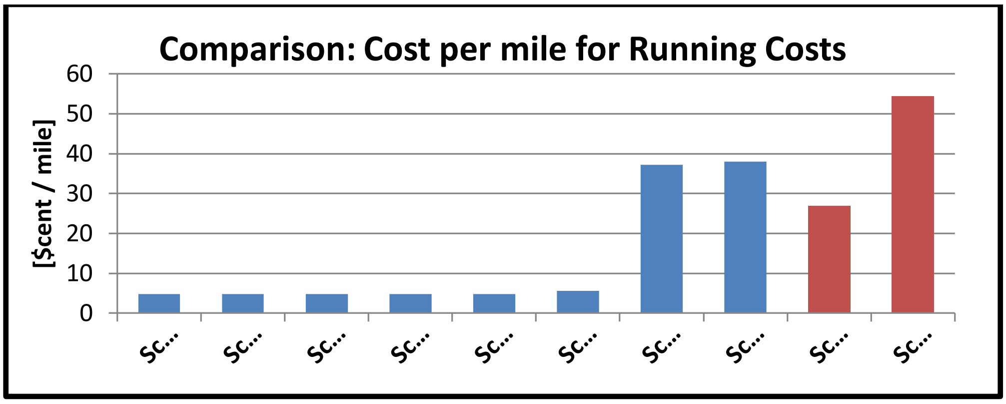


Fig. 51 Running Costs of Various Scenarios [Source: own Figure]

The running costs however show only one part of the full expenses. A Net Present Value analysis manages to cover and show better the real financial effort. NPV analyses are shown in the next chapters.

9.1.3.2 Net Present Value

The Fig. 52 shows the net present value calculation for several financial scenarios. The NPV analysis was done for 14 years, because this can be expected to be the vehicle life.

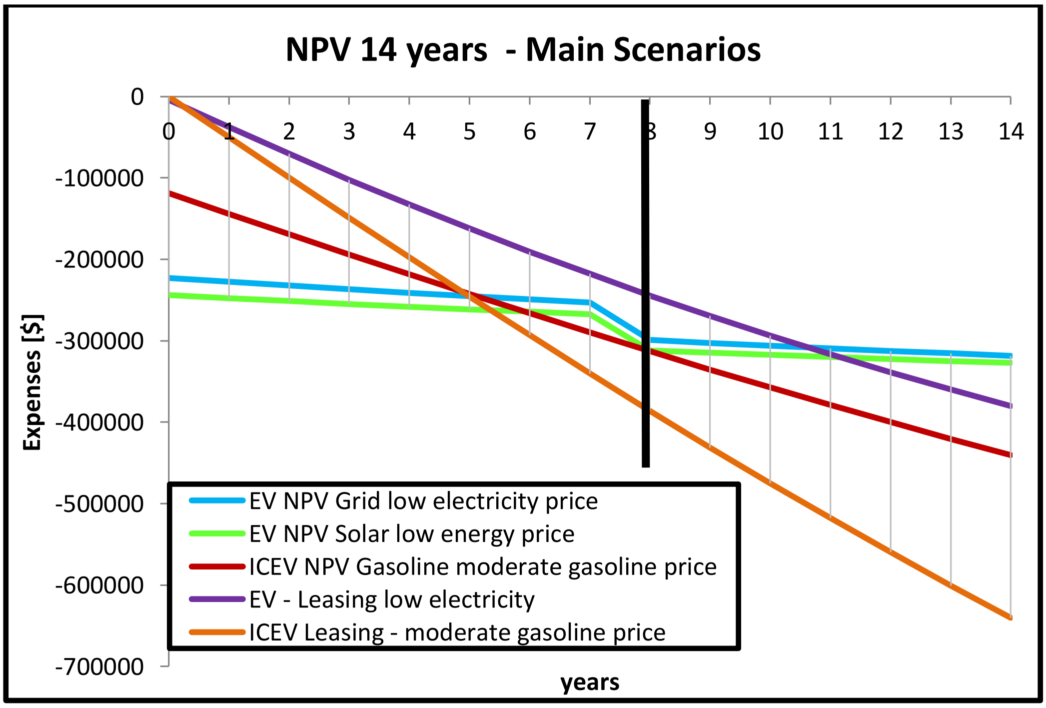


Fig. 52 NPV Analysis for 14 years [Source: own Figure]

Following scenarios are shown in this NPV chart.

SCN_ICEV --- Purchase, moderate price development	Red line
SCN_EV - Grid --- Purchase, With Tax Credit, NO solar	Blue Line
SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT	Green Line
SCN_ICEV --- Lease, moderate price development	Orange Line
SCN_EV - Grid --- Lease, NO Solar	Purple Line

It is good visible that after 8 years there is a battery exchange necessary for those scenarios that purchased EV's (drop in the green and blue line).

However 14 years is too long for financial considerations. This is why the following NPV charts will only be shown for 8 years.

The next NPV shows the close up for 8 year, for the main purchase scenarios and for leasing options. See Fig. 53.

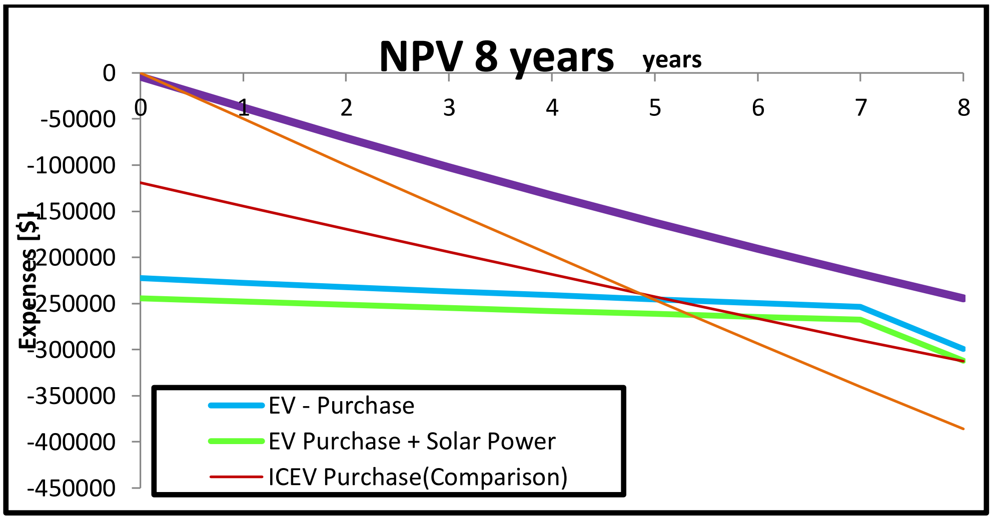


Fig. 53 NPV Analysis for 8 years [Source: own Figure]

With following scenarios are present.

SCN_ICEV --- Purchase	Red line
SCN_EV – Grid ---Purchase	Blue line

- SCN_EV – Solar ---Purchase — Green line
- SCN_ICEV --- Lease, moderate price development — Orange Line
- SCN_EV - Grid --- Lease, NO Solar — Purple Line

The blue line meets the red line after approximately 5 years. This means after 5 years electric vehicle purchase shows financial advantage over conventional car purchase. The scenario with solar power needs 6 years to break even with the gasoline scenario.

However due to the necessary battery exchange after 8 years the present value after 8 years is very similar again between the EV purchase scenario and the ICEV purchase scenario.

Looking at the orange line, which represents the leasing of conventional cars, it is apparent that it falls steeply. Because of the high running costs and the additional leasing effort. It can be stated that leasing ICEV's is financially the worst option.

However when looking at the purple line, which represents the leasing of 10 electric vehicles, the outcome looks very different. Thanks to good leasing offers and very low running costs the leasing of electric vehicles is proofed to be very feasible (it never touches any gasoline scenario line, and only reaches the purchase scenario of electric vehicles after 11 years).

9.1.3.3 Sensitivity Analysis for Federal Tax Credit

This chapter deals with the sensitivity analysis of financial input parameters.

The Fig. 54 shows the impact of the federal tax credit.

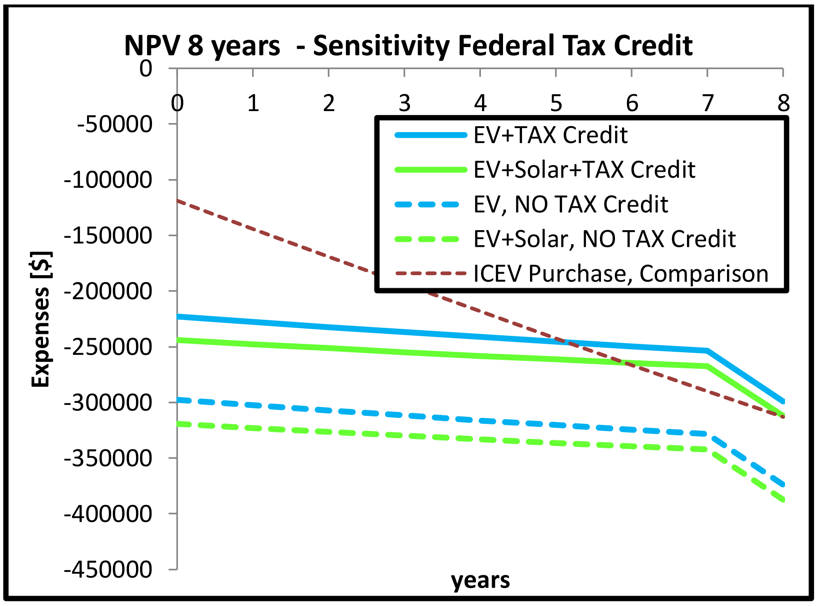


Fig. 54 Sensitivity Federal Tax Credit - NPV [Source: own Figure]

With following scenarios are present.

- SCN_EV - Grid --- Purchase, With Tax Credit, NO solar — blue line
- SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT — green line
- SCN_EV - Grid --- Purchase, NO Tax Credit, NO Solar — blue dotted
- SCN_EV - Solar --- Purchase, NO Tax Credit, Solar FIT — green dotted

And for comparison purposes:

- SCN_ICEV --- Purchase, low price development — red dotted

The scenarios without the federal tax credit granted have never a higher present value than the ICEV comparison scenario. This This shows the importance of the federal tax credit. Without it and under consideration of current market prices an electric vehicle is not feasible in the USA.

9.1.3.4 Sensitivity Analysis for Solar Power Feed in Tariff

The following Fig. 55 shows the impact of a feed in tariffs on solar power installations.

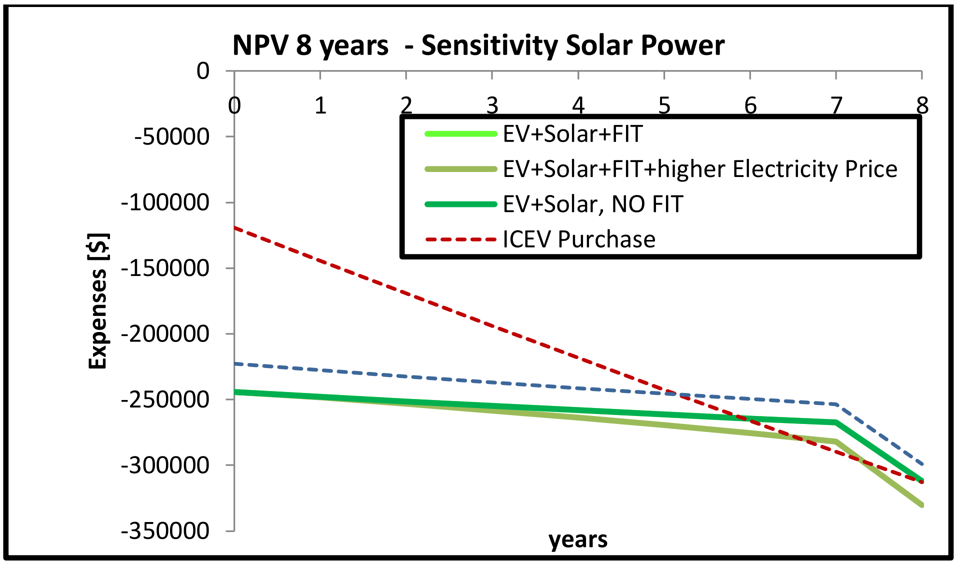


Fig. 55 Sensitivity Solar Feed in Tariff - NPV [Source: own Figure]

With following scenarios are present.

- SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT — bright green
- SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT , high electricity — gray green
- SCN_EV - Solar --- Purchase, With Tax Credit, Solar Own Use, NO FIT — green line

And for comparison purposes

- SCN_EV - Grid --- Purchase, With Tax Credit, NO solar — blue line
- SCN_ICEV --- Purchase, low price development — red dotted

It can be seen that none of the scenarios with solar power included can reach the curve of the SCN_EV – Grid Purchase (blue dotted line). Thus solar power implementation is financially not of interest (however ecologically it is).

9.1.3.5 Sensitivity Analysis for Night Electricity Tariff

This Fig. 56 shows the impact of different electricity purchase tariffs. Namely it compares the normal tariff with a night tariff (i.e. on-off peak time tariff).

While in the normal tariff the electricity is on a constant level, the on- off- peak tariff sells it for different prices, depending on the time. Following Fig. 56shows the price difference of electric vehicles charged with standard tariff and those charged with the night tariff.

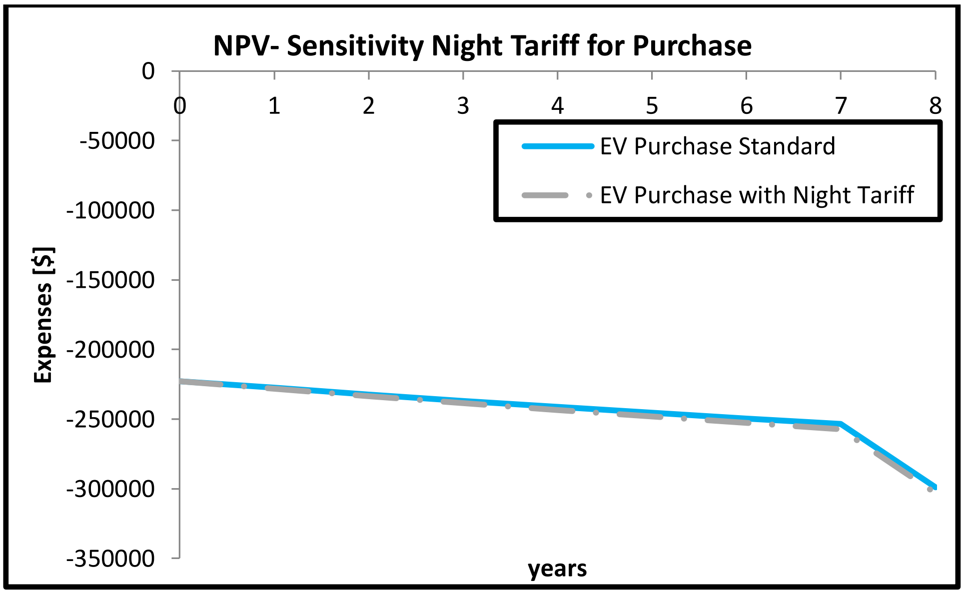


Fig. 56 Sensitivity Night Tariff - NPV [Source: own Figure]

With following scenarios are present.

- SCN_EV - Grid --- Purchase, With Tax Credit, NO solar — blue line
- SCN_EV - Grid --- EV Lease, NO Solar, Night Electricity — grey dotted

The analyzed scenarios however did not focus on only charging at night, but followed the attempt to charge when it is necessary, or when solar power is available. Thus not the full impact of the cheap night tariff can be seen. However even though the focus was not on night charging, it can be seen that the night tariff does not cost much extra. If electric vehicles are only charged at night time, a significant price advantage could be created, making running costs of electric vehicles even cheaper.

9.1.3.6 Sensitivity Analysis for Energy Price Rise

This Fig. 57 shows the influence of different energy price developments, both for electricity and gasoline.

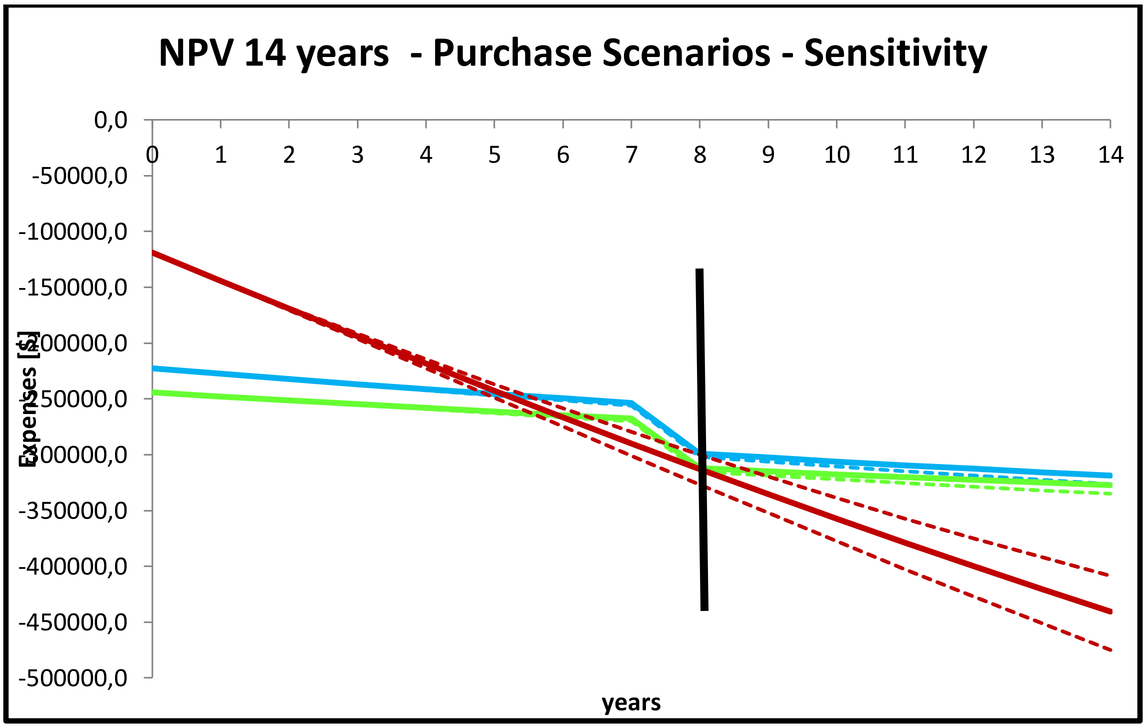


Fig. 57 Sensitivity Energy Price Development- NPV [Source: own Figure]

With following scenarios are present.

- SCN_ICEV --- Purchase, low price development red dotted
- SCN_ICEV --- Purchase, moderate price development red
- SCN_ICEV --- Purchase, high price development red dotted
- SCN_EV - Grid --- Purchase, With Tax Credit, NO solar, normal price blue
- SCN_EV - Grid --- Purchase, With Tax Credit, NO solar, high price blue dotted
- SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT,

normal price green

- SCN_EV - Solar --- Purchase, With Tax Credit, Solar FIT,
  high price green dotted

The diagram shows both the standard price development in full lines, and the differences in price development in dotted lines. It can be seen that for the high price rise scenario of electricity the break-even point is moved to a later point. Comparing the SCN_EV – Purchase high electricity price (worst scenario) with the comparison scenario of SCN_ICEV – Purchase, low price development (best scenario), the break-even is moved to around 5.5 years instead of 5 years. However this is the most negative forecast for electric vehicles. And still after 5.5 year the purchase of electric vehicles is financially feasible.

Similar behavior holds true for the scenario with solar power, as can be seen in the diagram. The break-even point moves from 6 years to 6.5 years, when considering the highest electricity price development and the lowest gasoline price development. Considering these forcasts the costs due to battery exchange after 8 years are slightly higher again than the comparison scenario of ICEV purchase. However already at year 9 the break-even is reached again.

9.1.3.7 Levelized Cost of Energy

The payback times with currently available gasoline price of 2.31 $ / gallon are between 5 and 6 years. The following chart Fig. 58 shows required gasoline price, if a payback time should be reached within 4, 6 or 8 years.

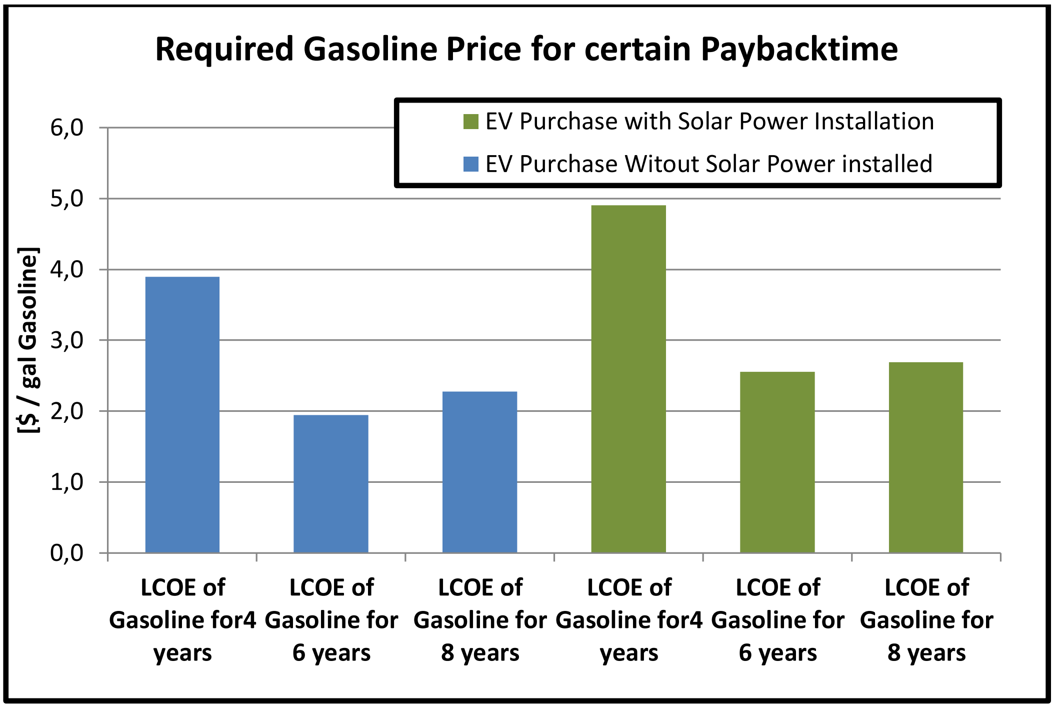


Fig. 58 Levelized Cost of Gasoline [Source: own Figure]

Following two scenarios are analyzed in comparison to the ICEV standard scenario .

- SCN_EV – Grid ---Purchase   Blue columns
- SCN_EV – Solar ---Purchase   Green columns

It can be seen that for a payback time after 4 years the gasoline price has to rise significantly first (almost 4$/gallon for the EV – grid scenario and almost 5$/gallon for the EV – Solar scenario). After 4 years however the EV – Grid scenario is feasible already with a gasoline price of only 2.00 $/gallon (lower than the initial input value for gasoline!). For making the EV – Solar scenario feasible after 4 years the gasoline price would need to be at 2.5$ / gallon. Considering a payback time of 8 years both levelized costs of Gasoline climb again. This is because after 8 years the battery exchange is required, which lowers the feasibility of both investigated scenarios.

9.1.4 Overall Results

The following table, Table 13, shows summarized the results of the 2 most promising scenarios for electric vehicles, in comparison with the standard ICEV – purchase scenario. Following scenarios and their benefits are highlighted:

- SCN_EV – Grid ---Purchase, No Solar
- SCN_EV - Grid --- Lease, No Solar

In comparison with:

- SCN_ICEV --- Lease, moderate price development

The Table 13 Main Results – Savannah Fleet Conversion Tool [Source: own Table]shows these benefits regarding energy efficiency, ecologic impacts and cost reduction, both on a yearly basis(for the sum of 10 vehicles) and on the overall savings of a Savannah city vehicle lifetime(8 years). .

Table 13 Main Results – Savannah Fleet Conversion Tool [Source: own Table]

Overall Results **(10 Vehicles)**					
for Current Car Exchange Analysis [yearly]	Gasoline [gal/year]	Prim Energy [MWh/year]	CO_2e [MT/year]	NPV [$/year]	8 year Savings [$]
Net Savings (EV Purchase)	**4,566.0**	**70.8**	**28.3**	**1,726.0**	**13,008**
Net Savings (EV Lease)	**4,566.0**	**70.8**	**28.3**	**8,559.0**	**68,472**

9.2 Comparison of various Calculation Tools

As mentioned it is of importance to proof that the shown results have claim for correctness. This is why the above mentioned results are compared to other city fleet conversion tools. The tools of comparison are mentioned in the chapter literature research, with their strengths and weaknesses. The same input as for the calculation for Savannah was used for these city fleet tools as well. The results, as far as applicable in the certain category, are presented in the Table 14 Sensitivity - Comparison of different Conversion Tools 1 [Source: own Table]

Table 14 Sensitivity - Comparison of different Conversion Tools 1 [Source: own Table]

Comparison of various Calculation Tools								
City Fleet Conversion Tools	Gasoline Savings [gal/a]	CO_2e emissions savings [t/a]	Fuel Costs Savings [$/a]	Fuel cost [$/gal]	electricity cost [$/kWh]	Annual Operation Savings [$/a]	simple Payback years	Payback in fleet miles
Savannah	**4,566**	**28.3**	**6,396**	**2.31**	**0.119**	**13,008**	**5- 6**	**526,700**
AFDC	4,445	31.0	4,911	2.06	0.130	N/A	N/A	N/A
AFLEET	3,830	47.4	6,342	2.31	0.119	20,257	5.5	576,650
Western Clean Cities	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

It can be seen that the Savannah City Fleet Conversion Tool is on the more conservative side (showing less benefits of EV's). While the calculated CO_2e emission savings of Savannah are at 28. t/a, AFDC calculates 31 t/a and AFLEET even 47.4 t/a. The break-even point is for Savannah and AFLEET tool similar (5 to 6 years).

The detailed report of other tools is found in the attachment.

The tool Western WA Clean Cities, which could not be compared with the above mentioned criteria, because it is only applicable for the grid of Seattle. However the Savannah Fleet Conversion Tool also has a result for the North West Coast gird. These two are compare in the following Table 15.

Table 15 Sensitivity - Comparison of different Conversion Tools 2 [Source: own Table]

Comparison of various Calculation Tools		
City Fleet Conversion Tools	electricity consumption per year [kWh/a]	CO_2e per year for EV's if NorthWest area [t/a]
Savannah	**32,945**	**12.3**
AFDC	N/A	N/A
AFLEET Tool	N/A	N/A
Western WA Clean Cities	32,945	9.53 to 14.79

The expected CO_2e emissions for the North West Coast are 12.4 t/a with the Savannah City Fleet Conversion Tool, and for Western WA Clean Cities it ranges from 9.53 to 14.79 t/a , depending on the chosen electricity provider.

10 DISCUSSIONS AND FINDINGS

Certain facilitations had to be made in order to enable the creation of this calculation tool with all the different sections of analysis, with the detailed energy balancing on an hourly basis, with the possibility to implement solar power, with the possibility to enable grid location specific results, etc.
The approximations and facilitations are chosen carefully in order not to interfere with the general result. The precise methodology of what is included and what was omitted can be found in the chapter methodology.

Here only the result of the program shall be analyzed. The results provided by this tool are reasonable, as proofed by other tools for city fleet conversions. The comparison shows that the Savannah Fleet Conversion Tool is on the more conservative side (as planned), other tools claim higher savings of CO_2 and costs.

However if certain aspects of the program has high priority to the user, it is advised to recalculate this specific part in a higher level of details (especially solar power or charging process).

<u>This said, following findings could be discovered regarding energy efficiency.</u>

- Electric vehicles are more energy efficient than conventional cars. MPGe values of current electric vehicles range above 100, while the average new gasoline car has 26 MPG.
- Considering the primary energy content of both electric vehicles and conventional cars, the advantage reduces. But even on a primary energy comparison, electric vehicles tend to be more efficient (consume less primary energy)
- Level 1 charger are OK for city fleet applications when the whole night is possible to be used for charging. Level 2 chargers are more advised however because they are faster, have a better charging efficiency and cost not significantly more.

- Level 3 chargers / DC fast charger unnecessary for fleet applications where charging overnight is an option. This charging system is not only very expensive but for fleet applications also unnecessary. Furthermore it cannot be used properly to combine with solar power charging.
- This is because the energy density of solar power is too low. A very big installation size is needed to provide the charging power of up to 120 kW for fast charging) for charging.
- Range of current EV's is sufficient for most city car driving patterns. The range of EV's is still expected to rise in the future.

Following ecologic findings are encountered.

- The local grid has big influence on the overall ecologic value of electric vehicles
- The most polluting grid zone in the USA still provides ecologic benefits compared to conventional cars.
- Life cycle assessments show that the higher CO_2e intensity of manufacturing EV's has only a small influence on the overall CO_2e emissions
- Electric Vehicles show additional health benefits with reducing the emissions on the street. The comparison of EV's with ICEV's show a significant reduction of NOX emissions, VOC emissions and CO emissions.
- The amount of SOx emissions is rising due to more use of electric vehicles. This is due to increased amount of electricity production. However the pollution does not happen at the tailpipe of the vehicles but decentralized at the power plants.

Following findings could be discovered regarding costs.

- Fuel costs per mile. Under current market conditions for gasoline and electricity electric vehicles drive very cost efficient compared to conventional cars already.
- The price gap of fuel costs per mile is expected to get even bigger. The reason is the expected price rise of gasoline. End consumer electricity price is expected to rise too, but not as strong as the gasoline price. Gasoline price development: The

International Energy Outlook portraits 3 scenarios for gasoline price development. Each of them forecasts a price rise. This means in the future electric vehicles tend to become even more feasible than they are now.

- Maintenance costs: less moving parts leads to less maintenance effort. Regenerative braking, less fluids to change and maintenance free electronic contribute as well to a further drop in maintenance costs.
- Low running costs. Considering both the fuel cost advantage and the maintenance cost reduction, electric vehicles are unbeatable at running costs. The costs the user has to pay per mile are significantly lower than with conventional cars.
- Purchase costs still expensive. Advances in technology and the high and still increasing production and sales rate of certain electric vehicles allow to expect further price decreases. However at the moment they are still high, significantly higher than their conventional car counterparts.
- Battery life expectancy. Most manufacturers currently give 8 years or 100,000 miles (160,000 km) on the life expectancy of an electric car battery pack. Although this is already a nice value, it is probably not enough for the full life time of a car. Furthermore it is not guaranteed that the battery might lose capacity over the time.
- Battery replacement / exchange costs. At the moment the battery pack still accounts for a significant amount of money. Battery costs of electric vehicles dropped by50% since the market launch of this technology. The future trend is to expect an even further drop in battery costs.
- Leasing an EV for limitation of risks. Leasing shows an option to limit the risk of battery life expectancy and the costs of a battery exchange. A third party takes the risks here.
- Leasing an ICEV. The reason why the City of Savannah was hesitating to lease conventional vehicles is apparent from the analysis. Leasing conventional cars generates high costs over the expected life time.
- Leasing an EV for price advantage. Although leasing conventional cars is a bad solution regarding costs, leasing an EV is very attractive. Of all the analyzed scenarios leasing an EV proofed to be the most feasible one.

- Federal Tax Credit. Has influence on both purchase and leasing. It is directly applicable only for the owner of a vehicle, however it is included in the EV-leasing offers to a certain extent. This explains the competitive leasing offer of the Nissan Leaf.
- Night tariff: although an interesting offer from the local electricity company, it needs to be considered well. If vehicles are really only charged at night this tariff generates even further cost reductions compared to gasoline cars. However if vehicles tend to be charged during work hours too, this tariff gets quickly expensive.
- Charging equipment: Level 1 and level 2 charging is sufficient for fleet applications (charging overnight) and very cost efficient.

11 Suggestions for City of Savannah

The next steps for the city of Savannah officials are suggested to be.

- Find out which vehicles are subjective to soon exchanges (depending on the purchase year, but also on the overall mileage and the general condition of the vehicle (recent maintenance costs)
- Among these vehicles find those with:
  - high mileage per year (advantage EV's at running costs)
  - relative uniform travel behavior (approximately same distance every day)
- For the expected daily travel distance, find a suiting EV with:
  - Battery capacity and subsequent range
  - Charging level input
- Make sure the EV can cover the full distance the vehicle is expected to drive per day. In this way the EV only has to be charged overnight, which enables:
  - The possibility to use only the significantly cheaper level 2 chargers
  - Have the working hours free for working.
- Consider leasing electric vehicles rather than buying.
  - Limits the risks (of battery life, etc.)
  - Is very economical, more economical than purchase of EV's

12 CONVERSION TABLE

Data for this thesis derived from international sources, but also from local US sources. Some of the units were US customary units (USC), others in the International System of Units (SI). Some of the conducted literature research presented their results in USC, or in SI, some in a mixture of both.

This setup makes it unavoidable to convert units in order to conduct the calculations. For any conversion that took place, the following conversion table is used [Porges, 2001, p. 5ff].

13 LIST OF ABBREVIATIONS

Abbreviation	Explanation
CO_2e	Carbon dioxide equivalents / Global Warming Potential
EPA	Environmental Protection Agency
EIAV	Energy Information Administration
EV	Electric Vehicles
ICEV	Internal Combustion Engine Vehicles
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
MPG	Miles per Gallon
MPGe	Miles per Gallon Equivalent
NPV	Net Present Value
PE	Primary Energy

14 LIST OF FIGURES

15 LIST OF TABLES

16 LIST OF EQUATIONS

17 REFERENCES/BIBLIOGRAPHY

Literature

Cowart William, Pesinova Veronika, Saile Sharon. 2003. An Assessment of GHG Emissions from the Transportation Sector. ICF Consulting & Environmental Protection Agency. 2003, p. 10f

Deru M., Torcellini P., 2007. NREL – National Renewable Energy Laboratroy - Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 Revised June 2007, et al

Diem Art, Quiroz Cristina, 2012. How to use eGRID for Carbon Footprinting Electricity Purchase in Greenhouse Gas Emission Inventories. U.S. EPA/OAP/CAMD, TranSystems, page 8, page 11

Ehsani Mehrdad, Yimin Gao, Ali Emad. 2010: Modern electric, hybrid electric and fuel cells vehicles – fundamentals, theory, and design; CRC Press, Taylor & Francis Group. Page 1-5, 120ff

EIA II, 2015. U.S Energy Information Administration - Annual Energy Outlook 2015, with projections to 2040. US. Department of Energy. DOE/EIA-0383(2015). Published in Washington, DC 20585, April 2015, et al

EPA, 2011 - United States Environmental Protection Agency - Office of Transportation and Air Quality, 2011: New Fuel Economy and Environment Labels for a New Generation of Vehicles; EPA-420-F-11-017a; et al

EPA, 2008. United States Environmental Protection Agency - Office of Transportation and Air Quality, 2008: Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks; EPA420-F-08-024; et al

EPA, 2014. United States Environmental Protection Agency - Office of Transportation and Air Quality, Greenhouse Gas Emissions from a Typical Passenger Vehicle; EPA420-F-08-024; 2014, et al

Forward Evan, Glitman Karen, Roberts David. 2013. An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency, Vermont Energy Investment Corporation Transportation Efficiency, Revised March 20, 2013, et al

GEFA Energy - Land - Water. 2012. 2012 GEORGIA ENERGY REPORT.

[Document] Atlanta, Georgia, USA : s.n., 2012, et al

van Haaren Rob, 2011. Assessment of Electric Cars‟ Range Requirements and Usage Patterns based on Driving Behavior recorded in the National Household Travel Survey of 2009, solar journey USA; p. 26

Nealer ,Reichmuth ,Anair. 2015. Cleaner Cars from Cradle to Grave How Electric Cars Beat Gasoline Cars on Lifetime Global Warming Emissions. © 2015 Union of Concerned Scientists All Rights Reserved, et al

NREL. 2012. National Renewable Energy Laboratory. Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. NREL/FS-6A20-56487 November 2012, et al

NREL, 2014. Photovoltaic System Pricing, Trends Historical, Recent, and Near-Term Projections 2014 Edition,. NREL/PR-6A20-62558. September 22, 2014,et al

Porges, F. 2001. HVAC Engineer's Handbook. Oxford. Butterworth-Heinemann, 2001, et al

Short, Walter, Packey, Daniel J. Holt, Thomas. 1995. A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies. [ed.] National Renewable Energy Laboratory. Golden : National Technical, 1995, et al

Ueno Kohta, Straube John, 2010. Understanding Primary/Source and Site Energy, Building Science Corporation, BSD-151. 10/06/10, et al

US.-Department of Energy, 2014. Clean Cities Report, Prepared by NREL – National Renewable Energy Laboratory. May 2014, et al

US.-Department of Energy IV, 2016. Clean Cities Vehicle Buyer’s Guide, Prepared by NREL- National Renewable Energy Laboratory, DOE/GO-102016-4843. February 2016, et al

Wilson Lindsay. 2013. Shades of Green: Electric Cars’ Carbon Emissions Around the Globe, Shrink That Footprint Green, et al

Yilmaz Murat, Krein Philip. 2012. Review of Charging Power Levels and Infrastructure for Plug-In Electric and Hybrid Vehicles and Commentary on Unidirectional Charging. University of Illinois. IEEE International Electrical Vehicle Conference 07/03/2012, South Carolina. et al

Online Research

AFDC I, 2016. Online Fleet Conversion Tool and Database. URL: http://www.afdc.energy.gov/uploads/publication/hybrid_plugin_ev.pdf, Date of Access July 2016

AFDC II, 2016. Online Fleet Conversion Tool and Database. URL: http://www.afdc.energy.gov/vehicles/electric_emissions_sources.html, Date of Access: July 2016

AFDC III, 2016. Online Fleet Conversion Tool and Database. URL: http://www.afdc.energy.gov/vehicles/electric_emissions.php, Date of Access July 2016

AFDC IV, 2016. Online Fleet Conversion Tool and Database. URL: http://www.afdc.energy.gov/vehicles/electric_maintenance.html, Date of Access: July 2016

AFDC V, 2016. Online Fleet Conversion Tool and Database. URL: https://www.afdc.energy.gov/prep/, Date of Access: August 2016

AFLEET Tool, 2016. Calculation tool for electric fleets. URL: http://www.westcoastelectricfleets.com/portfolio-items/alternative-fuel-life-cycle-environmental-and-economic-transportation-afleet-tool/, Date of Access: June 2016

Berkley Lab, 2016. Homepage of Berkley Lab. Analysis of purchase price decline of PV systems. URL: http://newscenter.lbl.gov/2013/08/12/installed-price-of-solar-photovoltaic-systems-in-the-u-s-continues-to-decline-at-a-rapid-pace/, date of Access; July 2016, published August 12, 2013

Business Con, 2016. Homepage for Assessment of Vehicle Cost per miles. URL: http://businessecon.org/2014/03/cost-per-mile-the-basic-formula/, Date of Access: September 2016

Charging Equipment Costs, 2016. Homepage of Home Depot. URL:. http://www.homedepot.com/p/Leviton-Evr-Green-Mini-Electric-Vehicle-Charging-Station-Level-2-Wall-Mounted-with-12-ft-Cord-000-EVBL2-P12/206617056?cm_mmc=Shopping%7cTHD%7cG%7c0%7cG-BASE-PLA-D27E-Electrical%7c&gclid=Cj0KEQjwt-G8BRDktsvwpPTn1PkBEiQA-MRsBe7T02_r1dMYnKgRa7wKspzjQ-rfMlCwt8t9cF7fHIUaAp258P8HAQ&gclsrc=aw.ds, Date of Access: May 2016

Chevrolet, I 2016. Homepage of Chevrolet USA. URL: http://www.chevrolet.com/bolt-ev-electric-vehicle.html, Date of Access: September 2016

Chevrolet II, 2016. Homepage of Chevrolet USA. URL: http://www.chevrolet.com/bolt-ev-electric-vehicle.html, Date of Access: September 2016

Compact of Mayors, 2015. Compliance for the Compact of Mayors, December 2015, URL: http://www.compactofmayors.org/ Date of Access: May 2016

Distance Online Tool, 2016. Homepage of online distance calculation tool between two spots. URL: http://www.distance-cities.com/distance-atlanta-ga-to-savannah-ga, Date of Access: September 2016

Georgia Gas, 2016. Gasoline Price for Savannah, URL: http://www.georgiagasprices.com/Savannah/index.aspx, Date of Access: July, 20th, 2016

Georgia Power I, 2016. Homepage of Georgia Power Electricity Company. URL: http://www.electricitylocal.com/states/georgia/savannah/, Date of Access: July 2016

Georgia Power II, 2016. Homepage of Georgia Power Electricity Company. URL: https://georgiapower.com/about-energy/electric-vehicles/what-rate-plan-is-best-for-you.cshtml, Date of Access: July 2016

Georgia Power III, 2016. Homepage of Georgia Power Electricity Company. URL: https://georgiapower.com/about-energy/electric-vehicles/what-rate-plan-is-best-for-you.cshtml, Date of Access: July 2016

Georgia Power IV, 2016. Homepage of Georgia Power Electricity Company. URL: http://georgiasolarinstallers.com/georgia_power_feed_in_tariff_vs_net_metering.html, Date of Access: September 2016

Georgia Power V, 2016. Homepage of Georgia Power Electricity Company. URL: http://georgiasolarinstallers.com/gpasi_georgiapoweradvancesolarinitiative.html, Date of Access: July 2016

Georgia Tech, 2015. Georgia Tech - Enterprise Innovation Institute, 2009, Saving Energy in Savannah. URL: http://innovate.gatech.edu/communities/georgia-tech-helps-city-of-savannah-reduce-energy-consumption/ Date of Access: October 2015

GREET. 2015. Emission Results created by Argonne National Laboratory on 11/12/2015 using GREET1_2015 version, October 2015 release https://greet.es.anl.gov/results, Date of Access July 2016

Ehow, 2016. Homepage of Ehow. Showing the process of calculating operating costs per mile: URL: http://www.ehow.com/how_8301653_calculate-cost-per-miles.html, Date of Access: September 2016

EIA I, 2015. US Energy Information Administration. Energy use for transportation URL: http://www.eia.gov/Energyexplained/?page=us_energy_transportation , Date of Access: October 2015

EIA I, 2016. US. Energy Information Administration. Georgia Electricity Profile 2014, Release date March 24, 2016. URL: http://www.eia.gov/electricity/state/georgia/, Date of Access: September 2016

EIA II 2016. US. Energy Information Administration., Gasoline Price Fluctuation, URL: https://www.eia.gov/energyexplained/index.cfm?page=gasoline_fluctuations, Date of Access: July 2016

EIA III, 2016. US. Energy Information Administration., Gasoline Price Development, URL: https://www.eia.gov/forecasts/aeo/section_prices.cfm#petliquids, date of Access: July 2016

EIA IV, 2016. US. Energy Information Administration., CO_2 emission by gasoline combusiton, URL: http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=10, date of Access: July 2016

EIA V, 2016. US. Energy Information Administration., Electricity Price development. URL: https://www.eia.gov/electricity/, Date of Access: July 2016

EIA VI, 2016. US. Energy Information Administration, Feed in tariffs. URL:http://www.eia.gov/electricity/policies/provider_programs.cfm, Date of Access: September 2016

EIA VII, 2016. US. Energy Information Adminisration, Grid emission factors. URL: http://www.eia.gov/oiaf/1605/coefficients.html#tbl2, Date of Access September 2016

EPA. 2016. Environmental Protection Agency - Energy and the Environment -GHG Equivalencies Calculator - Calculations and References, URL: https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references, Date of Access: September 2016

GREET Tool, 2016. Calculation tool for electric fleets. URL: https://greet.es.anl.gov/, Date of Access: June 2016

IRS, 2016. Homepage of International Revenue Service for Plug-In Electric Drive Vehicle Credit (IRC 30D). URL: https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d, Date of Access: July 2016

LatLong,, 2016. Online Geographic Tool for coordinates. URL: http://www.latlong.net/place/savannah-ga-usa-1787.html, Date of Access: September 2016

Nissan USA I, 2016. Homepage of Nissan USA, Lithium-Ion Battery Limited Warranty. URL: http://www.nissanusa.com/electric-cars/leaf/charging-range/battery/, Date of Access: September 2016

Nissan USA II, 2016. Homepage of Nissan USA. Specifications of Nissan Leaf. URL: http://www.nissanusa.com/electric-cars/leaf/versions-specs/, Date of Access: September 2016

Nissan USA III, 2016. Homepage of Nissan USA. Specifications of Nissan Leaf. URL: http://www.nissanusa.com/electric-cars/leaf/, Date of Access: September 2016

Nissan USA IV, 2016. Homepage of Nissan USA. Nissan Purchase and Lease Prices of Versa. URL: http://www.nissanusa.com/buildyournissan/transmission/index, Date of Access: September 2016

Nissan USA IV, 2016. Homepage of Nissan USA. Nissan Purchase and Lease Prices of Leaf. URL: http://nissanusa.com/buildyournissan/colors/index, Date of Access: September 2016

Nissan Global, 2016. Homepage of Nissan Global. Zero emissions. URL: http://www.nissan-global.com/EN/ZEROEMISSION/ Date of Access: September 2016

Propane Calculator, 2016. Homepage of the alternative vehicle calculation tool. URL:. http://www.propane.com/calculators/, Date of Access: July 2016

Sunelec, 2016. Homepage of Sunelec for module prices. URL: http://sunelec.com/solar-panels/, Date of Access: September 2016)

Sunpower, 2016. Homepage of Sunpower. Degradation Rate. URL: https://us.sunpower.com/sites/sunpower/files/media-library/white-papers/wp-sunpower-module-degradation-rate.pdf, Date of Access: September 2016

US.-Department of Energy I, 2016. The official US. government source for fuel economy information. URL: http://www.fueleconomy.gov/feg/label/learn-more-electric-label.shtml, Date of Access July 2016

US.-Department of Energy II, 2016. The official US. government source for fuel economy information. URL: http://www.fueleconomy.gov/feg/evtech.shtml, Date of Access: September 2016

US.-Department of Energy III, 2016: Presentation about Renewable Energy Costs: http://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf, page 5, Date of Access: June 2016

Westcoast Electric Fleets, 2016. Homepage of the westcoast fleet calculation tool. URL: http://www.westcoastelectricfleets.com/portfolio-items/wwccc-ghg-calculator/, Date of Access: June 2016

Electric Vehicle Magazines

ARC Financial, 2016: Homepage of ARC. URL: http://www.arcenergyideas.com/?p=63, Date of Access: September 2016

AJC, 2016. Homepage of the Newspaper AJC. URL: http://www.ajc.com/news/news/local/cobb-adds-more-electric-vehicles-to-fire-fleet/nsLQd/, Date of Access: September 2016

EV obsession 2016.Homepage of EV Obsession. URL: http://evobsession.com/electric-cars-2014-list/, Date of Access May 2016

Green Fleet Magazine I, 2016, Homepage of Green Fleet Magazine showing pioneering EV fleets. URL: http://www.greenfleetmagazine.com/channel/electric/article/story/2013/10/what-is-the-future-of-electric-vehicles-in-fleet-grn.aspx; Date of Access May 2016

Green Fleet Magazine II, 2016, Homepage of Green Fleet Magazine showing sales numbers. URL: http://www.greenfleetmagazine.com/fc_images/articles/M-PEV-chart.jpg, Date of Access: May 2016

Green Fleet Magazine III, 2016. Homepage of Green Fleet Magazine. Price development. http://www.greenfleetmagazine.com/article/story/2013/10/what-is-the-future-of-electric-vehicles-in-fleet-grn/page/2.aspx, Date of Access May 2016

Government Fleet 2015. Homepage of Governemnt Fleet. URL: http://www.government-fleet.com/channel/electric/news/story/2015/07/ga-county-expects-to-save-246k-with-leased-evs.aspx, Date of Access June 2016

Green Car Reports 2016. Homepage of electric vehicle economy data. URL: http://www.greencarreports.com/new-cars, Date of Access: July 2016

Green Car Reports II. 2016. Homepage of Green Car Reports. URL: http://www.greencarreports.com/news/1080871_electric-car-price-guide-every-2015-2016-plug-in-car-with-specs-updated, Date of Access: June 2016

Hybrid cars, 2013. Homepage for Range and MPGe. URL: http://www.hybridcars.com/2013-nissan-leafs-epa-estimated-range-and-mpge/, Date of Access: July 2016

Inside EV's 2016: Magazine about electric vehicles URL: http://insideevs.com/breaking-nissan-prices-leaf-battery-replacement-5499-new-packs-heat-durable/, Date of Access May 2016

Inside EV's II, 2016 . Magazine about electric vehicles. URL: http://insideevs.com/gm-chevrolet-bolt-for-2016-145kwh-cell-cost-volt-margin-improves-3500/, Date of Access: June 2016

Motor Report, 2016. Homepage of The Motor Report Magazine, showing range developments. URL: http://www.themotorreport.com.au/63671/2018-nissan-leaf-to-match-it-with-model-s-up-to-540km-of-range, Date of Access: September 2016

Plug in America I, 2016. Homepage of Plug in America. URL:. https://pluginamerica.org/why-go-plug-in/state-federal-incentives/?location=ca, Date of Access: September 2016

Plug in America II, 2016. Homepage of Plug in America. URL: http://www.pluginamerica.org/drivers-seat/understanding-electric-vehicle-charging, Date of Access: July 2016

Interviews

Fish Heather.2016. Meeting with Savannah City Fleet Management 04/13/2016 [interv.] Dominik Pfaffenbichler, Savannah, April 2016

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18 APPENDIX

Energy Balance: Output Page

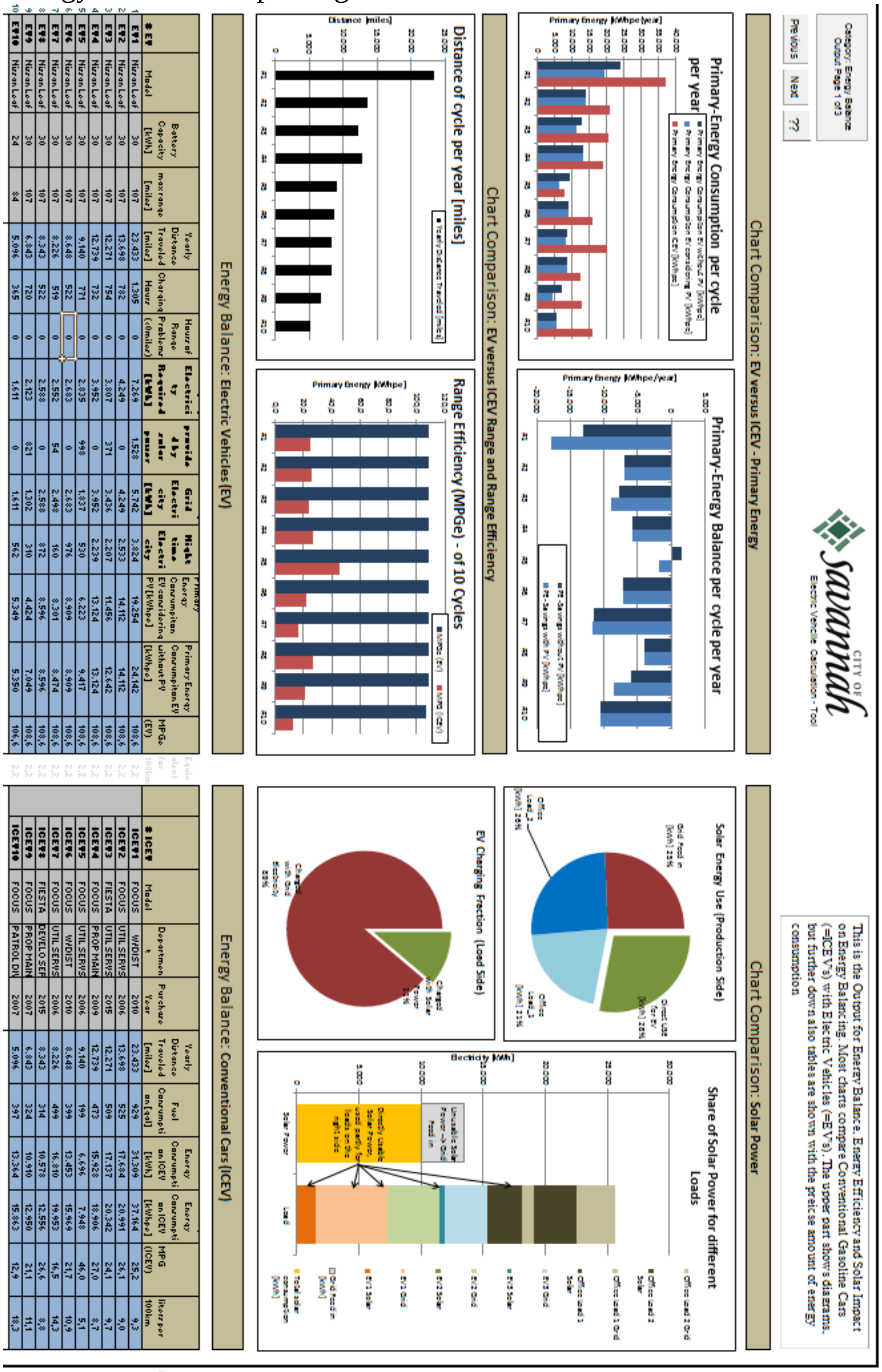


Fig. 59 Energy Balance Output Page [Source: own Figure]

Ecology Balance: Output Page

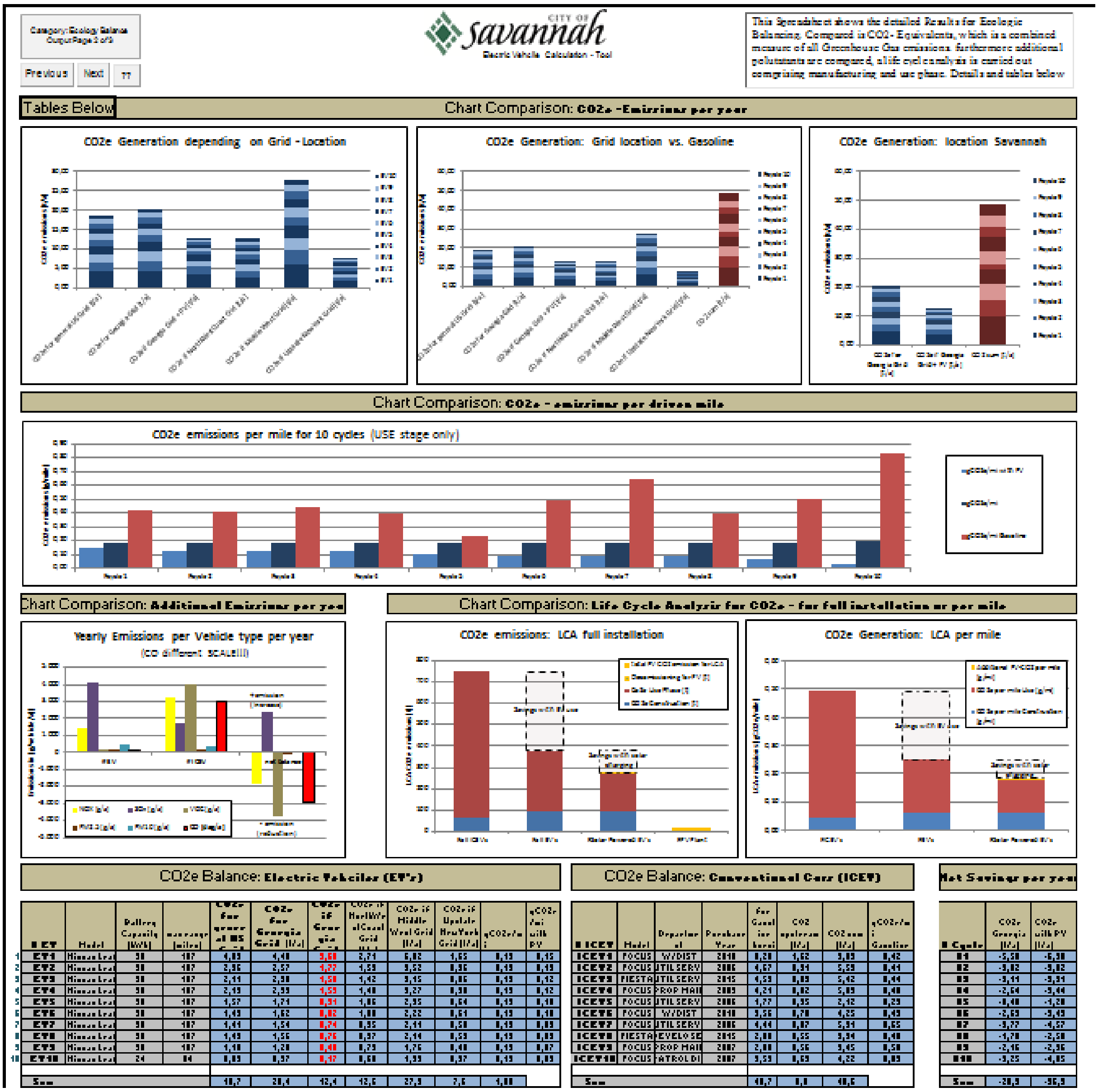


Fig. 60 Ecology Output Page [Source: own Figure]

Financial Feasibility: Output Page

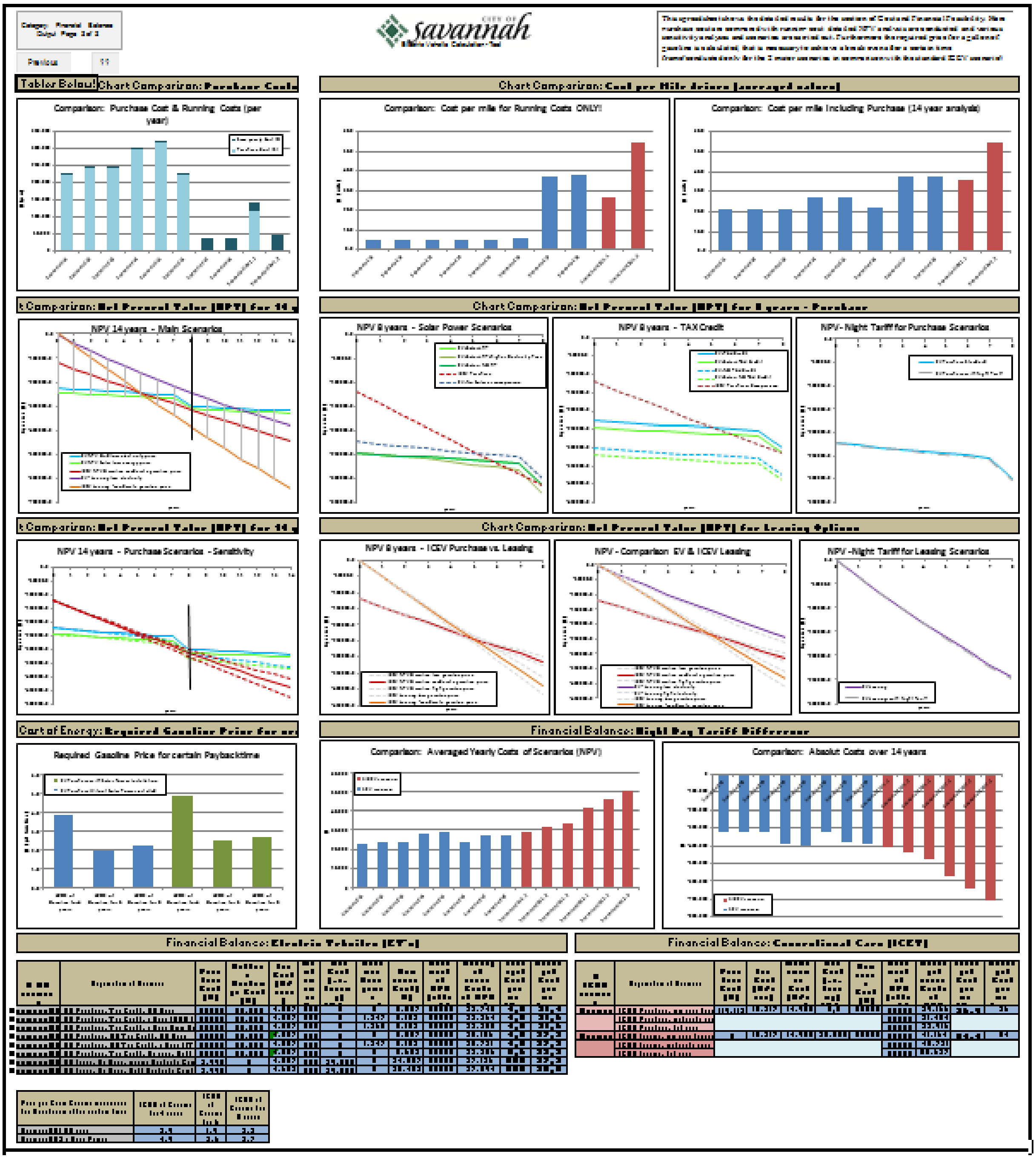


Fig. 61 Financial Feasibility Output Page [Source: own Figure]

For calculation of Solar charging used. Calculation out of PV Sol at the 4th of May.

Table 16 PV Sol hourly values for4th of May and 12th of December

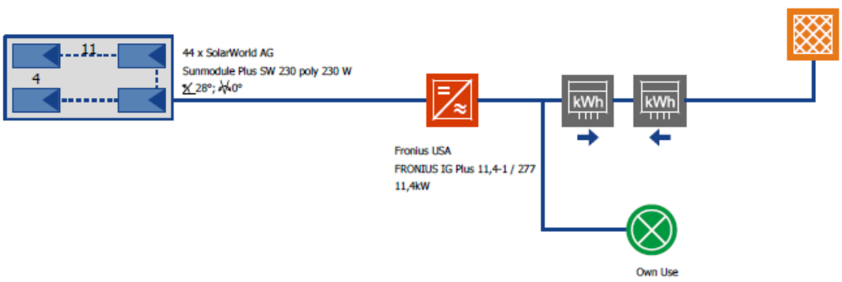
Energy from Inverter (AC)			Energy from Inverter (AC)		
sum Daily Value		64 [kWh]	sum Daily Value		45 [kWh]
Date:	Time		Date:	Time	
4. 5.	00:00	0	12.12.	00:00	0
4. 5.	01:00	0	12.12.	01:00	0
4. 5.	02:00	0	12.12.	02:00	0
4. 5.	03:00	0	12.12.	03:00	0
4. 5.	04:00	0	12.12.	04:00	0
4. 5.	05:00	0,02	12.12.	05:00	0
4. 5.	06:00	0,4	12.12.	06:00	0
4. 5.	07:00	2,1	12.12.	07:00	0,0
4. 5.	08:00	4,4	12.12.	08:00	2,3
4. 5.	09:00	6,3	12.12.	09:00	4,9
4. 5.	10:00	7,7	12.12.	10:00	6,2
4. 5.	11:00	8,6	12.12.	11:00	7,0
4. 5.	12:00	8,4	12.12.	12:00	7,3
4. 5.	13:00	7,9	12.12.	13:00	6,8
4. 5.	14:00	7,3	12.12.	14:00	5,5
4. 5.	15:00	5,7	12.12.	15:00	3,7
4. 5.	16:00	3,6	12.12.	16:00	1,5
4. 5.	17:00	1,4	12.12.	17:00	0
4. 5.	18:00	0,1	12.12.	18:00	0
4. 5.	19:00	0	12.12.	19:00	0
4. 5.	20:00	0	12.12.	20:00	0
4. 5.	21:00	0	12.12.	21:00	0
4. 5.	22:00	0	12.12.	22:00	0
4. 5.	23:00	0	12.12.	23:00	0

PVSol (10kWp, Azimuth = 0°, inclination = 28°.

Please enter under Options-> Settings

valentin software

Project Name:	Solar System Design	20.07.2016
Variant Reference:	System Variant	



Location:	SAVANNAH INTL AP	
Climate Data Record:	SAVANNAH INTL AP (1991-2005)	
PV Output:	10,12	kWp
Gross/Active PV Surface Area:	73,77 / 73,89	m²

PV Array Irradiation:	135.402	kWh
Energy Produced by PV Array (AC):	14.933	kWh
Energy to Grid:	14.932,7	kWh
Direct Use of PV Energy:	0	kWh
Energy from Grid:	18,6	kWh

System Efficiency:	11,0	%
Performance Ratio:	80,4	%
Inverter Efficiency:	95,5	%
PV Array Efficiency:	11,5	%
Specific Annual Yield:	1.474	kWh/kWp
CO2 Emissions Avoided:	13.219	kg/a

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

PV*SOL Expert 5.5 (R5) 1

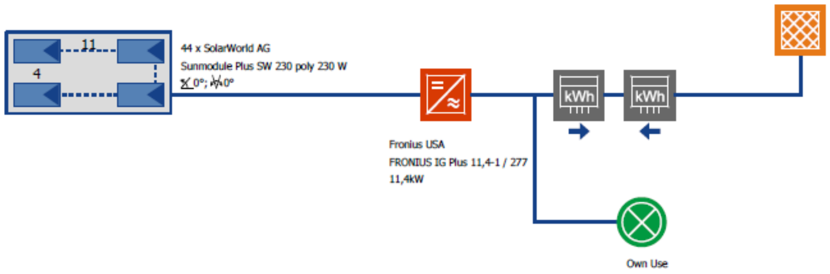
Fig. 62 PVSol Report 1 [Source: PVSol]

PVSol (10kWp, Azimuth = 0°, inclination = 0°.

Please enter under Options-> Settings

valentin software

Project Name:	Solar System Design	20.07.2016
Variant Reference:	System Variant	



Location:	SAVANNAH INTL AP	
Climate Data Record:	SAVANNAH INTL AP (1991-2005)	
PV Output:	10,12	kWp
Gross/Active PV Surface Area:	73,77 / 73,89	m²

PV Array Irradiation:	123.718	kWh
Energy Produced by PV Array (AC):	13.467	kWh
Energy to Grid:	13.466,7	kWh
Direct Use of PV Energy:	0	kWh
Energy from Grid:	18,2	kWh

System Efficiency:	10,9	%
Performance Ratio:	79,4	%
Inverter Efficiency:	95,5	%
PV Array Efficiency:	11,4	%
Specific Annual Yield:	1.329	kWh/kWp
CO2 Emissions Avoided:	11.920	kg/a

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

PV*SOL Expert 5.5 (R5) 1

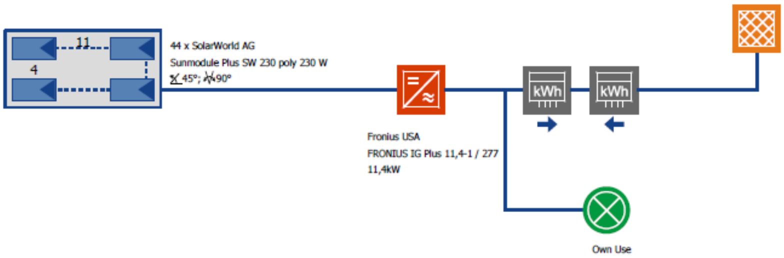
Fig. 63 PVSol Report 2 [Source: PVSol]

PVSol (10kWp, Azimuth = 90°, inclination = 45°.

Please enter under Options-> Settings

valentin software

Project Name:	Solar System Design	20.07.2016
Variant Reference:	System Variant	



Location:	SAVANNAH INTL AP	
Climate Data Record:	SAVANNAH INTL AP (1991-2005)	
PV Output:	10,12	kWp
Gross/Active PV Surface Area:	73,77 / 73,89	m²

PV Array Irradiation:	101.109	kWh
Energy Produced by PV Array (AC):	10.998	kWh
Energy to Grid:	10.997,6	kWh
Direct Use of PV Energy:	0	kWh
Energy from Grid:	18,6	kWh

System Efficiency:	10,9	%
Performance Ratio:	79,3	%
Inverter Efficiency:	95,1	%
PV Array Efficiency:	11,4	%
Specific Annual Yield:	1.085	kWh/kWp
CO2 Emissions Avoided:	9.732	kg/a

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

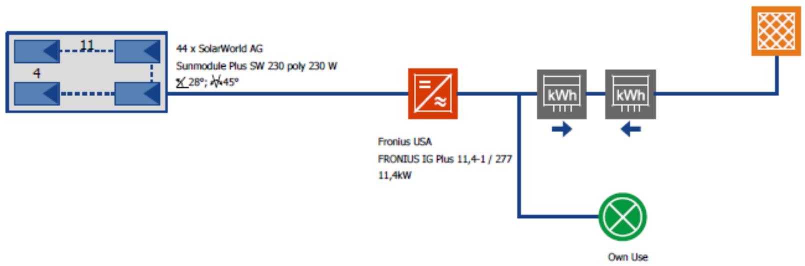
PV*SOL Expert 5.5 (R5) 1

Fig. 64 PVSol Report 3 [Source: PVSol]

PVSol (10kWp, Azimuth = 45°, inclination = 28°.

Please enter under Options-> Settings

Project Name:	Solar System Design	20.07.2016
Variant Reference:	System Variant	



Location:	SAVANNAH INTL AP	
Climate Data Record:	SAVANNAH INTL AP (1991-2005)	
PV Output:	10,12	kWp
Gross/Active PV Surface Area:	73,77 / 73,89	m²

PV Array Irradiation:	127.740	kWh
Energy Produced by PV Array (AC):	14.032	kWh
Energy to Grid:	14.032,2	kWh
Direct Use of PV Energy:	0	kWh
Energy from Grid:	18,6	kWh

System Efficiency:	11,0	%
Performance Ratio:	80,1	%
Inverter Efficiency:	95,4	%
PV Array Efficiency:	11,5	%
Specific Annual Yield:	1.385	kWh/kWp
CO2 Emissions Avoided:	12.421	kg/a

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

PV*SOL Expert 5.5 (R5) 1

Fig. 65 PVSol Report 4 [Source: PVSol]

Further List of input data chosen for the scenario analysis for the City of Savannah.

Table 17 Further Input Data chosen [Source: own Table]

Type	Amount	Unit	Description
Orientation	0	°Az	Orientation, south, east, west
Elevation	28	°	inclination of modules
Size	10	kWp	size of pv array
Feed in Tariff	0.1	$/kWh	price of electricity
PV installation	2.15	$/W	benchmark for newly installed PV
degradation	0.007	/year	yearly degradation
yearly yield	14,933	kWh/a	sum of produced energy
Normal Sale price	0.05	$/kWh	for solar enegy
electricity price	0.119	$/kWh	purchase price of electricity
gasoline price	2.31	$ per gal	as by July 2016 for Savannah
peak price electricity	0.2	$/kWh	electricity for day night charge
off peak price electricity	0.05	$/kWh	electricity for day night charge
Battery Life Expectancy	8	years	battery life time for EV's, or 100,000 km
CF / LCA Analysis	14	years	typical period for vehicle analyses
Hurdle Rate	0.03		3%
Price Rise 1 elec	-0.001		EIA price rise expectation
Price Rise 2 elec	0.02		local Georgia power price rise expectation
price rise 1 gasol	0.01		moderate rise
price rise 2 gasol	0.025		significant rise
price rise 3 gasol	0.043		Energy outlook
Working day	8	am	start of working day
EndWorkDay	5	pm	end of working day
SumWorkDay	9	hours	sum of working hours per day
Load1.1_Temp	5	kW	Office Load dependent on temp
f_Load1.1_Temp	37.7	°C	Office Threshold for starting of peak load
Load1.1_Temp	3	kW	Office Load dependent on temp
f_Load1.2_Temp	26.6	°C	Office Threshold for starting of base load
Load2_Time	2	kW	Office Load dependent on time
f_Load2_Start	9	am	Office Threshold for starting of load
f_Load2_End	5	pm	Office Threshold for starting of load
Air Con EV	1	%	Additional consumption
f_AC_start	25	°C	Above it AC turnes on
Warm up	1	%	To get Electronics to working temp
f_Warm up	5	°C	below it additional heating
Night Use	1	%	When Light is turned on

Emission factors for different regions in the USA: [cf.Diem, Quiroz: 2012, p.14]

Table 18 Emission values US grid [cf.Diem, Quiroz: 2012, p.14]

eGRID subregion acronym	eGRID subregion name	eGRID subregion annual CO_2 equivalent total output emission rate (lb/MWh)	eGRID subregion annual CO_2 equivalent non-baseload output emission rate (lb/MWh)
SUBRGN	**SRNAME**	**SRCO2RTA**	**SRNBC2ER**
AKGD	ASCC Alaska Grid	1,283.82	1,323.41
AKMS	ASCC Miscellaneous	523.05	1,474.49
ERCT	ERCOT All	1,186.14	1,158.20
FRCC	FRCC All	1,181.63	1,305.85
HIMS	HICC Miscellaneous	1,357.46	1,623.22
HIOA	HICC Oahu	1,602.30	1,629.49
MROE	MRO East	1,600.54	1,878.27
MROW	MRO West	1,637.82	2,127.82
NYLI	NPCC Long Island	1,353.86	1,338.32
NEWE	NPCC New England	734.29	1,163.21
NYCW	NPCC NYC/Westchester	612.04	1,119.25
NYUP	NPCC Upstate NY	500.35	1,353.21
RFCE	RFC East	952.63	1,636.62
RFCM	RFC Michigan	1,668.76	1,844.44
RFCW	RFC West	1,528.76	2,012.22
SRMW	SERC Midwest	1,759.15	2,204.50
SRMV	SERC Mississippi Valley	1,006.12	1,204.40
SRSO	SERC South	1,332.59	1,629.86
SRTV	SERC Tennessee Valley	1,364.92	1,931.14
SRVC	SERC Virginia/Carolina	1,041.73	1,686.09
SPNO	SPP North	1,825.15	2,157.95
SPSO	SPP South	1,606.26	1,518.94
CAMX	WECC California	661.20	995.85
NWPP	WECC Northwest	823.40	1,411.18
RMPA	WECC Rockies	1,833.41	1,764.09
AZNM	WECC Southwest	1,196.58	1,190.97
U.S.		**1,222.29**	**1,562.22**

Online Calculation Tool [cf. Westcoast Electric Fleets, 2016]:

Greenhouse Gas Analysis: Transportation Emissions

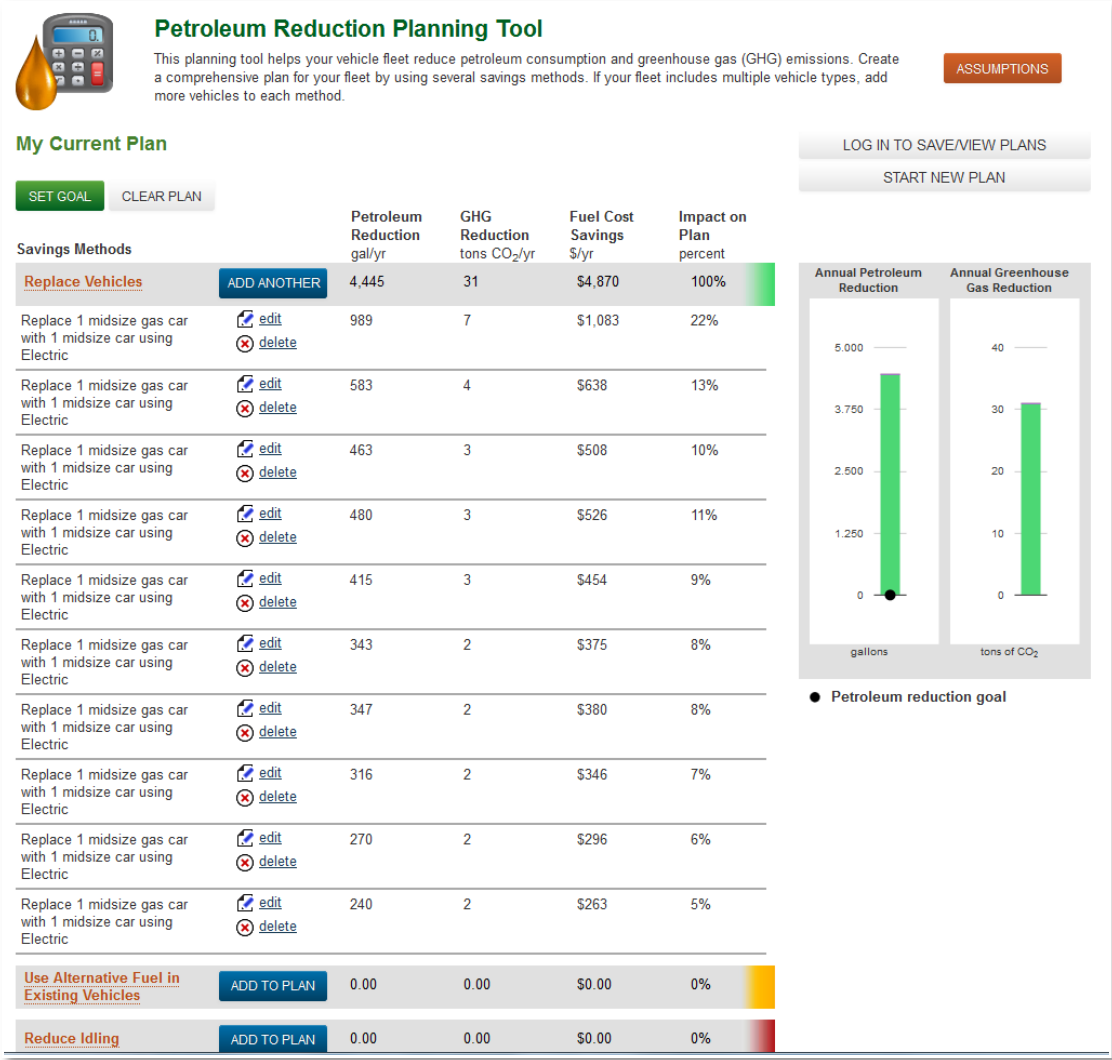
Prepared for:

Date:

Fuel types	Quantity used	Units	Well to wheel greenhouse gases (metric tons)	Emission factor source
Electricity (Puget Sound	32.945	Megawatt hours	14.794,1	2014 PSE Greenhouse Gas Inventory
Electricity (WECC North	32.945	Megawatt hours	9.997,2	EPA EGRID 2013 emission data
Electricity (Avista)	32.945	Megawatt hours	9.534,0	Avista 2015 performance report "The Power of Shared Value
Electricity (Seattle City	32.945	Megawatt hours	496,6	The Climate Registry retail electricity emission factor

Fig. 66 Online Calculation Tool [cf. Westcoast Electric Fleets, 2016]:

Online Calculation Tool [cf. AFDC V, 2016]:



Petroleum Reduction Planning Tool

This planning tool helps your vehicle fleet reduce petroleum consumption and greenhouse gas (GHG) emissions. Create a comprehensive plan for your fleet by using several savings methods. If your fleet includes multiple vehicle types, add more vehicles to each method.

ASSUMPTIONS

My Current Plan

LOG IN TO SAVE/VIEW PLANS

START NEW PLAN

SET GOAL CLEAR PLAN

Savings Methods		Petroleum Reduction gal/yr	GHG Reduction tons CO_2/yr	Fuel Cost Savings $/yr	Impact on Plan percent
Replace Vehicles	ADD ANOTHER	4,445	31	$4,870	100%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	989	7	$1,083	22%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	583	4	$638	13%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	463	3	$508	10%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	480	3	$526	11%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	415	3	$454	9%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	343	2	$375	8%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	347	2	$380	8%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	316	2	$346	7%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	270	2	$296	6%
Replace 1 midsize gas car with 1 midsize car using Electric	edit delete	240	2	$263	5%
Use Alternative Fuel in Existing Vehicles	ADD TO PLAN	0.00	0.00	$0.00	0%
Reduce Idling	ADD TO PLAN	0.00	0.00	$0.00	0%

Fig. 67 Online Calculation Tool [cf. AFDC V, 2016]

Online Calculation Tool [cf. AFLEET, 2016].

Table 19 AFLEET tool [cf. AFLEET, 2016]

Simple Payback Calculator

	Gasoline	Diesel	Gasoline HEV	Gasoline PHEV	Gasoline EREV	EV	Diesel HEV	Diesel HHV	B20	B100	E85	LPG	CNG	LNG	LNG / Diesel Pilot Ignition
Light-Duty Vehicle Inputs															
Vehicle Type	Passenger Car														
Number of LDVs	10	0	0	0	0	10			0	0	0	0	0		
Annual Mileage	10.534	12.400	12.400	12.400	12.400	10.534			12.400	12.400	12.400	12.400	12.400		
Fuel Economy (MPGGE)	23,7	32,0	37,4	41,4	31,5	105,0			32,0	32,0	26,7	26,7	25,4		
Fuel Consumption (GGE/100mi)	4,2	3,1	2,7	2,4	3,2	1,0	0,0	0,0	3,1	3,1	3,7	3,7	3,9		
CD Electricity Use (kWh/100mi)				22,6	33,6	31,3									
CD Electricity Use (GGE/100mi)				0,7	1,0										
CD Gasoline Use (GGE/100mi)				1,4	0,0										
PHEV CD Range (miles)				10,9	33,1										
Charges/day				1,0	1,0										
Days driven/week				5	5										
Share of CD miles				23%	70%										
Purchase Price ($/vehicle)	$11.911	$22.500	$28.000	$33.000	$35.000	$23.000			$22.500	$22.500	$20.000	$26.000	$27.000		
Incentive ($/vehicle)	$0	$0	$0	$0	$0	$0			$0	$0	$0	$0	$0		
Maintenance & Repair ($/mile)	$0,14	$0,19	$0,14	$0,13	$0,13	$0,01			$0,19	$0,19	$0,14	$0,14	$0,14		
Heavy-Duty Vehicle Inputs															
Vehicle Type	Combination Long-Haul Truck														
Number of HDVs	0	0				0	0	0	0	0	0	0	0	0	0
Annual Mileage	0	170.000				0	170.000	0	170.000	170.000	0	0	170.000	170.000	170.000
Fuel Economy (MPGGE)	4,3	5,2				14,7	5,5	5,2	5,2	5,2	4,3	4,7	4,7	4,7	5,2
Fuel Consumption (GGE/100mi)	23,1	19,2				6,8	18,1	19,2	19,2	19,2	23,1	21,4	21,4	21,4	19,2
Fuel Consumption (DGE/100mi)	20,3	17,0				6,0	15,9	17,0	17,0	17,0	20,3	18,8	18,8	18,8	17,0
CD Electricity Use (kWh/100mi)						223,4									
Share of LNG Fuel Use (energy %)															95%
DEF Use (% of fuel consumption)	0%	2%				2%	2%	2%	2%	2%	0%	0%	0%	0%	2%
Purchase Price ($/vehicle)	$0	$100.000				$0	$140.000	$0	$100.000	$100.000	$0	$0	$165.000	$150.000	$190.000
Incentive ($/vehicle)	$0	$0				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintenance & Repair ($/mile)	$0,14	$0,19				$0,00	$0,18	$0,18	$0,19	$0,19	$0,00	$0,00	$0,19	$0,19	$0,20
Fuel and DEF Price															
Primary Fuel Price ($/GGE)	$2,31	$3,56	$2,31	$2,31	$2,31	$3,91	$3,56	$3,56	$3,66	$4,27	$4,64	$3,84	$2,21	$2,29	$2,29
Secondary Fuel Price ($/GGE)				$3,91	$3,91										$3,56
DEF Price ($/gallon)		$2,80					$2,80	$2,80	$2,80	$2,80			$2,80	$2,80	$2,80
Acquisition Cost															
Light-Duty (LD) Fleet Cost	$119.110	$0	$0	$0	$0	$230.000	$0	$0	$0	$0	$0	$0	$0	$0	$0
Heavy-Duty (HD) Fleet Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Operating Cost															
LD Fuel Cost	$10.267	$0	$0	$0	$0	$3.925	$0	$0	$0	$0	$0	$0	$0	$0	$0
LD Maintenance Cost	$14.968	$0	$0	$0	$0	$1.053	$0	$0	$0	$0	$0	$0	$0	$0	$0
HD Fuel Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
HD Diesel Exhaust Fluid Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
HD Maintenance Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Operating Savings															
Compared to Gasoline LD Fleet						$20.257									
Compared to Diesel HD Fleet															
Simple Payback															
LD Fleet (miles)						57.665,0									
LD Fleet (years)						5,5									
HD Fleet (miles)															
HD Fleet (years)															
Life-Cycle Petroleum Use (barrels)															
LD Petroleum Use	92,7	0,0	0,0	0,0	0,0	1,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
HD Petroleum Use	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Life-Cycle Greenhouse Gas (GHG) Emissions (short tons)															
LD GHG Emissions	53,6	0,0	0,0	0,0	0,0	1,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
HD GHG Emissions	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Vehicle Operation Air Pollutant Emissions (lb)															
Light-Duty Vehicle Type	Passenger Car														
CO	530,1	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		
NOx	20,2	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		
PM10	1,2	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		
PM10 (TBW)	4,2	0,0	0,0	0,0	0,0	4,2			0,0	0,0	0,0	0,0	0,0		
PM2.5	0,9	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		
PM2.5 (TBW)	1,2	0,0	0,0	0,0	0,0	1,2			0,0	0,0	0,0	0,0	0,0		
VOC	16,8	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		
VOC (Evap)	7,4	0,0	0,0	0,0	0,0				0,0	0,0	0,0	0,0	0,0		

Emission factors for Transportation Fuels [cf. EIA VII, 2016]:

Table 20 Emission Values Gasoline [cf. EIA VII, 2016]

2. Carbon Dioxide Emission Factors for Transportation Fuels[1]

Transportation Fuel	Emission Factors: Kilograms CO_2 Per Unit of Volume		Emission Factors: Kilograms CO_2 Per Million Btu
Aviation Gasoline	8.32	per gallon	69.19
Biodiesel			
-B100	0.00	per gallon	0.00
-B20	8.12	per gallon	59.44
-B10	9.13	per gallon	66.35
-B5	9.64	per gallon	69.76
-B2	9.94	per gallon	71.80
Diesel Fuel (No. 1 and No. 2)	10.15	per gallon	73.15
Ethanol/Ethanol Blends			
-E100	0.00	per gallon	0.00
-E85	1.34	per gallon	14.79
-E10 (Gasohol)	8.02	per gallon	66.30
Methanol/Methanol Blends			
-M100	4.11	per gallon	63.62
-M85	4.83	per gallon	65.56
Motor Gasoline	8.91	per gallon	71.26
Jet Fuel, Kerosene	9.57	per gallon	70.88
Natural Gas	54.60	per Mcf	53.06
Propane	5.74	per gallon	63.07
Residual Fuel (No. 5 and No. 6 Fuel Oil)	11.79	per gallon	78.80

[1]Emissions factors calculated from data in: (1) Energy Information Administration, Documentation for Emissions of Greenhouse Gases in the U.S. 2005, DOE/EIA-0638 (2005), October 2007, Tables 6-1, 6-4, and 6-5.Â (Non-biogenic carbon content and gross heat of combustion for motor gasoline and diesel (distillate fuel)). (2) U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels & Advanced Vehicles Data Center, Fuel Properties web page (http://www.eere.energy.gov/afdc/fuels/properties.html). (Biodiesel gross heat of combustion). (3) Energy Information Administration, Annual Energy Review 2006, DOE/EIA-0384(2006), June 2007, Table A3, p. 361. (Gross heat of combustion for ethanol). (4) Stacy C. Davis and Susan W. Diegel, Transportation Energy Data Book, Edition 26, Oak Ridge National Laboratory, ORNL-6978, 2007, Table B.7 TablesÂ 6.7 and B.4. (Density and gross heat of combustion of methanol.)

Georgia State Averaged Electricity Price [cf. EIA I, 2016].

Table 21 Savannah Electricity Price [cf. EIA I, 2016]

Georgia Electricity Profile 2014

Table 1. 2014 Summary statistics (Georgia)

Item	Value	Rank
Primary energy source		**Coal**
Net summer capacity (megawatts)	**38,250**	**7**
Electric utilities	28,873	3
IPP & CHP	9,377	10
Net generation (megawatthours)	**125,837,224**	**10**
Electric utilities	109,523,336	4
IPP & CHP	16,313,888	20
Emissions		
Sulfur dioxide (short tons)	105,998	11
Nitrogen oxide (short tons)	58,144	14
Carbon dioxide (thousand metric tons)	62,516	12
Sulfur dioxide (lbs/MWh)	1.7	24
Nitrogen oxide (lbs/MWh)	0.9	35
Carbon dioxide (lbs/MWh)	1,093	28
Total retail sales (megawatthours)	**135,789,932**	**8**
Full service provider sales	135,789,932	4
Energy-only provider sales		
Direct use (megawatthours)	**4,565,846**	**8**
Average retail price (cents/kWh)	**10.03**	**22**

kWh = Kilowatthours.
Sources: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report." U.S. Energy Information Administration, Form EIA-861,"Annual Electric Power Industry Report." U.S. Energy Information Administration, Form EIA-923, "Power Plant Operations Report" and predecessor forms.

<u>Following queries are used in the randomize mile generator. The full code is below:</u>

If RandomNumber < 10 Then → Current Distance = 1 km

ElseIf RandomNumber < 21 Then → current Distance = 2 km

ElseIf RandomNumber < 33 Then → Current Distance = 3 km

ElseIf RandomNumber < 43 Then → Current Distance = 4 km

ElseIf RandomNumber < 57 Then → Current Distance = 5 or 6 km

ElseIf RandomNumber < 66 Then → Current Distance = 7 or 8 km

ElseIf RandomNumber < 76 Then → Current Distance = 9, 10 or 11 km

ElseIf RandomNumber < 86 Then → Current Distance = 12, 13, 14, 15 or 16 km

ElseIf RandomNumber < 94 Then → Current Distance = 17 to 26 km

ElseIf RandomNumber < 101 Then →Current Distance = 27 to 60 km

ElseIf RandomNumber < (ProbabilityNumber + 1) Then → Current Distance = 0 km

<u>Full Code</u>

```
If YearlyDistance < 9501 Then
   ProbabilityNumber = (14629 - YearlyDistance) / 20.5
ElseIf YearlyDistance > 14000 Then
   ProbabilityNumber = (40000 - YearlyDistance) / 150
Else
   ProbabilityNumber = (23623 - YearlyDistance) / 55
End If
If ProbabilityNumber < 101
   ProbabilityNumber = 100 'maximum range for given hours of operation
End If
U = 6 ' set it to first line to start calculation
For I = 1 To 365 ' loop for all the days of a year
For U = U To U + WorkingHours - 1
Randomize
RandomNumber = Int((ProbabilityNumber) * Rnd + 1)
If RandomNumber < 10 Then
   Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = "1"
ElseIf RandomNumber < 21 Then
   Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = "2"
ElseIf RandomNumber < 33 Then
   Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = "3"
ElseIf RandomNumber < 43 Then
   Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = "4"
ElseIf RandomNumber < 57 Then
   RandomNumber2 = Int((2) * Rnd + 5) 'random km range between 5 and 6
   Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < 66 Then
   RandomNumber2 = Int((2) * Rnd + 7) 'random km range between 7 and 8
```

```
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < 76 Then
    RandomNumber2 = Int((3) * Rnd + 9) 'Random number between 9 and 11
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < 86 Then
    RandomNumber2 = Int((5) * Rnd + 12) 'random km range between 12 and 16
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < 94 Then
    RandomNumber2 = Int((10) * Rnd + 17) 'random km range between 17 and 26
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < 101 Then
    RandomNumber2 = Int((34) * Rnd + 27) 'random km range between 27 and 60
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = RandomNumber2
ElseIf RandomNumber < (ProbabilityNumber + 1) Then
    Worksheets("Energy Balance").Cells(U + StartWorkingTime, 6) = 0
End If
```

Nissan Leaf Specifications [cf. Nissan USA II, 2016]:

COMPARE UP TO
3 VERSIONS

- ☑ S
- ☑ SV
- ☑ SL

> Compare LEAF® to Competitors

			
	S Starting MSRP* $29,010 MORE DETAILS · BUILD & PRICE	**SV** Starting MSRP* $34,200 MORE DETAILS · BUILD & PRICE	**SL** Starting MSRP* $36,790 MORE DETAILS · BUILD & PRICE
− Key Features			
Range	Up to 84 miles*	Up to 107 miles*	Up to 107 miles*
MSRP	$29,010 Starting MSRP*	$34,200 Starting MSRP*	$36,790 Starting MSRP*
Motor	107 Horsepower	107 Horsepower	107 Horsepower
Features	• 24kWh lithium-ion (Li-ion) battery with 84 mile range [*] • 80 kW AC synchronous electric motor • Zero tailpipe emissions [*] • Nissan Intelligent Key® with Push Button Start • Bluetooth® Hands-free Phone System [*]	• Includes S features plus: • 30kWh lithium-ion (Li-ion) battery with 107 mile range [*] • Quick charge port • NissanConnect℠ with Navigation and Mobile Apps [*] • NissanConnect℠ EV [*]	• Includes SV features plus: • 30kWh lithium-ion (Li-ion) battery with 107 mile range [*] • Automatic on/off LED low-beam headlights • Fog Lights • Leather-appointed seats
− Mechanical			
ELECTRIC MOTOR			
80 kW AC synchronous electric motor	● Standard	● Standard	● Standard
24 kWh lithium-ion (Li-ion) battery	● Standard	⊗ Not Available	⊗ Not Available
30 kWh lithium-ion (Li-ion) battery	Not Available	● Standard	● Standard
3.6 kW onboard charger	● Standard	⊗ Not Available	⊗ Not Available
6.6 kW onboard charger [*]	○ Optional	● Standard	● Standard
BRAKES			
Front and rear vented disc brakes	● Standard	● Standard	● Standard
Regenerative braking system	● Standard	● Standard	● Standard
− Fuel Economy			
City Range[*]	126	124	124
Highway Range[*]	101	101	101
Combined Range[*]	114	112	112

Fig. 68 Nissan Leaf Specifications [cf. Nissan USA II, 2016]