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OFFICIAL MASTER'S DEGREE IN THE  
ELECTRIC POWER INDUSTRY

Master's Thesis

**Interaction between DER  
adoption decisions, tariff  
design and power system cost  
recovery**

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## **Abstract**

Increasing concerns over global warming, unstable prices of fossil fuels, pollution are only few of the reasons for the growth of the renewable generation. Renewable generation is supported at different levels, but lately distributed generation at the customer level started increasing. Unfortunately, distributed generation has its own disadvantages, and the main drawback is a deficit in the cost recovery and as the result, the cross-subsidization among consumers. In this thesis, the methodology to evaluate the effect of the tariff design on the cost recovery of the system when solar PV is installed is proposed. This methodology was used for the Spanish residential and commercial customers. Three models, Financial Model (Model I), DER-CAM (Model II) and Cost Recovery Model (Model III) were utilized. Firstly, monthly payable amounts for regulated activities for all tariff designs are calculated in model I. Secondly, the tariffs from the model I are utilized in the DER-CAM to find the annual deficit created by a PV owner. Then, these results are further used in the cost recovery model to analyze the system cost recovery deficit. This study compares the deficits created by various tariff designs under different scenarios of self-generation.

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# **1 Introduction**

## **1.1 General context**

The Oil Crisis of 1973 with its unpredictable prices for oil initiated the beginning of various policies that would lessen the future dependency on the oil and assure the security of supply. Aside from that, the finiteness of fossil fuels, which will need approximately 10,000,000 years to replenish for what we have utilized in 150 years. As well as the unprecedented increase in the greenhouse gas emissions that resulted in the accelerated global warming. Besides that, the high levels of pollution that are pumped into the local environment and that initiate public health problems and endanger environmentally sensitive areas, give rise to the necessity of cleaner energy sources. The promotion and expansion of renewable energy sources that would solve abovementioned problems have become one of the most significant topics of the century (Mason, 2017).

Renewable energy offers numerous benefits to the whole system. One of the most significant benefits is the minimal lifetime greenhouse emission that it gives out during manufacturing, installation, operation and maintenance, dismantling and decommissioning (UCS, 2013). Moreover, one more benefit that comes from renewables is the potential improvement in the public health. According to the study done by the (Machol & Rizk, 2013) only in the United States, approximately \$361.7 to \$886.5 billions are spent annually for health conditions connected to the utilization of fossil fuels. Furthermore, renewable energy gives the opportunity for many countries to diversify their energy supply, as the result lessen the dependency on the foreign

fossil fuels and avoid the critical situations similar to the Oil Crisis (The Alternative Daily, 2017). In addition to it, renewable energy sources, as the name says for it, provide an enormous and unlimited energy supply. Besides, the renewable energy brings different economic advantages. It is labor intensive, this means that there is more jobs created for each unit of energy generated compared to the fossil fuel energy, which is mostly automatized (UCS, 2013). Renewable energy has a stable fuel price, while the energy from fossil fuels is disposed to the unstable prices for the fuels. The analysis done by the (UCS, 2013) shows that if the standard of 25% of renewable energy is accepted then it would lead to the decrease of natural gas prices by 4.1%.

Investment in the renewable energy is increasing every year, both in the developed and developing countries. According to the report from (BNEF and UNEP, 2016) the money committed to the renewable energy excluding large hydroelectric projects increased 5% to \$285.9 billion surpassing the preceding record of \$278.5 billion of 2011. Moreover, by the end of 2015, renewable capacity in place could supply 23.7% of the global electricity (REN21, 2016).

## **1.2 Solar generation, smart-metering and distributed energy generation**

One of the fastest growing areas of renewable generation is solar energy, which had record additions for two consecutive years, 2015 and 2016. (REN21, 2016). As this area continues to grow, the manufacturing costs continue to fall. As it was mentioned by (Thetford, 2013), global PV module costs decreased by 62% between 2011 and 2013. In

addition to this, according to the (BNEF and UNEP, 2016) the global average levelized cost of electricity for crystalline silicon PV was \$122 per MWh in the second half of the 2015, while in 2014 it was \$143 per MWh.

Moreover, solar generation has experienced a noteworthy increase in the number of both, residential and industrial electricity consumers, who prefer to produce their own energy (REN21, 2016). This increase is not only connected to the decreasing prices of the PV technology, but as well as to the emergence of other technologies. One of such technologies is smart metering, which initially was used for the commercial and industrial customers due to the necessity of more sophisticated rates and detailed billing data (EEI, AEIC and UTC, 2011). There are various benefits of the smart meters and one of them is visibility. Smart meters allow consumers to see exactly how much energy they use and when they use this energy, so they can start utilizing energy more efficiently (Whitlock, 2015). Furthermore, according to the same source (Whitlock, 2015), smart-meters are essential for the integration of the renewable energy, since renewable energy is intermittent and smart-meters can finely balance this intermittency. Moreover, according to the (EC-JRC, 2017) cost of the smart meters averages between €200 and €250 per customer, while it approximately saves €160 for gas and €309 for the electricity per customer.

These different technologies, their decreasing manufacturing prices and benefits, accelerated the growth of the prosumers, i.e. customers who are both consumers and producers of the energy. Being a prosumer has many of the aforementioned benefits, but in addition, "it can reduce

some power losses due to network transmission and distribution, the network footprint, reserve generation capacity, etc.” (Khalilpour & Vassallo, 2015). However, the main problem that increasing number of prosumers bring is “living off-grid” or “leaving the grid” idea (Khalilpour & Vassallo, 2015). It is when the customers decide to leave the grid and produce their own energy, because producing their own energy may be equal or lower than the electricity prices from the utilities. The main problem behind this phenomenon is the cost-recovery concern, when the utilities still need to recover the costs, but the number of customers is decreasing. There may be two various outcomes of that, first one is when utilities may need to absorb the unpaid costs, which is usually referred to as a revenue erosion (Picciariello, Vergara, Reneses, Frias, & Soder, 2015). While the second one is when the utilities increase their tariffs in order to meet the revenue requirements, and users without distributed generation will have bigger exposure to the rates, so they will be cross-subsidizing the customers with self-generation (Picciariello, Vergara, Reneses, Frias, & Soder, 2015).

One of the efficient ways to solve the cross-subsidization issue is an appropriate tariff design and shorter net-metering design. However, it was also mentioned that the tariff design is more significant in the issue of cross-subsidization, rather than the net-metering (Eid, Reneses Guillén, Frías Marín, & Hakvoort, 2014). The same issue was investigated by (Borenstein, 2015) who looked at the role of the retail design in the installation of solar PVs. In his work, it was mentioned that the retail rate design is one of the most indirect incentives for installing the solar PVs, he stated that volumetric design is used to

incentives customers to invest into solar PVs. While, it can also be stated that with no fixed component and with predominantly volumetric component, there is a big possibility of acquiring cost recovery deficit.

Moreover, the tariff design in the time of the self-generation is a hot topic, both in the USA and Europe. According to the, (Bade, 2015) more than 20 states in the USA are raging about increasing fixed terms in the bills, while utilities claim that it is a necessary step for recovering the costs. The similar issue is being discussed in many of the European countries. According to the (Maincent,, Pienkowski, Kalantzis, & Johannesson Linden, 2014), several European countries have a deficit due to different reasons, but one of it was a tariffs that do not reflect the true costs. Since tariff design plays an important role in the cost recovery, as well as since cost recovery is a hot topic in different continents, it is of a great interest to study the impact of the tariff design in more depth.

### **1.3 Objectives**

The objective of this master thesis is to create a simplified methodology to assess the connection between DER adoption decisions, tariff design and power system cost recovery. In other words, this methodology will calculate the extent of cost recovery in different regulated activities, under various tariff designs and under different alternatives of self-generation. The developed methodology will be adaptable for different electricity systems, but in this specific study it will be utilized for the Spanish system.

The tariff designs used in this study are made up of different tariff terms, either volumetric, fixed, capacity or a mix of them. It is outside of the scope of this study to determine a new tariff design from the scratch. Moreover, this study also does not take into account storage units as batteries or electric vehicle (EV) options.

#### **1.4 Structure of the thesis**

After presenting the introduction into the subject and objectives of this master thesis, the chapter 2 will discuss similar works done on this topic. The chapter 2 will start with the brief introduction into the literature review and continue on the details of the renewable energy support in the European Union (EU). Afterwards, the particulars on the PV and battery technologies will be presented. Then, the case studies done on the related topic will be introduced.

Chapter 3 will cover the detailed problem description and methodology. Three different models will be presented. Model I is the financial model for tariff calculation, and complete information on the model I will be given in the methodology. In other words, the election of regulated activities, cost allocation to these activities; tariff design selection and calculation will be presented. Next, the model II, which is the Distributed Energy Resources Customer Adoption Model (DER-CAM) and its utilization in this master thesis, will be introduced. Afterwards, the model III, which is the cost recovery model and calculation of the deficit created by different tariff designs after the installation of solar PV will be explained.

Chapter 4 will cover the results obtained from this case study, and chapter 5 will present a brief conclusion on the work done.

## **2 Literature Review**

The first step that is investigated in the literature review is the existing renewable energy support in the European Union (EU). Then, the current PV technologies and the trend of the costs for the technologies are presented. It is followed by the available battery technologies and the development of their costs. Moreover, the detailed case studies on different tariff designs are introduced. It was considered significant to present the case studies done on the effect of different tariff designs, since as it was mentioned in the work by (Eid, Reneses Guillén, Frías Marín, & Hakvoort, 2014), tariff design plays initially more important role in the subject of cost recovery.

### **2.1 Renewable energy Support in EU**

One of the aims that European Union holds is the promotion of the renewable energy generation among the member countries. The main renewable target was published in Renewable Energy Directive, according to which "*the EU has to fulfill at least 20% of their total energy needs with renewables by 2020*". Moreover, EU is planning to become a global renewable energy leader and produce at least 27% of its energy from renewable energy sources (European Commission, 2017). In order to reach this aim, part of the electricity production has to be from the renewables, and this has to be supported on the governmental level. Nowadays, there are many different Renewable Energy Support (RES) schemes, such as feed-in-tariffs (FIT), feed-in-premiums (FIP), quota obligations, loan guarantees, soft loans, investment grants, tax incentives and tendering schemes.

Feed-in-tariffs (FIT) is a fixed price paid for per unit of energy (MWh) produced during a fixed time period. It is considered one of the reasons for a fast development of renewable energy generation, because it shields the investors from the risks of the electricity market. FIT is transparent and easy to implement, but one of the main disadvantages of it is calculating the appropriate levels of tariffs and adjusting them afterwards, since regulators have a right to change the tariff if needed (Erbach, 2016).

Feed-in-premiums (FIP) is a scheme that provides specific addition to the top of the market price. It is becoming widely popular, since it obliges renewable energy producers to be more efficient in the market. Moreover, with the FIP renewable energy can be sold both through the market and through the bilateral agreements (Erbach, 2016).

FIP can be either fixed or sliding, at a constant rate independent of market and at variable rate depending on market evolution accordingly. Fixed premium is considered simple in design, but there is a chance of overcompensation or undercompensation. In order to avoid them, FIP or total remuneration (FIP+market price) usually have minimum and maximum rate (floor and cap accordingly). While, sliding premium is calculated based on the difference between market prices and predefined reference tariff level (Energypedia, 2014).

Quota obligations are when government obliges energy distributors to produce specific part of its energy from renewable energy sources (RES). In case they cannot produce enough, distributors can obtain the tradable certificates

from RES producers. In the case of quota obligations, government sets the quantity and the market determines price (Erbach, 2016). Moreover, tenders are more seen as a "common design option" that is applied in combination with any other support schemes. While, the tax incentives are seen as a complementary to other support schemes (Held, Ragwitz, Gephart, de Visser, & Klessman, 2014).

## **2.2 PV technology**

Many different types of solar energy systems have been developed in the recent years. However, one with the highest addition rate is considered to be solar PV technology (Malinowski, Leon, & Abu-RUB, 2017). PV technology has many advantages, it is considered to have "quiet energy conversion, easy design and installation, nice architectural visibility, long lifetime with less maintenance requirement, easy transportation and lightweight, and acceptable price" (Malinowski, Leon, & Abu-RUB, 2017).

There are various PV cells available nowadays, but the dominant one in the market is mono-crystalline silicon (mono-Si), which comprises 69 percent of the market. It is followed by multi-crystalline Silicon (multi-Si) that makes up 24 percent, which is followed by Cadmium-Telluride (CdTe), Copper-Indium-Gallium-Selenide (CIGS) and Amorphous Silicon (a-Si) (Figure I).

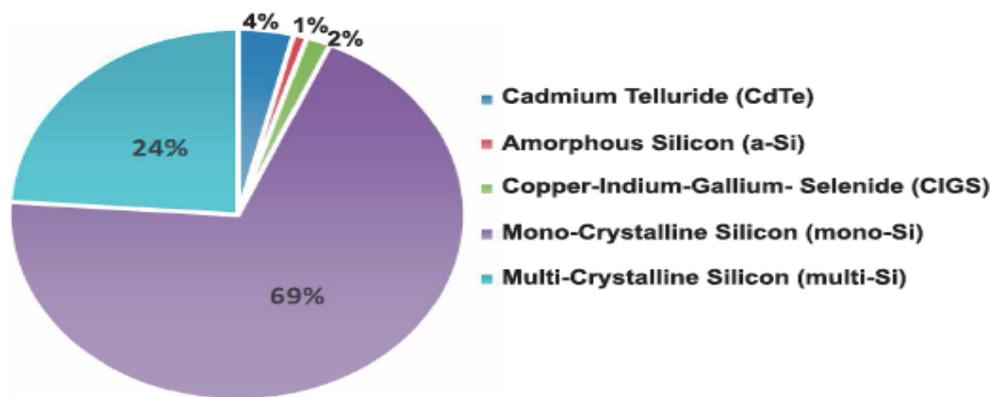


Figure I: Global PV Market Technology Percentages in 2015 (Source: (Malinowski, Leon, & Abu-RUB, 2017))

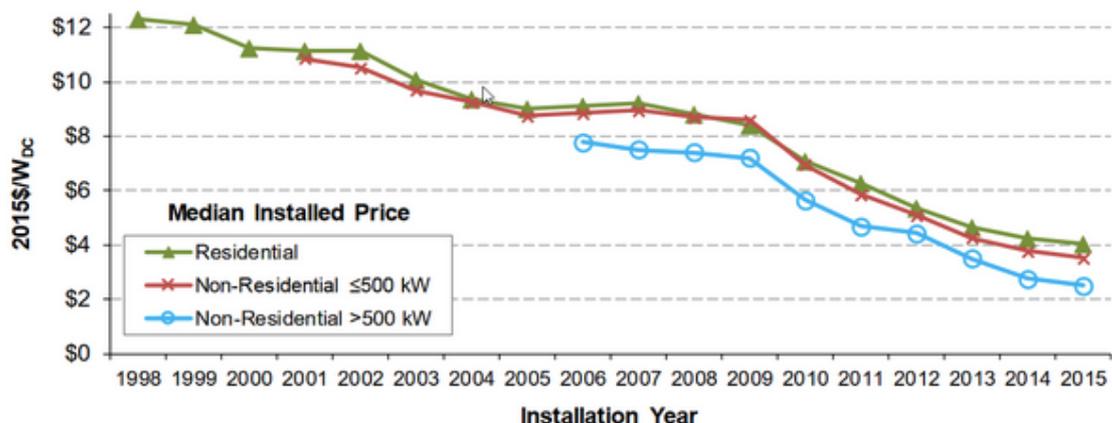
According to many different sources solar PV is one of the most promising technologies nowadays. The International Energy Agency (IEA) mentioned in its study that the global share of the solar PVs in the electricity generation would reach 16% by 2050 (IEA, 2014). The Renewable Energy Policy Network for the 21<sup>st</sup> Century (REN21) made a similar statement on the solar PV, where it mentioned that one of the highest capacity addition rates belonged to solar PVs. In addition to this, (Messenger & Abtahi, 2017) mention in their book that in the recent years the United States has seen the biggest grid-connected renewable capacity addition. It was stated that in 2014, 3776MW of solar energy was added, while in 2015 solar generation added 2598 MW of capacity.

Moreover, many economical studies about the solar PVs have been conducted. (Chung, Davidson, Fu, Ardani, & Margolis, 2015) have developed market segment-specific methodology that benchmarks prices of PV systems sold into residential, commercial and utility segments. They show in their report

that prices for PV systems for all segments (residential, commercial and utility) decrease.

In addition to it, in the article by (Malinowski, Leon, & Abu-RUB, 2017), they mention that there was a reduction of 56% in the total cost of PV systems, 77% in the PV modules, 45% in the inverter cost and 44% in the installations-related costs from 2009 to 2015.

Furthermore, in the study done by the Lawrence Berkeley National Laboratory (Barbose & Darghouth, 2016), it was mentioned that the installed costs for non-utility scale installations in the USA fell 6-12% per year from 1998 to 2015. From 2014 to 2015 the residential median costs in the USA decreased by 5% and non-residential ( $\leq 500$  kW) median costs declined by 7-9% (Figure II).



*Notes: Median installed prices are shown only if 20 or more observations are available for a given year and customer segment.*

Figure II: National Median Installed Solar Prices 1998-2015 (Source: (Barbose & Darghouth, 2016))

## 2.3 Battery Technology

Energy supplied from a distributed energy resources is impacted by a variable renewable energy sources. In order to balance this inconsistency there is a need for energy storage. Many studies have been conducted to see the

development of battery technology and to grasp the trend in the price evolution. Nowadays, there are four main types of batteries that are suitable for small-scale applications, such as residential and commercial buildings (Garimella & C.Nair, 2009). They are: Lead-Acid, Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH) and Lithium-Ion batteries.

- **Lead-Acid batteries** have been in the market for over a century. They are considered to be a viable solution due to its low maintenance necessities, easy installation, comparatively low self-discharge rates and cost-competitiveness (Garimella & C.Nair, 2009). However, the main disadvantages include "relatively limited cycle life, low-energy density, and a resulting large footprint, which can be a limiting factor in urban applications " (Baker, 2008).

- **Nickel Cadmium (NiCd) batteries** have been in the market as long as lead-acid batteries. The main advantages of these batteries are longer life cycle, higher energy-density and low maintenance requirements as well. While the major drawbacks are toxicity of the cadmium, as the result the recycling issues of it. As well as lower energy efficiencies and higher costs compared to lead-acid batteries, the NiCd batteries may cost up to 10 times more than lead-acid batteries (Hadjipaschalis, Poullikkas, & Efthimiou, 2009).

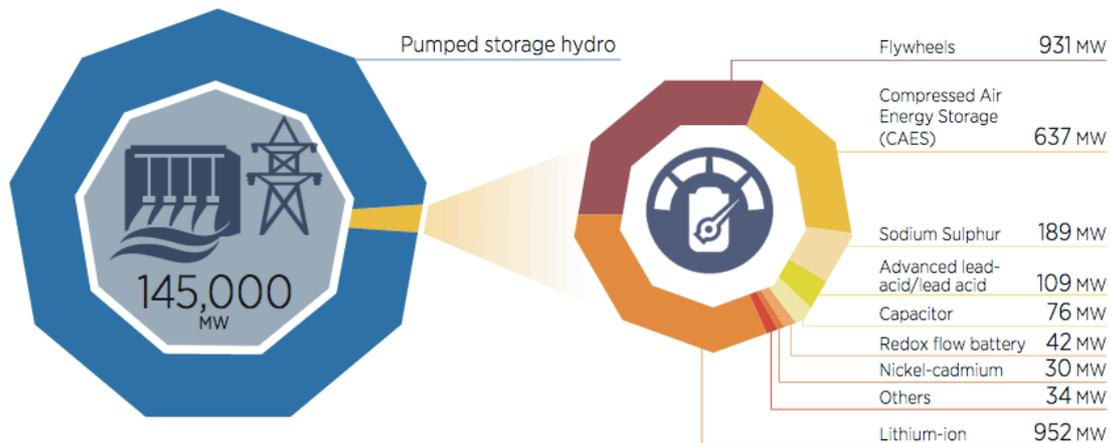
- **Nickel Metal Hydride (NiMH) batteries** have compact and light weighted structure. They can easily replace NiCd batteries, since they provide almost the same cycle life characteristics, but are also environmentally friendly (Garimella & C.Nair, 2009). The main disadvantage of the NiMH batteries is "severe self-discharge (up to 25% per

month), which means that valuable energy storage (long term) would be lost" (J.Hall & J.Bain, 2008) (J.Hall & J.Bain, 2008).

- **Lithium-Ion batteries** have "the highest energy density and an energy-storage efficiency of close to 100%" (J.Hall & J.Bain, 2008). This shows that lithium-ion batteries have the highest potential for future developments. Nevertheless, the main drawbacks include high cost and fragility. These batteries need protection circuit for safety, which results in the high costs (Chen, Cong, Yang, Tan, Li, & Ding, 2009).

Generally, there is a tendency of decreasing costs in the battery industry. The tendency of decreasing costs is connected not only to the renewable generation, but also to the economies of scale, manufacturing capacity, development of the electric vehicles (EV) and others (IRENA 2015). According to the conservative estimates, the general residential storage in Australia and Europe cost EUR 2000/kWh in 2015 and it is predicted to cost EUR 900/kWh in 2020. This shows that the payback period for this system decreases from 15 years to 9 years (IRENA, 2015). Furthermore, (IHS Markit, 2015) mentions that the lithium ion batteries lead the decrease in the prices of battery technology. They stated that on average the prices of lithium ion batteries fell 53 percent between 2012 and 2015, and by 2019 they are expected to decline by half. The same point is proved by the (BNEF and McKinsey&Company, 2016), which indicates that the cost of lithium-ion batteries experienced 65% reduction from 2010 to 2015, it fell from 1000\$/kWh to 350\$/kWh; and is expected to fall below 100\$/kWh in the next decade. Moreover, this tendency

of decreasing costs resulted in the significant shift towards lithium-ion batteries (IRENA, 2017). Lithium-ion batteries have the biggest global capacity among abovementioned electrochemical batteries with the capacity of 952 MW. While, the lead-acid batteries take up 109 MW and Nickel-Cadmium (NiCd) batteries make up 30 MW of capacity (Figure III).



*Note: Pumped storage data are for 2016; other data are for 2014.  
Source: IRENA, 2015h; pumped storage data from IHA, 2016*

**Figure III: Share of Various Storage Technologies in Global Electricity Storage System (Source: (IRENA, 2017))**

Moreover, additional cost reductions plus “Further, regulations are beginning to move away from an approach to grid services centered on fossil fuels. All these factors will continue to drive the use of battery storage in the electricity grid to unprecedented levels, albeit starting from a very low baseline” (IRENA, 2015).

## **2.4 Tariff design analyses on single and group of residential customers**

(Eid, Reneses Guillén, Frías Marín, & Hakvoort, 2014) examine the effect of different tariff designs and net metering in Spain on the cost recovery of the system and cross subsidy issues when PV systems are installed by residential customers. It was found out that the fixed tariff design is the best for the distribution system operator (DSO) because their income is not affected. However, this type of tariff design does not incentivize the efficient utilization of the network, and moreover it results in the cross-subsidies among the customers. In spite of its' simplicity, fixed tariff is not recommended to be used.

Moreover, it was also discovered that the energy tariff with the net-metering with increasing rolling credit timeframe decreases the income of the DSOs and results in the cross-subsidies. However, it also incentivizes customers to invest into solar PVs since this tariff type decreases the bill of the prosumer.

In addition to it, capacity tariff was examined and it was concluded that observed maximum capacity charging improves the cost-causality compared to the charging based on the contracted capacity. However, charging based on the network user's contribution to the system peak would improve cost-causality more. In general, if peak consumption does not occur simultaneously to the peak production, then distributed generation (DG) does not help to reduce the peak demand. Moreover, this tariff also incentivizes local storage and self-consumption, which helps for the security of supply and sustainability.

The similar issue of tariff design and net-metering effects for residential customers in the United States was investigated by (Barbose, Wiser, & R. Darghouth, 2011). However, in this paper the focus is given to the savings, the customer can make if he/she invests into the solar PV. It was found in this paper that the savings from the net-metering depend mostly on the tariff design used and it was concluded that inspecting the extent to which the tariff design affects the economics of net-metering is critical for the policymakers. Moreover, it was determined that inclining block rates provide greater incentive to invest into solar PVs, especially to the high usage customers. While, with the time-of-use (TOU) pricing customer's decision to invest into solar PVs depend on factors such as customer's load profile, the size of the PV system compared to the customer's load profile. However, when the solar PV meets only the small fraction of the customer's load, it was found out that TOU pricing yields lower savings than a non-time differentiated rate.

The analogous issue of influence of tariff design in the United States on the economics of the customers with the solar PVs was also investigated by (Mills, Wiser, Barbose, & Golove, 2008). The same point of the importance of tariff design was proved in this study. They used the value of PV utility bill savings per *kWh* generated, in order to see the difference between investing and not investing into solar PVs. According to this study, the effectiveness of capacity retail rate is dependent on the load profile of the customer. If customer's peak usage is in the afternoon, then there will be big savings since the peak production with solar PV is also at that period of the day. However, for the customers with flat or inverted (peak usage at

night) load profiles capacity rate is not useful for the savings of the customer. Furthermore, volumetric rates were considered to be good for the customers with any load profile. Moreover, TOU (time-of-use)-based volumetric rates are considered to be the best among all possible volumetric rate designs. Also, it was found out that volumetric rate is beneficial for the customer with both high and small PV penetration, while capacity rate is only good with small PV penetration.

Some other study looked into the possibility of going off-grid when the customers are joined as integrated community energy systems (ICES). In the study done by the (Prasad Koirala, Chaves Avila, Gomez, & A.Hakvoort, 2016) ICES optimization model, which is a mixed integer linear programming model, was solved in the GAMS (general algebraic modeling system) for Dutch households. The main objective of the model was to minimize annualized total energy costs. As reported by this study, having ICES is already a better option than being solely grid-supplied alternative, both in terms of decreasing costs and CO2 emissions. Moreover, it was also concluded that at this moment going off-grid is not an option, since for reliability reasons grid-defected systems need to be oversized, which in return will have big amounts of unused energy that will need to be curtailed. However, when the costs of storing the energy will decrease further improvements in the economics of the ICES, both grid-connected and grid-defected, can be anticipated.

Two more studies were done by (Speidel & Braunl, 2016) for Australian residential customer and by (EPRI, 2016) for American residential customer. The HOMER, a software tool for distributed generation power system design was utilized

to assist in sizing of the off-grid process for the American residential customer. After which, the financial analysis of the chosen model was made and profitability of the project was measured through NPC (Net Present Cost) and LCOLS (Levelized Cost of Load Served) of on-grid and off-grid options. While, in the Australian case the model for estimating the power usage and savings in energy costs from the mix of PV, storage and EV was used. According to both papers, going off-grid is not an option with the present technologies. In case customer wants to go off-grid 99.99% then cost per kWh of energy would cost 10 times more than energy from the grid (EPRI, 2016). Both investigations mention that solar PVs and storage system has to be oversized in case customer want to go off-grid, but this will results in the spillages during peak PV penetration. With the technology of nowadays, it is better to invest into PV and stay grid-connected.

This work will focus not only on the different tariff designs, but also on the various customer types, which are residential and commercial consumers. Moreover, the impact of the solar PV installation on the system cost recovery for both types of the consumers with different tariff designs will be analyzed. All of this will be adapted to the Spanish case.

### **3 Problem Description and Methodology**

#### **3.1 Problem Description**

Deficit in the cost recovery is a problem that affects different groups of customers, utilities, network owners and etc. In this specific case, deficit occurs due to the customers that own distributed energy resources (DER), and this issue is relevant to all countries that have a potential to have prosumers. The main problem with the deficit in the cost recovery is the consequences it can bring, such as cross-subsidies, when the customers without DER have to cover the costs that are not collected from the prosumers (Picciariello, Vergara, Reneses, Frias, & Soder, 2015). As the result, the costs will increase for those customers who obtain energy from the utilities, and even more people would have incentive to invest into DER and produce their own energy; this as the result, will expedite the defection of the grid (Khalilpour & Vassallo, 2015).

However, the extent of the deficit can be influenced by many factors that can be tailored in order to lessen the cross-subsidization. As it was mentioned before, one of the significant factors that impact the deficit is the tariff structure (Eid, Reneses Guillén, Frías Marín, & Hakvoort, 2014). Choosing the right tariff design may reduce the deficit in the cost recovery, as the result, it reduces cross-subsidization among customers to the point that it can be negligible. The aim of the following methodology is to evaluate the effect different tariff designs have on the cost recovery when the decision to invest into solar PVs is taken.

### **3.2 Methodology**

The proposed methodology focuses on the different tariff designs such as volumetric, fixed, peak charge and peak-capacity network charge tariffs. The research concentrates on the residential and commercial customers, who are considered to be low-voltage and medium-voltage consumers accordingly. Moreover, it examines the effect of different tariffs on the adoption of PV by end users through the Distributed Energy Resource Customer Adoption Model (DER-CAM) and assesses the extent of cost recovery.

The methodology that has been developed is as following:

- The structure of the costs' of regulated activities was characterized and assumptions were made in order to allocate these costs to different regulated activities.
- Possible tariff designs are identified through researches and papers done on this topic previously. Then, the proposed tariffs, for regulated part of the electricity system, are calculated in the model I.
- The tariffs calculated in model I are used as an inputs in the DER-CAM in order to get the necessary information for the model III.
- Energy purchases from the utility, tariffs, contracted capacity costs, upfront capital costs and peak capacity network charge costs are used as an inputs in model III in order to see the difference in the cost recovery between installing and not installing solar PV panels. Moreover, the monthly due payments for residential and commercial customers are calculated as well.

The following diagram illustrates the interaction among three models (Figure IV):

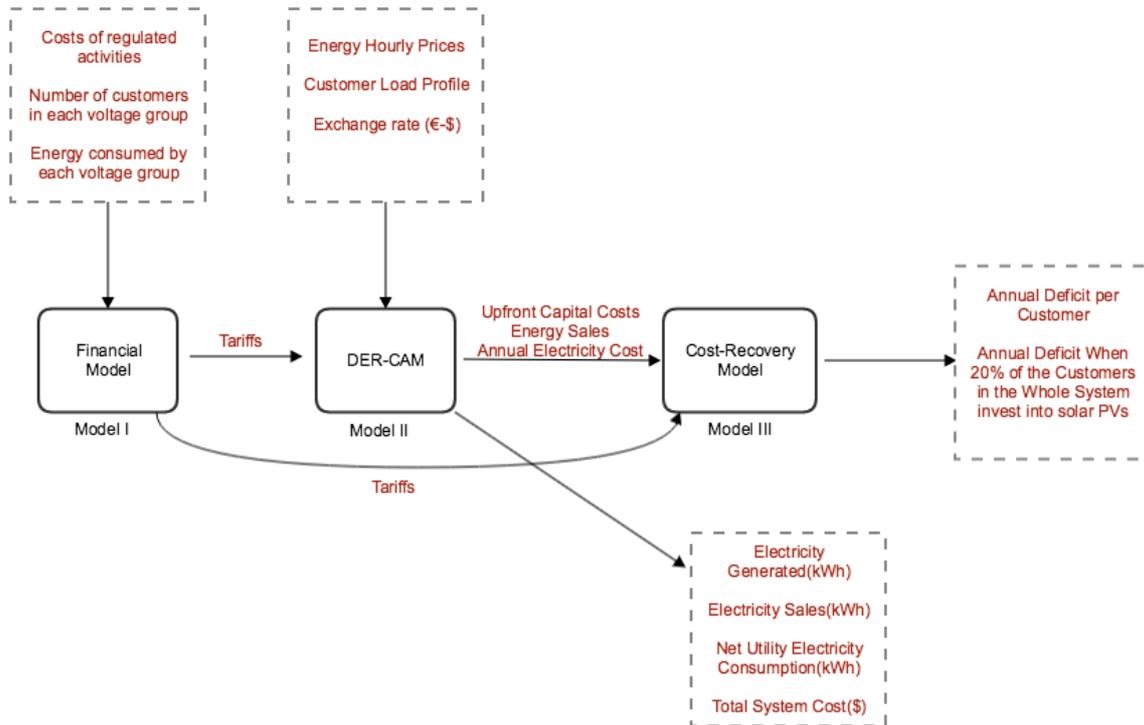


Figure IV: Interaction Among 3 Models

The chapter is organized as following, first of all, model I is reviewed and the process of cost allocation among regulated activities, and selection and calculation of tariff designs is explained. Secondly, the Distributed Energy Resource Customer Adoption Model (DER-CAM) is described and its utilization in this work is examined. Finally, the calculation of the difference in the cost recovery between PV and non-PV cases and monthly due payments of the customers is explained.

### 3.2.1 Model I

In this part of the methodology there are 4 main steps: selection of regulated activities, cost allocation among regulated activities, selection of tariff designs, and calculation of selected tariff designs. First the regulated

activities and cost allocation is explained, and then election of the tariff design and calculation is described in details.

#### *3.2.1.1 Regulated Activities Election*

Model I was built in the Microsoft Excel in order to assess the chosen tariff designs. In this model regulated part of the electricity system was considered. Important regulated activities were chosen based on the *report from the Spanish National Commission for Markets and Competition (CNMC, 2016)*.

The activities were divided as following:

- Distribution
- Transmission
- Renewable Energy Support (RES)
- Capacity Payment
- Interruptibility Service
- Other

Moreover, the reference value for the total cost was also based on the information *from the Spanish National Commission for Markets and Competition (CNMC, 2016)*. While, the cost allocation among these regulated activities was based on the information from *Annual Report by ACER (ACER/CEER, 2016)* and the website of *Red Electrica de España (REE, 2016)*.

#### *3.2.1.2 Cost Allocation Among Regulated Activities*

As it was previously mentioned the cost allocation among regulated activities was based on the *Annual Report by ACER (ACER/CEER, 2016)* and the website of *Red Electrica de España (REE, 2016)*. The following procedure was essential

since there is no detailed information on how the Spanish Ministry for Energy calculates the regulated tariffs, because of which certain assumptions had to be made based on the little information available. *Capacity payment* and *interruptibility service* values were calculated by using the "energy consumed by a customer type" from the report of the Spanish National Commission for Markets and Competition and "payments for each MWh of service by a customer type" from the website of Red Electrica de España (REE, 2016). The following formulas were used to calculate the values:

- *Payment for capacity service =*  
 $\sum \text{Energy consumed by a customer type} * \text{payment for capacity service by a customer type}$

- *Payment for interruptibility service =*  
 $\sum \text{Energy consumed by a customer type} * \text{payment for interruptibility service by a customer type}$

Where energy consumed is in *kWh* and payment is in *euros/kWh*.

- Percentages of Distribution, Transmission, RES and Other services

This step was essential due to the fact that because there is no tariff calculation methodology utilized in Spain. Therefore, it was impossible to clearly know how much of each regulated activity is allocated to each tariff category and component.

The composition of the final electricity price shows greatly varying percentages of each regulated activity

(Figure V). For example, energy makes up to 40 % of the final price of the electricity, while transmission makes up only 4% of the final price. Moreover, distribution is responsible up to 22% of the electricity price, whilst renewable energy support (RES) makes up to 16% of the electricity price. In addition, VAT amounts for 17% and other charges constitute 1% from the final price of the electricity.

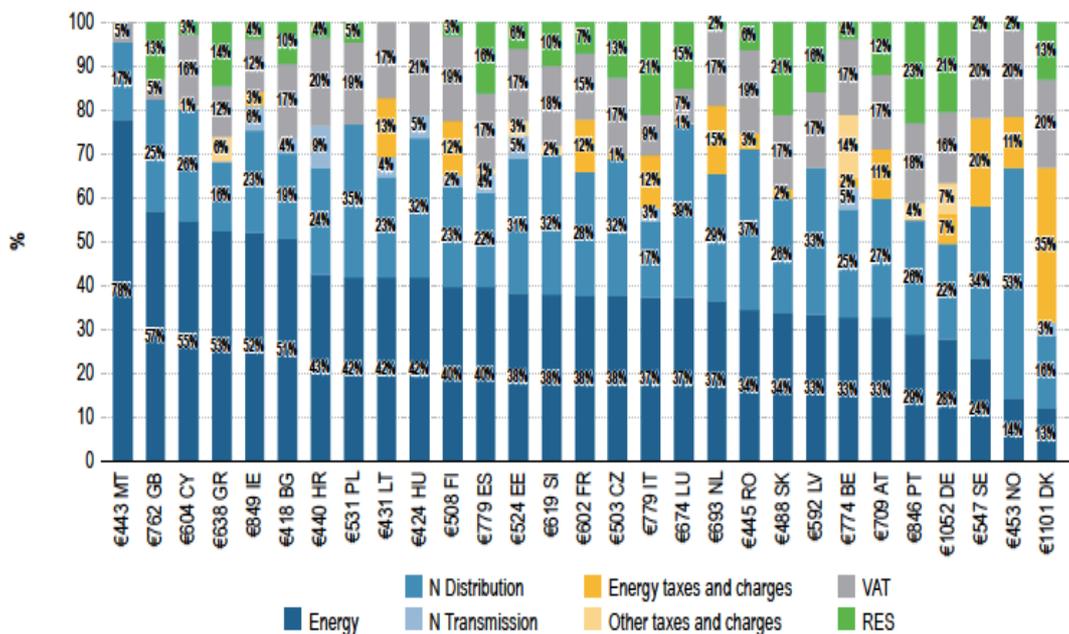


Figure V: POTP Electricity Break-down of the Incumbents' Standard Offers for Households in Capital Cities-November-December 2015 (%) ( Source: (ACER/CEER, 2016) )

However, the final percentages of *distribution*, *transmission*, *RES* and *other* activities without *energy*, *VAT* and *taxes* components had to be calculated. The following formula was utilized to find the percentages of the specific activity without *energy*, *VAT* and *taxes*:

- *Final % of the specific regulated activity =*

$$\frac{\% \text{ of the specific activity from the ACER} \times 100}{\text{Sum of the \% of transmission, distribution, RES and other}}$$

In order to find the due payments for other regulated activities *final percentage of the specific regulated activity* and the reference value for the total cost from the *Spanish National Commission for Markets and Competition (CNMC, 2016)* were used. Following formulas were utilized:

- *Annual Payment due without capacity and interruptibility services = the reference value for the total cost – (payment for capacity service + payment for interruptibility service)*

- *Payment value for specific activity = Final % of the specific regulated activity \* Annual Payment due without capacity and interruptibility services*

#### *3.2.1.3 Tariff Design Selection*

Different tariff designs were chosen based on the previous work done in this field, and based on the incentives they give to customers. Volumetric tariff incentivizes to increase self-generation since customers are charged per kWh of electricity bought from a grid. While under capacity tariff the costs are reduced only if the consumption reduces the peak-load. Under fixed tariffs customers are not encouraged to become energy-efficient since consumers are charged at a fixed rate despite the changes in the consumption. There are different structures within each tariff design and they are presented below:

- Volumetric tariff is charged per kWh consumed and can be easily implemented with conventional meters. Different volumetric tariffs are: 1) proportionate: consumers pay per kWh; 2) progressive: the tariff per kWh increases with an increasing consumption; 3) regressive: the tariff per kWh

decreases with an increasing consumption; 4) time-of-use (TOU): different tariff depending of the time of utilization (off/on peak) (European Commission, 2015).

- Capacity tariff are mainly capacity driven therefore costs depend on the peak load. Different capacity tariffs are: 1) flat: a fixed charge based on measured capacity (kW) or connected capacity (kVA); 2) variable: different capacity with different tariff per level; 3) time-of-use (TOU): different tariffs depending on the available grid capacity (requires smart meter). (European Commission, 2015)

- Fixed tariff: Unlike the tariff designs mentioned previously, fixed tariff does not depend on the customer behavior and may be billed on different temporal basis (monthly, semi-annually, annually). Fixed tariff is charged based on the number of customers. (Chaves Avila, Reneses , Abdelmotteleb, & Gomez San Roman , 2017)

Tariff designs utilized in this study are volumetric tariff, fixed tariff, peak charge tariff and peak coincidence network charge (PCNC) tariff. PCNC tariff is a forward-looking charge and it takes into account the future network reinforcements needed (Chaves Avila, Reneses , Abdelmotteleb, & Gomez San Roman , 2017). The charges are assigned to the consumer during the peak system consumption hours. Volumetric tariff is made up of energy term, while fixed tariff is made up of the fixed term only. Moreover, peak charge tariff is the combination of capacity and energy terms. Peak charge tariff is based on the individual peak of the customer. Whilst, peak coincidence network charge (PCNC) is an arrangement of capacity, fixed and

energy terms (Table 1) and it is based on the peak of the system.

<b>Volumetric Tariff</b>	<b>Fixed Tariff</b>	<b>Peak Charge Tariff</b>	<b>Peak Coincidence Network Charge</b>
Energy term	Fixed term	Capacity+Energy terms	Capacity+Fixed+Energy terms

Table 1: Different Tariff Designs Utilized in the Work

### 3.2.1.4 Tariff Design Calculation

#### **Purely Volumetric Tariff**

In the purely volumetric tariff, the total annual payment for the regulated activities is allocated through the energy term. The payment due to each customer based on the volumetric tariff was found through the formula:

- $$\frac{\text{Share of regulated costs allocated to the energy term}}{\sum \text{Energy consumed}}$$

where *share of regulated costs allocated to the energy term* is in euros and *total energy consumed* is in kWh.

#### **Purely Fixed Tariff**

In the purely fixed tariff, the total annual payment for the regulated activities is allocated through the fixed term. The payment due to each customer based on the fixed tariff was found through the following formula:

- $$\frac{\text{Total annual payment for regulated activities}}{\sum \text{number of consumers}}$$

where *total annual payment for regulated activities* is in euros and *total number of consumers* is in customers.

#### **Peak Charge Tariff**

The peak charge tariff is the current Spanish case tariff, which takes into account the peak capacity of the customer.

The payable costs are intended to be recovered through volumetric and capacity terms. The payment due to each customer based on the peak charge tariff was found through following formulas:

- **Network costs:**

- $$\frac{\text{Network costs}}{\text{Peak coincidence capacity of the customer}}$$

where *network cost* is in euros and *peak coincidence capacity of the customer* is in kW.

Moreover, *peak coincidence capacity of the customer* was found through the following steps:

- *Average value of the load of the customer for every month*  
*from hours 17:00 to 21:00 for low voltage customers*  
*OR from hours 9:00 to 14:00 for medium voltage customer*

The following hours were chosen in the cases mentioned above based on the peak demand of the consumer. It was noticed from the load data that the residential customer has the peak consumption from hour 17:00 to 21:00, while the commercial customer has the peak consumption from hour 9:00 to 14:00.

- *number of consumers in the specific customer type \* maximum value from all the average values found in the previous step*

where *maximum value from all the average values found in the first step* is in kW and *number of consumers in the specific voltage group* is in customers.

- **All other costs**

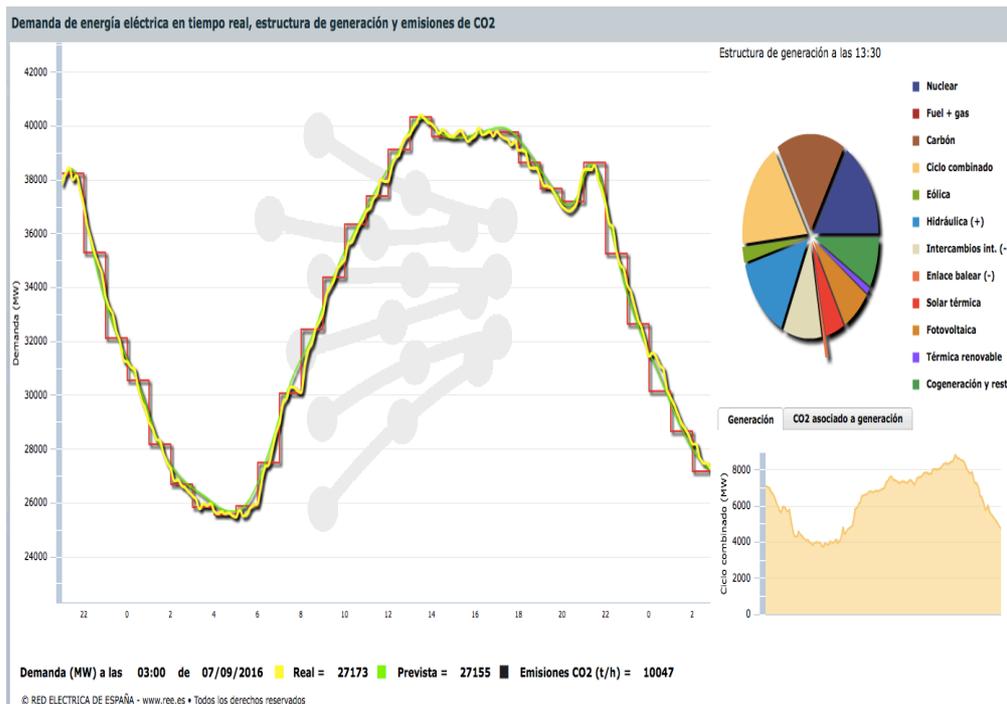
- $$\frac{\text{Total Regulated Costs} - \text{Network Costs}}{\sum \text{Energy consumed in the specific voltage group}}$$

where *total regulated costs-network costs* is in euros and *total energy consumed in the specific voltage group* is in kWh.

### **Peak Coincidence Network Charge (PCNC)**

In the Peak Coincidence Network Charge (PCNC) all three terms are used: volumetric, capacity and fixed. The main aim of the following tariff is to affect the consumption of the energy during the peak demand of the system since the network peak is the main reason for the network reinforcements, because when existing capacity of the network is not able to fully serve the demand that is when the reinforcements are essential (Chaves Avila, Reneses , Abdelmotteleb, & Gomez San Roman , 2017).

According to (REE, 2016), the peak demand of the whole system was chosen to be the 7<sup>th</sup> of September 2016 from 12 to 2 pm (Figure VI).



**Figure VI: Electricity Demand in Real Time, Generation Structure and CO2 Emissions (Source: (REE, 2016))**

In the following tariff, the 20% of the due network payment, which includes transmission and distribution, was recovered through the capacity term, while 80% of it was recollected through the fixed term. This division of the network payment was based on the paper by (Chaves Avila, Reneses, Abdelmottaleb, & Gomez San Roman, 2017), where 20% of the costs were assumed to be proportional to the network reinforcements necessary in the future. Moreover, capacity and interruptibility services were also allocated through the capacity term.

While, the RES payment was recovered through the volumetric term. The main reason for allocating RES to the volumetric term was the fact that this policy is directly connected to the electricity consumption. Different renewable policies, such as European Commission's "20-20-20" policy that targets the 20 percent of energy to be from the renewable

energy sources is an example of it. When the electricity consumption increases, then the payment for such services increases as a consequence (MIT and IIT-Comillas, 2016).

Other regulated activities were recovered through the fixed term to ensure the full recovery of the payments, since these payments are not connected to the electricity consumption or the peak capacity demand.

The payment due to each term was found in these steps:

1. The payment due for each of the regulated activities was divided among volumetric, fixed and capacity terms.
2. The total sum of volumetric, fixed and capacity terms among regulated activities was calculated.

**Step 1:**

- **Other Cost**

- $$\frac{\textit{Other cost}}{\sum \textit{number of consumers in the specific voltage group}}$$

where *other cost* is in euros and *total number of consumers in the specific voltage group* is in customers.

- **Renewable Energy Support Cost**

- $$\frac{\textit{Renewable Energy Support cost}}{\sum \textit{Energy consumed in the specific voltage group}}$$

where *renewable energy support cost* is in euros and *total energy consumed in the specific voltage group* is in kWh.

- **Network Costs:**

As previously mentioned 20% of the network costs were allocated through the capacity term:

- $$\frac{0.2 * \textit{Network costs}}{\textit{Peak coincidence capacity of the whole system}}$$

where *network cost* is in euros and *peak coincidence capacity of the whole system* is in kW.

Moreover, peak coincidence capacity of the whole system was found through the following formula:

- $$\frac{\text{number of consumers in the specific voltage group} * \text{average of the load for the consumers in the specific voltage group}}{\text{from hours 12:00 to 14:00 from the 7th of September 2016}}$$

where average if the load for the consumers in the specific voltage group is in kW and number of consumers in the specific voltage group is in customers.

Other, 80% of the network costs is allocated through the fixed tariff:

- $$\frac{0.8 * \text{Network costs}}{\text{Number of consumers in the specific group}}$$

where network costs are in euros and number of consumers in the specific group is in customers.

#### • **Capacity and Interruptibility Services Costs**

Capacity and Interruptibility Services Costs were allocated based on the peak coincidence capacity of the whole system as well. The following formulas were utilized:

- $$\frac{\text{Capacity service cost}}{\text{Peak coincidence capacity of the whole system}}$$

- $$\frac{\text{Interruptibility service cost}}{\text{Peak coincidence capacity of the whole system}}$$

where services costs are in euros and peak coincidence capacity of the whole system is in kW.

#### **Step 2:**

In this final step of PCNC tariff the total sum of fixed, volumetric and capacity terms among regulated activities is found.

- Fixed:

*Other + Network*



investment and planning of distributed energy resources (DER) in the houses and microgrids (Stadler, Baldassari, Forget, & Wagner , 2016).

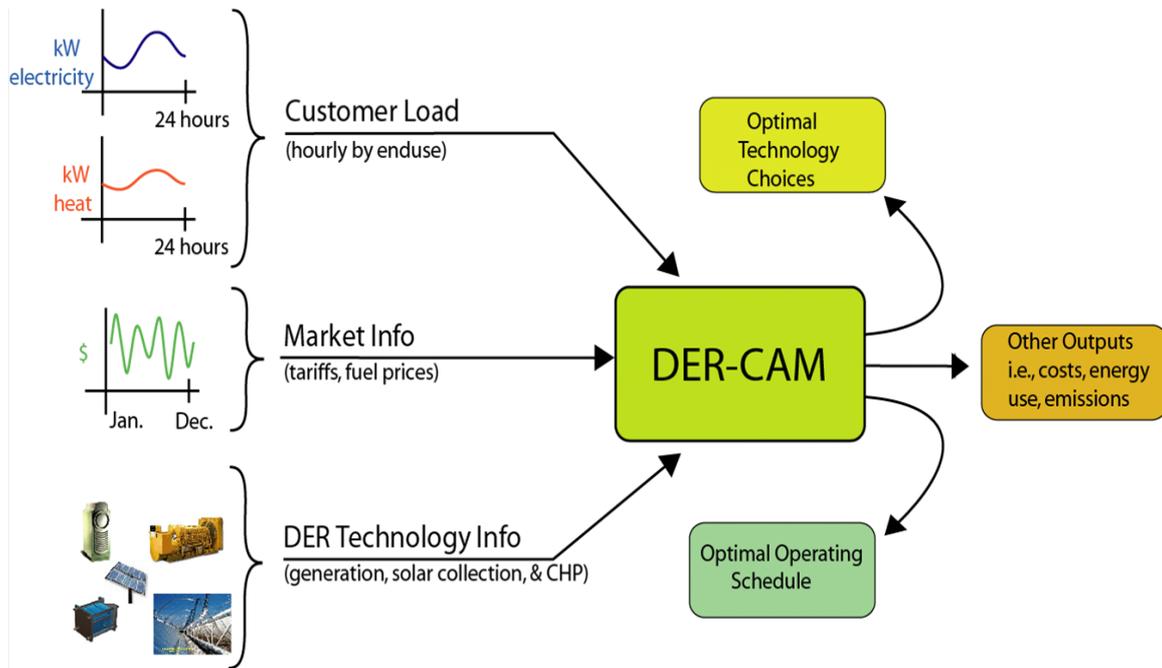
DER-CAM chooses optimal portfolio of technologies that minimizes the total energy cost or carbon dioxide (CO<sub>2</sub>) emissions, or even both at the same time. The main inputs in DER-CAM are:

- Customer's load profile, which include electricity, electric refrigeration and cooling, space heat, hot water and natural gas only data.
- Customers electricity tariff, natural gas prices and other price data.
- Capital costs, operation and maintenance costs, fuel costs associated with different technologies, and discount rate on customer's investment and maximum allowed payback.
- Basic technical performance indicators of generation and storage technologies.

Moreover, DER-CAM gives such outputs as:

- Optimal capacity of DER.
  - Detailed economic results.
  - Optimized strategic dispatch of all DER
- (Stadler, Baldassari, Forget, & Wagner , 2016)

The work process of the DER-CAM is illustrated below ((Figure VIII)).



(Figure VIII: The work process of the DER-CAM (Source: (Stadler M. , 2009))

DER-CAM was utilized in many different studies before. One of those studies was done by (Momber, et al., 2010) where integration of the plug-in electric vehicles (PEV) into a building's Energy Management System (EM) was analyzed. The relationship between them was analyzed through the DER-CAM, which finds the optimal equipment combinations to meet microgrid requirements at minimum cost, carbon footprint or other criteria. Moreover, (Chandran , Firestone, Siddiqui, Stadler, Venkataramanan , & Marnay, 2007) utilized DER-CAM in the election of optimal technology for commercial buildings. In their study the optimal technology combination for commercial building, the hotel, was analyzed in four different cases:

1. A *do nothing* case, when all investments are disabled
2. An *invest run* which finds the optimal investment
3. A *low storage price* run as sensitivity
4. A *low storage price but with no storage*, in order to assess the value of storage systems.

Many more similar studies that investigate the optimal technology combination, the optimal DER investment has been carried out through the utilization of the DER-CAM.

### 3.2.3 Model III

The model III is a financial model executed in Microsoft Excel. It was built in order to assess the impact of each tariff design on a cost recovery of the system. In order to carry out the process of assessment, outputs from DER-CAM and model I are used as an inputs in the model III. Moreover, the breakdown of the costs by regulated activities was also presented below.

The given figure is the illustration of the Model III(Figure IX):

Volumetric tariff deficit									
	Utility Energy consumption(kWh)	tariff(euro/kWh)	Yearly payable by building for regulated part(EUROS)	Total Annual difference between PV and non-PV for one customer	Number of customer in the system	Total Annual difference between PV and non-PV in the whole system			
WITH PV 100%	156431.3179	€ 0.05	€ 8,228.86	1089.75	88855	€ 96,830,085.16	This is the worst case scenario		
WITHOUT PV	177147.6375	€ 0.05	€ 9,318.61						
20% PV penetration					17771	€ 19,366,017.03	This is if the 20% of the customer is volumetric		
							WITH PV per customer	685.738129	
							NO PV per customer	776.550956	
Spanish case									
	Utility Energy consumption(kWh)	tariff(euro/kWh)	Yearly payable by building for regulated part(EUROS)	ANNUAL Difference between PV and NON-PV case PER CUSTOMER					
WITH PV	156431.3179	0.013377416	2092.646822	277.1308262					
WITHOUT PV	177147.6375	0.013377416	2369.777648						
			monthly payable by a building	Payable monthly	volumetric	capacity			
WITHOUT PV	capacity contracted per building	33.0672	278.2565578	WITH PV per customer monthly	174.387235	220.6531902			
Tariff (euro/kW)	33.362	280.7372648	30.165	NO PV per customer monthly	197.481471	257.2633928			
8.414881146	28.2721	253.8348898	28.3988						
	28.2721	237.9063613	31.1365						
	28.3988	238.9725267	31.1365						
	31.1365	262.0099468	33.9028						
	33.9028	285.2880325	30.6913						
	30.6913	258.2636417	30.518						
	30.518	256.8053428	28.2025						
	28.2025	237.3206855	28.7936						
	28.7936	242.2947218	30.3594						
	30.3594	255.4707427							
			monthly payable by a building	Difference between PV and NON-PV case					
WITH PV	capacity contracted per building	30.1505	253.712874	24.54368384					
Tariff (euro/kW)	30.4452	256.1927395	30.4452	24.54452533					
8.414881146	26.5113	223.0894385	30.74545124						

Figure IX: Representation of Model III

### 3.2.3.1 Assessment of Deficit of Regulated Activities

In order to see the impact that a specific tariff has on the system, two different cases were looked at.

- People in the examined site that invest in the DER.
- People in the examined site that do not invest in the DER.

The deficit and the monthly amounts payable for the customers for regulated activities will be analyzed in this part. The difference in the yearly payable amount between two cases is the deficit for that specific site.

The general procedure will be presented below, however not all terms would be relevant in every tariff design.

- In order to find the deficit that occurs due to the **volumetric term**, the following formulas were utilized:

- Payable amount **with** investment in the DER:

$$\text{Utility Energy Consumption} * \text{tariff}$$

where Utility Energy Consumption is in *kWh* and tariff is in *euro/kWh*.

- Payable amount **without** investment in the DER:

$$\text{Utility Energy Consumption} * \text{tariff}$$

where Utility Energy Consumption is in *kWh* and tariff is in *euro/kWh*.

- **Deficit** due to the volumetric term:

$$\text{Payable amount without investment in the DER}$$

$$- \text{Payable amount with investment in the DER}$$

where both payable amounts are in *euros*.

- In order to find the deficit that occurs due to the **capacity part** of the PCNC, following formulas were utilized:

- Payable monthly amount **without** investment:

$$\text{Capacity contracted} * \text{capacity tariff}$$

where Capacity contracted is in kW and capacity tariff is in euros/kW per month.

- Payable monthly amount with investment:

$$\text{Capacity contracted} * \text{capacity tariff}$$

where Capacity contracted is in kW and capacity tariff is in euros/kW per month.

- Deficit in PCNC for every month:

$$\text{Payable amount without investment in the DER}$$

$$- \text{payable amount with investment in the DER}$$

where both amounts are in euros.

- In order to find the total deficit, the following formula was utilized:

- Total Monthly Deficit:

$$\text{Monthly Deficit due to the Volumetric Term}$$

$$+ \text{Monthly Deficit due to the Capacity Term}$$

where both amounts are in euros.

### 3.2.3.2 Breakdown by Regulated Activities

In order to see the impact that a specific tariff has on the system, two different cases were looked at.

- People in the examined site that invest in the DER.
- People in the examined site that do not invest in the DER.

Costs for six different activities were compared in two cases, and these activities are presented below:

- Network
- RES
- Other Regulated Costs

- Energy Purchase
- Energy Sales
- Upfront Capital Costs

\**Energy Sales, Upfront Capital Costs* are the outputs of DER-CAM, while *Energy Purchase* is found through the *Annual Electricity Costs* of DER-CAM results.

Where,

- *Network = Transmission + Distribution*
- *Other Regulated Costs = Interruptibility + Capacity + Other*

And

- *Annual Electricity Cost = Energy Purchase + Annual Capacity Cost + Annual PCNC Cost +*

*Total Regulated Activity Cost recovered through the energy term.*

\*Depending on the design analyzed some terms would not be relevant

And

- *Total Regulated Activity Cost recovered through the energy term = Annual Electricity Consumption from the Utility \* Sum of tariffs of Regulated Activities recovered through the energy term*

### **Purely Volumetric Tariff**

In the volumetric tariff all regulated activities are recovered through the energy term and there is no *annual capacity cost* or *annual PCNC cost*.

**Peak Charge Tariff**

In the peak charge tariff all the regulated activities, except the network are recovered through the energy term. While, the network is recovered through the capacity term and it is known as "*annual capacity cost*".

**Peak Coincidence Network Charge (PCNC)**

In the peak coincidence network charge (PCNC) RES is recovered through the energy term. While, 80% of the network costs and all other regulated costs are recovered through the fixed term. Moreover, 20% of the network costs, capacity costs and interruptibility costs are recovered through the capacity term and it is known as "*annual PCNC cost*".

## 4. Case Study and Results

In this section the case studies that were run for the city of Madrid, Spain would be discussed. Two different case studies, one for residential and other for commercial customers, were carried out. In the residential case study, the building with 16 apartments in the city of Madrid was considered. While, in the commercial customer case one independent customer of the Madrid city was studied. First the background on the case study will be presented and afterwards the data utilized will be presented. Later, the results for PV and non-PV cases will be introduced.

### 4.1 Data

#### 4.1.1 Rooftop area

The information on the rooftop area was taken from (Ordóñez, 2010). According to it, the standard area for a residential building is  $35\text{m}^2$ , while it is  $140\text{m}^2$  for the commercial customers (Table 2). Moreover, in order to see the difference that the available rooftop area can make, two more scenarios were analyzed. These scenarios are as following: 1) when the rooftop area is doubled and 2) when the rooftop area is unlimited.

	<b>Residential Rooftop Area (<math>\text{m}^2</math>)</b>	<b>Commercial Rooftop Area (<math>\text{m}^2</math>)</b>
Standard	35	140
Doubled	70	280
Unlimited	unlimited	unlimited

Table 2: Rooftop Area for Residential and Commercial Customers

#### 4.1.2 Electricity Prices

Electricity prices were taken from (REE, 2016) for the Spanish market. The hourly prices for the year 2016, for 8784 hours were utilized. For this specific case study, electricity prices were normalized through the following steps:

- Electricity prices were classified by days of the week (1 being Monday and 7 being Sunday) and every day is made up of 24 hourly data.
- One average value for the data from day 1 to day 5 (Monday-Friday) was found for **each hour** of **every month**. Then it was called a **week** price.
- One average value for the data from day 6 to day 7 (Saturday-Sunday) was found for **each hour** of **every month**. Then it was called a **weekend** price.
- One maximum value for the data from day 1 to day 7 (Monday-Sunday) was found for **each hour** of **every month**. Then it was called a **peak** price.
- The final data set had 864 hourly data for weekday, weekend and peak of every month of the year.

#### 4.1.3 Customer Load Profile

The customer load profile for residential customers was simulated by the use of the eQUEST software (Associates, 2016). The load for the residential customer is the representative load for the building with 16 apartments of Madrid. While the commercial load was based on the information from both (IIT, 2017) and (CNMC, 2016).

#### **4.1.4 Exchange and Discount Rates**

The data source for the exchange rate was taken from (XE, 2017). The exchange rate of 1.09 was used in order to convert the tariffs for regulated activities that were in € into \$. While, the discount rate has already been provided in the DER-CAM code, since the DER-CAM has been previously utilized by the IIT.

#### **4.1.5 Costs of Regulated Activities**

The costs of regulated activities were taken and distributed into different components based on the information from (CNMC, 2016), (ACER/CEER, 2016) and (REE, 2016). The following procedure was necessary since there is no thorough information on how the Spanish Ministry for Energy allocates the costs of regulated activities to tariff categories and tariff components. It was presumed that the calculations made based on the information from abovementioned sources are closely related to the real data. The steps followed for the calculation of the values are presented in the methodology of this work.

#### **4.1.6 Number of Customers and Energy Consumed**

Energy consumed and number of customers for the year 2016 were taken from the (CNMC, 2016). For residential customers the data for all low voltage consumers, including tariff categories 2.0A, 2.0 DHA, 2.0DHS, 2.1A, 2.1DHA, 2.1DHS and 3.0A were utilized. While for the commercial customers only data for the 3.1A consumers was used. The table below provides the data used (Table 3):

	<b>Residential Customers</b>	<b>Commercial Customers</b>
Number of Customers	29,056,340	88,855
Energy Consumed (MWh)	110,999,000	15,582,000

Table 3: Number of Customers and Energy Consumer

## 4.2 Results

In this section results for two different customer types residential and commercial, will be provided. Moreover, two different scenarios with alternative regulation for self-generation i.e. with sales (hourly energy surplus is remunerated at market prices) and no sales (prosumers are not remunerated for the surplus they inject back into the grid) for 3 models will be subsequently presented.

Residential customers in Spain are divided into three groups, depending on the power contracted. Those with the power contracted less than or equal to 10 kW, those with power contracted more than 10 kW but less than or equal to 15 kW and those with the power contracted more than 15 kW. However, in this work, residential customers were looked at as one group. Moreover, there are types of the commercial customers in Spain: 3.1A, 6.1A and 6.1B. However, in this specific work customers of 3.1A group will be looked into.

### 4.2.1 Model I

The following tables show the amount payable by each tariff term for every regulated activity in each tariff design.

In the table below for the residential customers, the following can be noticed:

- The distribution makes up the biggest part of the whole sum of regulated activities with the value of \$5,251,568,427.83 While, the lowest sum belongs to the interruptibility service with the value of \$234,718,485.40
- Moreover, the volumetric term is based only on the energy term. Fixed tariff encompasses only fixed term. While, peak charge tariff is made up of both energy and capacity term and PCNC tariff includes all three terms (Table 4).

Regulated Activity	Annual Payable Amount(\$)	Term	Volumetric Tariff	Fixed Tariff	Peak Charge Tariff	PCNC Tariff
Distribution	5,251,568,427.83	Energy term(\$/kWh)	0.047	0	0	0
		Capacity term(\$/kW)	0	0	3.065	2.562
		Fixed term(\$/customer)	0	15.061	0	12.049
Transmission	953,898,171.46	Energy term(\$/kWh)	0.009	0	0	0
		Capacity term(\$/kW)	0	0	0.557	0.465
		Fixed term(\$/customer)	0	2.736	0	2.189
RES	3,815,592,685.84	Energy term(\$/kWh)	0.034	0	0.034	0.034
		Capacity term(\$/kW)	0	0	0	0
		Fixed term(\$/customer)	0	10.943	0	0
Capacity payment	493,624,049.00	Energy term(\$/kWh)	0.004	0	0.004	0
		Capacity term(\$/kW)	0	0	0	1.204
		Fixed term(\$/customer)	0	1.416	0	0
Interruptibility Service	234,718,485.40	Energy term(\$/kWh)	0.002	0	0.002	0
		Capacity term(\$/kW)	0	0	0	0.573
		Fixed term(\$/customer)	0	0.673	0	0
Other	235,910,300.47	Energy term(\$/kWh)	0.002	0	0.002	0
		Capacity term(\$/kW)	0	0	0	0
		Fixed term(\$/customer)	0	0.677	0	0.677
Total(\$)	10,985,312,120.00	Energy term(\$/kWh)	0.099	0	0.043	0.034
		Capacity term(\$/kW)	0	0	3.622	4.804
		Fixed term(\$/customer)	0	31.506	0	14.914

Table 4: Monthly Payable Amounts for Residential Customer for Each Regulated Activity

In the last rows of the table, the total amounts payable for each term by every tariff design can be noticed. With the volumetric tariff, monthly due payment for residential customers for regulated activities is 0.099\$/kWh, while with the fixed term 31.506 is due for the regulated activities monthly. In the peak charge tariff case, the energy term payment due is 0.043\$/kWh and capacity term due is 3.622 \$/kW monthly. The last one, PCNC tariff has the

energy term of 0.034\$/kWh, 4.804\$/kW monthly and 14.914\$/customer monthly (Table 4).

The table below provides the results for commercial customer. According to the results obtained (Table 5):

- The biggest amount among regulated activities belongs to the distribution with the value of \$566,298,205.11. While, the smallest amount in the commercial customer case belongs to other regulated activities with the amount of \$8,129,487.93.
- In this case, as in commercial case tariff designs follow exactly the same pattern with the inclusion of specific tariff terms in their structure.

Regulated Activity	Annual Payable Amount(\$)	Term	Volumetric Tariff	Fixed Tariff	Peak Charge Tariff	PCNC Tariff
Distribution	566,298,205.11	Energy term(\$/kWh)	0.036	0	0	0
		Capacity term(\$/kW)	0	0	7.796	1.638
		Fixed term(\$/customer)	0	531.107	0	424.886
Transmission	99,934,977.37	Energy term(\$/kWh)	0.006	0	0	0
		Capacity term(\$/kW)	0	0	1.376	0.289
		Fixed term(\$/customer)	0	93.725	0	74.980
RES	127,361,977.58	Energy term(\$/kWh)	0.008	0	0.008	0.008
		Capacity term(\$/kW)	0	0	0	0
		Fixed term(\$/customer)	0	119.447	0	0
Capacity payment	58,765,954.80	Energy term(\$/kWh)	0.004	0	0.004	0
		Capacity term(\$/kW)	0	0	0	0.850
		Fixed term(\$/customer)	0	55.114	0	0
Interruptibility Service	32,949,697.20	Energy term(\$/kWh)	0.002	0	0.002	0
		Capacity term(\$/kW)	0	0	0	0.476
		Fixed term(\$/customer)	0	30.902	0	0
Other	8,129,487.93	Energy term(\$/kWh)	0.001	0	0.001	0
		Capacity term(\$/kW)	0	0	0	0
		Fixed term(\$/customer)	0	7.624	0	7.624
Total(\$)	893,440,300.00	Energy term(\$/kWh)	0.057	0	0.015	0.008
		Capacity term(\$/kW)	0	0	9.172	3.253
		Fixed term(\$/customer)	0	837.920	0	507.490

Table 5: Monthly Payable Amounts for Commercial Customer for Each Regulated Activity

The total amounts payable for the commercial customer are presented in the last rows of the table as well. In the volumetric tariff case the amount due is 0.057\$/kWh and with the fixed tariff it is 837.920\$/customer monthly. Moreover, in the peak charge tariff case the volumetric

term is 0.015\$/kWh and capacity term is 9.172\$/kW. In the PCNC case volumetric term is 0.008\$/kWh, capacity term is 3.253\$/kW monthly and fixed term is 507.490\$/customer monthly (Table 5).

#### 4.2.2 Model II

The annual results from DER-CAM are provided below. Two different scenarios, sales back to the grid and no sales were analyzed for all tariff designs of both customer types. In the case of the residential table, the annual results for the building, which includes 16 apartments, are delivered below in (Table 6).

Scenario	Roof Surface(m2)	Tariff	Installed Capacity: Photovoltaic (kW)	Electricity Generated(kWh)	Electricity Sales(kWh)	Net Utility Electricity Consumption (kWh)	Ratio of the Energy Produced Over Total Demand of the Building(%)	Ratio of the Installed Capacity of the Solar PV Over the Contracted Capacity of the Building(%)
No PV	ALL	All	0	0	0	71429.29	0%	0%
Sales	35	Volumetric	5.35	5179.08	0	66250.21	7.3%	6.7%
		Fixed	0	0	0	71429.29	0%	0%
		Peak Charge	5.35	5179.08	0	66250.21	7.3%	6.7%
		PCNC	5.35	5179.08	0	66250.21	7.3%	6.7%
	70	Volumetric	10.70	10358.16	69.67	61140.80	14.5%	13.4%
		Fixed	0	0	69.67	71429.29	0%	0%
		Peak Charge	10.70	10358.16	69.67	61140.80	14.5%	13.4%
		PCNC	10.70	10358.16	69.67	61140.80	14.5%	13.4%
	Unlimited	Volumetric	69.87	67619.59	39370.09	43179.79	94.7%	87.4%
		Fixed	0	0	0	71429.29	0%	0%
		Peak Charge	48.05	46499.97	21379.19	46308.52	65.1%	60.1%
		PCNC	50.51	48883.22	23320.34	45866.41	68.4%	63.2%
No sales	35	Volumetric	5.35	5179.08	0	66250.21	7.3%	6.7%
		Fixed	0	0	0	71429.29	0%	0%
		Peak Charge	5.35	5179.08	0	66250.21	7.3%	6.7%
		PCNC	5.35	5179.08	0	66250.21	7.3%	6.7%
	70	Volumetric	10.70	10288.49	0	61140.80	14.4%	13.4%
		Fixed	0	0	0	71429.29	0%	0%
		Peak Charge	10.70	10288.49	0	61140.80	14.4%	13.4%
		PCNC	10.70	10288.49	0	61140.80	14.4%	13.4%
	Unlimited	Volumetric	34.04	21747.21	0	49682.08	30.5%	42.6%
		Fixed	0	0	0	71429.29	0%	0%
		Peak Charge	22.84	17756.42	0	53672.87	24.9%	28.6%
		PCNC	19.89	16380.90	0	55048.39	22.9%	24.9%

Table 6: DER-CAM Output for Residential Customer

The primary takeaways from the results of residential customers are as following:

- With the roof surface of 35m<sup>2</sup> residential customers invest into the solar PV of 5.35 kW capacity, but all the energy generated is utilized by the site itself, none of the energy is sold back to the grid in both no sales and sales scenarios. This shows that the average roof surface available in Madrid for the residential building may not even be sufficient enough to fulfill the needs of customers.
- While when the roof surface of 70m<sup>2</sup> is available, people also double the capacity of the solar PV to the 10.70 kW. At this point there is a 69.67kWh sale back to the grid. This shows that when the roof surface is doubled the energy produced by the solar PV is enough to fulfill the demand at that moment.
- Moreover, when the area is unlimited and there is a sale back to the grid, PCNC tariff has a bigger capacity than peak charge tariff, 50.51kW and 48.05kW accordingly, which is directly connected to the charging time of the tariff. PCNC tariff in the residential case is charged between 12:00 and 14:00, which incentivizes to have higher capacity of the solar PV and its penetration due to the concurrence with the peak hour of the sunshine. While, peak charge tariff in the residential case is charged from 19:00 to 21:00, which is not the time of solar PV generation, so it lessens the motivation to invest into bigger capacity.
- One common point is that it is profitable for the building to install PV panels up to a maximum available surface under all tariff designs except the purely fixed one.

- Following conclusions can be made based on **the ratio of the energy produced locally over total demand of the building**. When the roof surface of 35m<sup>2</sup> is available, both sales and no sales cases, have the same ratio of the 7.3%. While, with the roof surface of 70m<sup>2</sup>, sales case has the ratio of 14.5% and no sales case has the ratio of 14.4%.
- **The ratio of the energy produced locally over the total demand of the building** with the unlimited roof surface has various ratios compared to other roof surfaces. In the sales case volumetric tariff has a ratio of 94.7%, which means that almost all of the energy needed is produced locally. While, the peak charge tariff has a ratio of 65.1% and PCNC tariff has a ratio of 68.4%. Moreover, in the no sales case, volumetric tariff has the ratio of 30.5%, peak charge tariff has the ratio of 24.9% and PCNC charge has the ratio of 22.9%.
- In addition, **ratio of the installed solar PV capacity over the contracted capacity of the building** was calculated. For both sales and no sales case, when the roof surface is 35m<sup>2</sup> then the ratio is 6.7%, while when roof surface is 70m<sup>2</sup> then the ratio is 13.4%. The case of the unlimited area is different for sales and no sales self-generation options. In the sales scenario, volumetric tariff has a ratio of 87.4%, peak charge tariff has a ratio of 60.1% and PCNC tariff has a ratio of 63.2%. In the no sales case, volumetric tariff obtained ratio of 42.6%, peak charge tariff obtained ratio of the 28.6% and PCNC tariff obtained a ratio of 24.9%.

The annual results for one commercial customer are provided below (Table 9):

Scenario	Roof Surface(m2)	Tariff	Installed Capacity: Photovoltaic (kW)	Electricity Generated(kWh)	Electricity Sales(kWh)	Net Utility Electricity Consumption (kWh)	Ratio of the Energy Produced Over Total Demand of the Building(%)	Ratio of the Installed Capacity of the Solar PV Over the Contracted Capacity of the Building(%)
No PV	ALL	All	0	0	0	177147.64	0%	0%
Sales	140	Volumetric	21.41	20716.32	0	156431.32	11.7%	29.2%
		Fixed	0	0	0	177147.64	0%	0%
		Peak Charge	21.41	20716.32	0	156431.32	11.7%	29.2%
		PCNC	21.41	20716.32	0	156431.32	11.7%	29.2%
	280	Volumetric	42.81	41432.64	9.98	135724.98	23.4%	58.3%
		Fixed	0	0	0	177147.64	0%	0%
		Peak Charge	42.81	41432.64	9.98	135724.98	23.4%	58.3%
		PCNC	42.81	41432.64	9.98	135724.98	23.4%	58.3%
	Unlimited	Volumetric	159.53	154385.27	62731.53	85493.90	87.2%	217.3%
		Fixed	54.33	52580.30	575.15	125142.48	29.7%	74.0%
		Peak Charge	93.47	90461.09	15380.46	102067.01	51.1%	127.3%
		PCNC	91.12	88182.39	14073.07	103038.32	49.8%	124.1%
No sales	140	Volumetric	21.41	20716.32	0	156431.32	11.7%	29.2%
		Fixed	0	0	0	177147.64	0%	0%
		Peak Charge	21.41	20716.32	0	156431.32	11.7%	29.2%
		PCNC	21.41	20716.32	0	156431.32	11.7%	29.2%
	280	Volumetric	42.81	41422.66	0	135724.98	23.4%	58.3%
		Fixed	0	0	0	177147.64	0%	0%
		Peak Charge	42.81	41422.66	0	135724.98	23.4%	58.3%
		PCNC	42.81	41422.66	0	135724.98	23.4%	58.3%
	Unlimited	Volumetric	93.68	75162.33	0	101985.31	42.4%	127.6%
		Fixed	0	0	0	177147.64	0%	0%
		Peak Charge	64.66	60022.58	0	117125.06	33.9%	88.1%
		PCNC	62.03	58135.05	0	119012.59	32.8%	84.5%

Table 7: DER-CAM Output for Commercial Customer

Following main conclusions were made based on the commercial customer result:

- The same pattern as in the case of the residential customers is followed here. The smallest roof surface of 140m<sup>2</sup> may not be sufficient enough to provide all the necessary energy for the commercial customer. So, with this roof surface there are no sales back to the grid, even in the sales scenario. While with the roof surface of 280m<sup>2</sup> 9.98 kWh of energy is sold annually. In the unlimited roof surface case, with the volumetric tariff 62731.53 kWh of energy is sold annually. While, with peak charge tariff 15380.46 kWh and with PCNC 14073.07 kWh of energy is sold annually.

- One interesting point in the case of commercial customers is that the peak charge tariff has bigger capacity than the PCNC tariff in both sales and no sales scenarios of unlimited roof surface. This is also connected to the charging time of the tariffs, since peak charge tariff is charged between 9:00 am and 12:00, while the PCNC tariff is charged between 12:00 and 14:00 in the commercial customer case.
- Additionally, in the sales scenario with unlimited roof surface, the fixed tariff has a solar PV capacity of 54.33 kW and it sells 575.15kWh of energy annually. This shows that with the unlimited roof surface and sales options, even when all regulated activities are recovered, it is profitable to install the solar PV due to the energy savings.
- As in the residential case, in the commercial customer case it is profitable for the building to install PV panels up to a maximum available surface under all tariff designs, even sometimes with the fixed tariff design.
- Following conclusions can be made based on **the ratio of the energy produced locally over total demand of the building**. When the roof surface of 140m<sup>2</sup> is available, both sales and no sales cases, have the same ratio of the 11.7%. While, with the roof surface of 280m<sup>2</sup>, sales and no sales cases have the ratio of 23.4%.

- **The ratio of the energy produced locally over the total demand of the building** with the unlimited roof surface has various ratios compared to other roof surfaces. In the sales case volumetric tariff has a ratio of 87.2%, which means that big part of the energy needed is produced locally. While, the peak charge tariff has a ratio of 51.1%, PCNC tariff has a ratio of 49.8% and fixed charge has ratio of 29.7%. Moreover, in the no sales case, volumetric tariff has the ratio of 42.4%, peak charge tariff has the ratio of 33.9% and PCNC charge has the ratio of 32.8%.
- In addition, **ratio of the installed solar PV capacity over the contracted capacity of the building** was calculated. For both sales and no sales case, when the roof surface is 140m<sup>2</sup> the ratio is 29.2%, while when roof surface is 280m<sup>2</sup> then the ratio is 58.3%. The case of the unlimited area is different for sales and no sales self-generation options. In the sales scenario, volumetric tariff has a ratio of 217.3%, fixed tariff has a ratio of 74% peak charge tariff has a ratio of 127.3% and PCNC tariff has a ratio of 124.1%. In the no sales case, volumetric tariff obtained ratio of 127.6%, peak charge tariff obtained ratio of the 88.1% and PCNC tariff obtained a ratio of 84.5%. In both no sales and sales scenarios, the capacity ratios are big, since the peak consumption of the commercial customer, which is usually commercial centers that work during the sunshine, coincides with the peak generation of the solar PVs, which occurs during the sunshine. There is a big incentive to install big

capacities to generate all possible energy for self-consumption and for the sales back to the grid as well.

Furthermore, a detailed economic assessment that combines the outputs of both models, model II and model III, is presented.

In this part, the annual payable amounts for activities for residential customer are illustrated through a bar chart. The results for the unlimited roof surface for different tariff designs and both scenarios will be provided below in order to compare them.

- Volumetric tariff with unlimited roof surface:

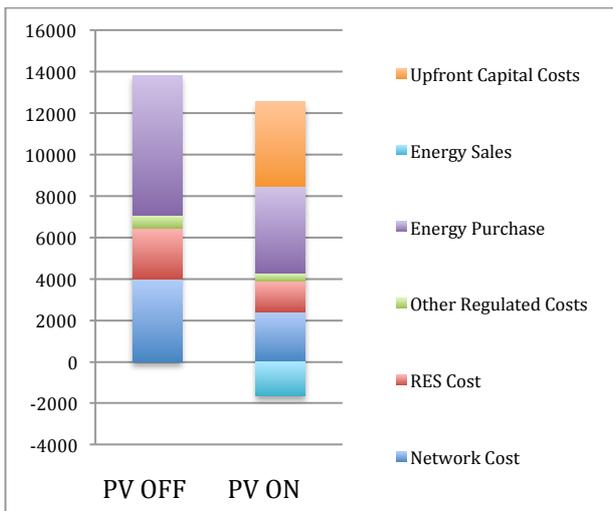


Figure X: Annual Cost of Activities with Sales (\$)

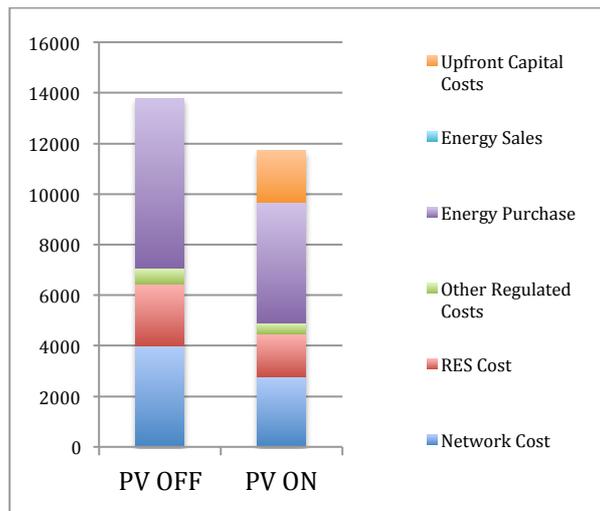


Figure XI: Annual Cost of Activities no Sales (\$)

- Peak charge tariff with unlimited roof surface:

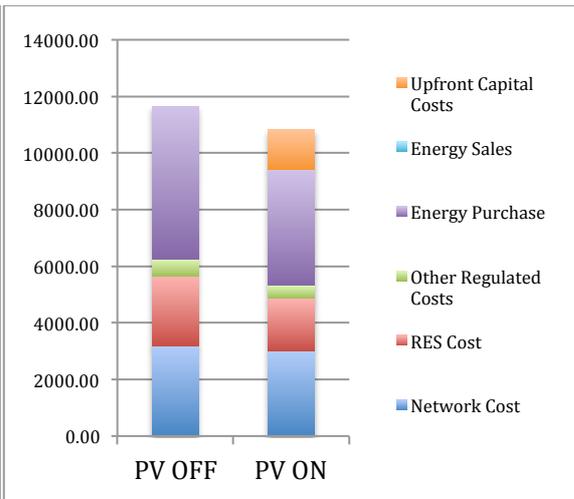
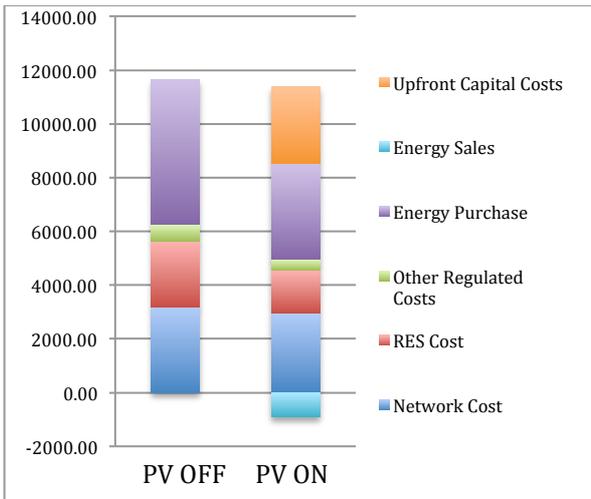


Figure XII: Annual Cost of Activities with Sales (\$)

Figure XIII: Annual Cost of Activities No Sales(\$)

- PCNC tariff with unlimited roof surface:

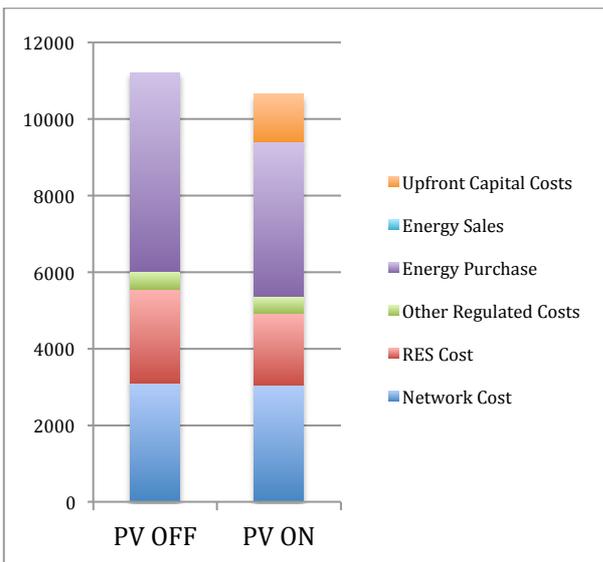
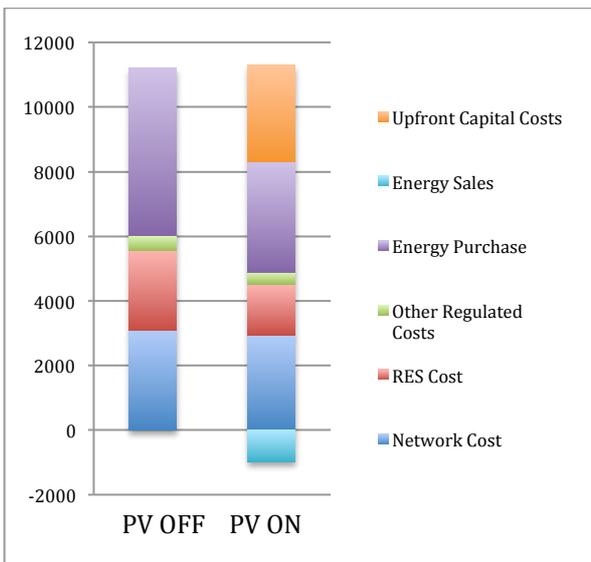


Figure XIV: Annual Cost of Activities with Sales (\$)

Figure XV: Annual Cost of Activities No Sales(\$)

Comparing different bar charts for residential and commercial customers, the following conclusions were made:

- Results from the roof surfaces of 35m<sup>2</sup>, 70 m<sup>2</sup> for residential customers and results from roof surfaces of 140m<sup>2</sup>, 280m<sup>2</sup> for commercial customers have exactly the same results in sales and no sales cases. This is

connected to the capacity of the solar PV installed. In both cases the maximum capacity for the available roof surface is installed, but it is enough only to generate some part of the energy, but not to the sell back to the grid.

- However, the results from the unlimited roof surfaces for both customer types differ between sales and no-sales scenarios. In both, residential and commercial customers with the no sales scenario, no sales have smaller values than the sales scenario for all of the activities. When the roof surface is unlimited, customers would invest into big capacities; and this trend is higher with sales scenarios, when electricity can be sold back to the grid. (Figure X, Figure ~~xii~~, Figure XIV).

Below the tables with annual savings and percentage of savings from the original bill are provided. In the residential table case, following is noticed: The volumetric tariff results in the highest savings by a customer in all three roof surfaces and both self-generation scenarios. While, the PCNC tariff results in the lowest savings by a customer in all tariff designs and in both scenarios. The highest saving of 20.8% from the original bill occurs when volumetric tariff with unlimited roof surface and sales back to the grid is used. While for the same scenario and roof surface, with the PCNC tariff only 7.7% of the savings from the original bill occur (Table 8). However, the annual payable cost is the lowest with the PCNC tariff in all cases. For example, in the same case as mentioned above the annual payable amount with

volumetric tariff is \$13791.11 in no PV case and \$10916.92 in PV case. Whilst, with the PCNC tariff for the same situation in no PV case \$11199.05 has to be paid and in PV case \$10334.23 has to be paid (Table 8).

Scenario	Roof Surface(m2)	Tariff	Annual Cost Without PV(\$)	Annual Cost With PV(\$)	Annual Savings by a Customer(\$)	Percentage of Savings from the Original Bill(%)
Sales	35	Volumetric	13791.11	13220.98	35.63	4.1%
	35	Peak	11640.90	11383.43	16.09	2.2%
	35	PCNC	11199.05	11049.25	9.36	1.3%
	70	Volumetric	13791.11	12546.72	77.77	9.0%
	70	Peak	11640.90	11051.38	36.84	5.1%
	70	PCNC	11199.05	10789.32	25.61	3.7%
	unlimited	Volumetric	13791.11	10916.92	179.64	20.8%
	unlimited	Peak	11640.90	10501.42	71.22	9.8%
	unlimited	PCNC	11199.05	10334.23	54.05	7.7%
No sales	35	Volumetric	13791.11	13220.98	35.63	4.1%
	35	Peak	11640.90	11383.43	16.09	2.2%
	35	PCNC	11199.05	11049.25	9.36	1.3%
	70	Volumetric	13791.11	12550.06	77.57	9.0%
	70	Peak	11640.90	11054.72	36.64	5.0%
	70	PCNC	11199.05	10792.66	25.40	3.6%
	unlimited	Volumetric	13791.11	11718.44	129.54	15.0%
	unlimited	Peak	11640.90	10843.63	49.83	6.8%
	unlimited	PCNC	11199.05	10645.54	34.59	4.9%

Table 8: Annual Savings and Percentage of Savings from the Original Bill by One Residential Customer

In the case of the commercial customer the same pattern as in the residential customer case is followed. Volumetric tariff has the highest savings level, while the PCNC tariff has the lowest savings. For example, in the unlimited roof surface case with the sales scenario, volumetric tariff saves up to 23.8% from the bill annually, while for the same case PCNC tariff only saves 4.6% from the bill annually. While again, annual payable amounts is the lowest with the PCNC tariff, which means that in spite of having the lowest savings between PV and no PV case, PCNC tariff is the best choice due to the smallest annual amounts due (Table 9).

Scenario	Roof Surface(m2)	Tariff	Annual Cost Without PV(\$)	Annual Cost With PV(\$)	Annual Savings by a Customer(\$)	Percentage of Savings from the Original Bill(%)
Sales	140	Volumetric	24279.01	22805.67	1473.34	6.1%
	140	Peak	20843.96	19602.96	1241.00	6.0%
	140	PCNC	16109.32	15924.56	184.76	1.1%
	280	Volumetric	24279.01	21218.41	3060.60	12.6%
	280	Peak	20843.96	18934.23	1909.73	9.2%
	280	PCNC	16109.32	15625.22	484.10	3.0%
	unlimited	Volumetric	24279.01	18510.95	5768.06	23.8%
	unlimited	Peak	20843.96	18493.43	2350.53	11.3%
	unlimited	PCNC	16109.32	15362.31	747.01	4.6%
No sales	140	Volumetric	24279.01	22805.67	1473.34	6.1%
	140	Peak	20843.96	19602.96	1241.00	6.0%
	140	PCNC	16109.32	15924.56	184.76	1.1%
	280	Volumetric	24279.01	21218.77	3060.24	12.6%
	280	Peak	20843.96	18934.59	1909.37	9.2%
	280	PCNC	16109.32	15625.58	483.74	3.0%
	unlimited	Volumetric	24279.01	19540.18	4738.84	19.5%
	unlimited	Peak	20843.96	18671.31	2172.65	10.4%
	unlimited	PCNC	16109.32	15484.18	625.14	4.0%

Table 9: Annual Savings and Percentage of Savings from the Original Bill by One Commercial Customer

#### 4.2.3 Model III

In this part the results of the cost recovery model are provided for residential and commercial customers. The annual deficits calculated for each customer give us the opportunity to calculate the possible deficit on the system level if specific percentage of customers from the whole system decides to invest into the solar. In this case the 20% penetration level was assumed in order to see the impact if 20% of customers in the system invest into solar PV.

The common trend for residential and commercial customers is the fact that the lowest annual deficit amount belongs to the PCNC tariff. This means that almost all regulated cost will be recovered if this tariff is utilized. While the volumetric tariff gives the highest annual deficit and peak charge tariff results in much lower deficit than the volumetric tariff, but still higher deficit than the PCNC

tariff. Moreover, fixed tariff will always recover all the regulated costs in both customer types.

In the residential customer table, one of the outputs that catch attention is the volumetric tariff with the unlimited roof surface that reaches the amount of \$1,015 million if 20% of the people in the system invest into solar PVs. In this case regulated activities cost will have a deficit of 9.24%.

Moreover, as it was expected the lowest amount is reached with the roof surface of 35m<sup>2</sup>, both in sales and no sales case, since in the sales scenario there is not enough generation to sell the electricity to the grid due to the small capacity of the solar PV. In both scenarios, the lowest value was attained with PCNC tariff and it was \$104 million. In this roof surface of 35m<sup>2</sup>, the percentage of the deficit that occurs if 20% of the people in the system invest into solar PVs is 0.94% from the total sum (Table 10).

Scenario	Roof Surface(m2)	Tariff	Annual Deficit from Regulated Activities Per Customer(\$)	Annual Deficit from Regulated Activities in Case of 20% Penetration by the Whole System ( million of \$)	Percentage of Annual Deficit from Regulated Activities in Case of 20% Penetration by the Whole System ( million of \$)
All	All	Fixed	0	0	0%
Sales	35	Volumetric	32.04	186.00	1.69%
		Peak Charge	18.99	110.00	1.00%
		PCNC	17.82	104.00	0.94%
	70	Volumetric	63.64	370.00	3.37%
		Peak Charge	35.42	206.00	1.87%
		PCNC	32.35	188.00	1.71%
	Unlimited	Volumetric	174.74	1,015.00	9.24%
		Peak Charge	82.36	479.00	4.36%
		PCNC	74.80	435.00	3.96%
No Sales	35	Volumetric	32.04	186.00	1.69%
		Peak Charge	18.99	110.00	1.00%
		PCNC	17.82	104.00	0.94%
	70	Volumetric	63.64	370.00	3.37%
		Peak Charge	35.42	206.00	1.87%
		PCNC	32.35	188.00	1.71%
	Unlimited	Volumetric	134.52	782.00	7.12%
		Peak Charge	58.92	342.00	3.12%
		PCNC	49.03	285.00	2.59%

Table 10: Cost Recovery Results for Residential Consumer (\$)

In the commercial customer case, the same trend is followed as in the residential customer case. The highest deficit of \$93 million is achieved with the unlimited roof surface and volumetric tariff. This amount constitutes 10.45% from the total payable cost of the regulated activities. While the smallest value of deficit, \$6 million is achieved with the roof surface of 140m<sup>2</sup> and with the PCNC tariff. It constitutes only 0.67% from the total amount of regulated activities cost. More detailed results for all cases are provided below (Table 11):

Scenario	Roof Surface(m2)	Tariff	Annual Deficit from Regulated Activities Per Customer(\$)	Annual Deficit from Regulated Activities in Case of 20% Penetration by the Whole System ( million of \$)	Percentage of Annual Deficit from Regulated Activities in Case of 20% Penetration by the Whole System ( million of \$)
All	All	Fixed	0	0	0%
Sales	140	Volumetric	1,187.83	21.00	2.36%
		Peak Charge	780.93	14.00	1.55%
		PCNC	339.16	6.00	0.67%
	280	Volumetric	2,375.09	42.00	4.72%
		Peak Charge	1,215.67	22.00	2.42%
		PCNC	555.51	10.00	1.10%
	Unlimited	Volumetric	5,255.24	93.00	10.45%
		Peak Charge	1,738.70	31.00	3.46%
		PCNC	834.06	15.00	1.66%
No Sales	140	Volumetric	1,187.83	21.00	2.36%
		Peak Charge	780.93	14.00	1.55%
		PCNC	339.16	6.00	0.67%
	280	Volumetric	2,375.09	42.00	4.72%
		Peak Charge	1,215.67	22.00	2.42%
		PCNC	555.51	10.00	1.10%
	Unlimited	Volumetric	4,309.66	77.00	8.57%
		Peak Charge	1,509.77	27.00	3.00%
		PCNC	699.76	12.00	1.39%

Table 11: Cost Recovery Results for Commercial Consumer (\$)

## 5. Conclusion

Global warming, unstable prices of fossil fuels, environmental and health problems, and many more other motives are the reason for the support of the renewable generation. Nowadays, renewable generation is not only supported at the utility level, but generation by the final customers is increasing as well. The distributed energy generation not only brings the benefits, but the difficulties as well. The main problem that distributed generation creates is the deficit in the cost recovery.

In this work **the connection** between the tariff designs, the decision to invest into distributed energy resources (DER) and cost recovery of the regulated activities was investigated. Moreover, the cost recovery of the whole system was also examined. Mainly, the extent of the deficit in the cost recovery under different tariff designs was studied. Four different tariff designs were studied and they are following: 1) Volumetric tariff 2) Fixed tariff 3) Peak Charge tariff and 4) Peak Coincidence Network Charge (PCNC).

A simple methodology was created for this work and it includes three models: Financial Model to calculate regulated tariffs (Model I), DER-CAM that optimizes end-user DER investment decisions (Model II) and Cost Recovery Model to calculate the tariff deficit potentially caused by DER adoption (Model III).

The following conclusions were obtained from the model I, in both residential and commercial customers case. Distribution accounts for the highest amount among all regulated activities. While, the activity with the lowest

annual amount due is interruptibility service in the case of residential consumers and other regulated activities in the case of the commercial consumers. Moreover, moving towards more cost-reflective tariff designs could imply dramatic changes in the current tariff structures and levels.

While from model II, following can be noticed, in both customer types the smallest surface area, which is considered to be the representative area for the Madrid city, is not enough to produce the energy needed for the customer when the sun is shining. Moreover, the next roof surface available, which is the doubled version of the representative roof surface, has small sales back to the grid, 69.97kWh annually in the residential case and 9.98 kWh annually in the commercial case, which is 0.676% and 0.024% from the all generated energy annually. In addition to it, the ratio of the energy produced locally over the total demand of the building and the ratio of the installed capacity of PV over the contracted capacity of the consumer increase as the roof surface increases. One common point is that it is better for the customer to install PV panels up to a maximum available surface under all tariff designs except the fixed tariff.

Moreover, the volumetric tariff brings the biggest savings in both scenarios and all roof surfaces. While, the lowest savings belong to the PCNC tariff. However, when the total annual amount payable is taken into account, the PCNC tariff has the lowest amounts due, so in spite of having the lowest savings between PV and no-PV case PCNC tariff is **the best** due to the annual amounts payable.

From the results of model III, the PCNC tariff recovers most of the regulated costs, while the tariff that results

in the biggest deficit is the volumetric tariff. This deficit was also examined on the system level assuming 20% of the customers in the whole system invest into the solar PV. The sales scenario has bigger deficits than no sales scenario, since with the sales option customers tend to invest into bigger capacities of solar PVs. In order to recover the most of the regulated costs, it is better to use the PCNC tariff, since it supports the installation of distributed generation and results in the lowest deficit amounts, as well as in the smallest annual payments due by a customer.

The results from this work show only the economic side of investing into solar PVs, but when a customer decides to install the distributed generation, other factors such as bureaucracy around the procedures of installing the distributed generation can make it less appealing for the final users. Moreover, if the savings experienced by the customer are low, customer may be reluctant to install solar PV, as the result different factors have to be taken into account by a consumer before installing the solar PV. This methodology could be applied in other European countries. It could be interesting to examine the effect of the tariffs when the different net-metering policies are utilized. Moreover, further work can be done on the PCNC tariff. Specifically, more detailed approach for determining the share of the network costs applicable to the capacity and fixed term can be investigated.

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**Annex A**

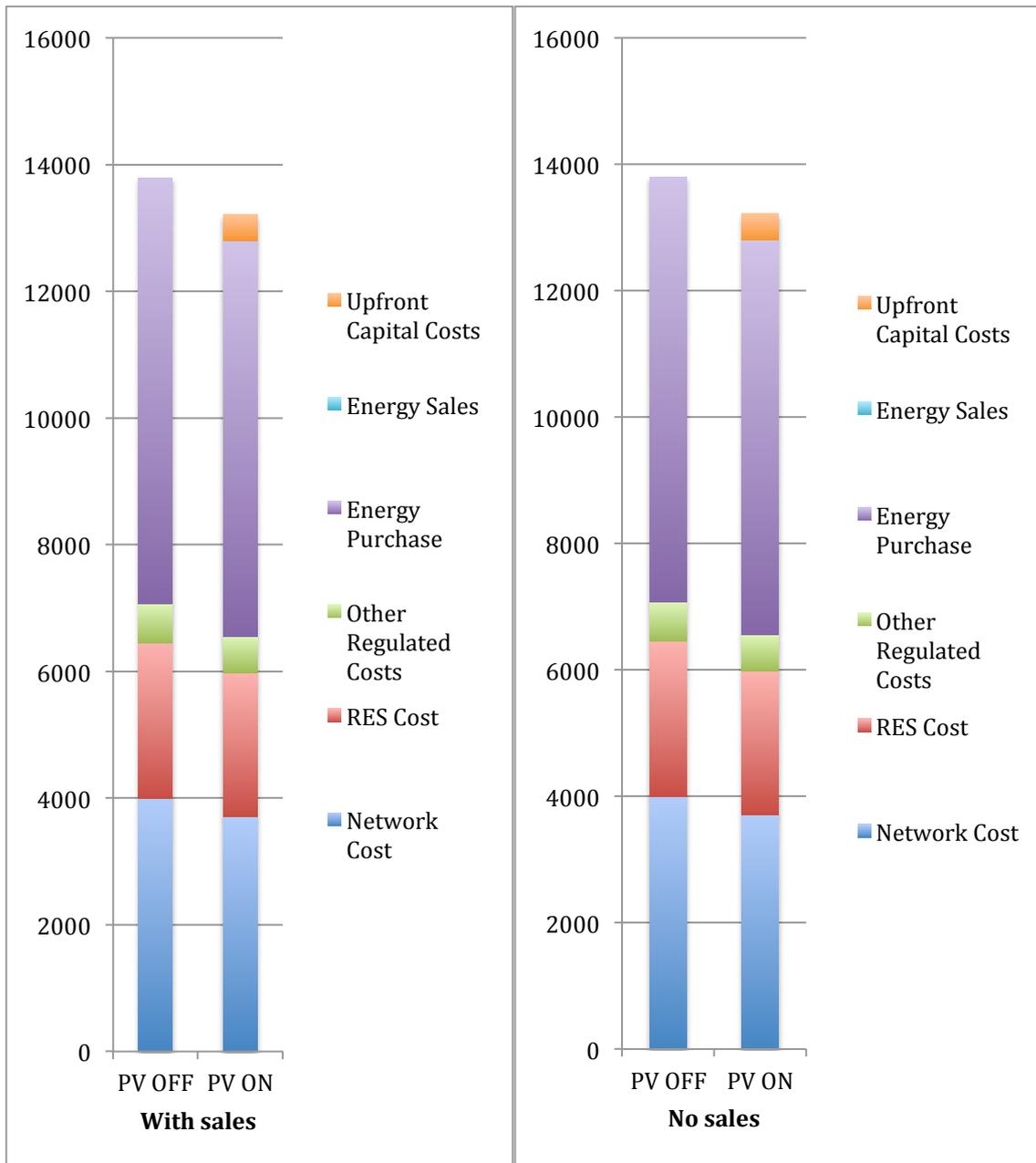


Figure XVI: Annual Cost of Activities with 35m<sup>2</sup> Area with Volumetric Tariff for Residential Customer(\$)

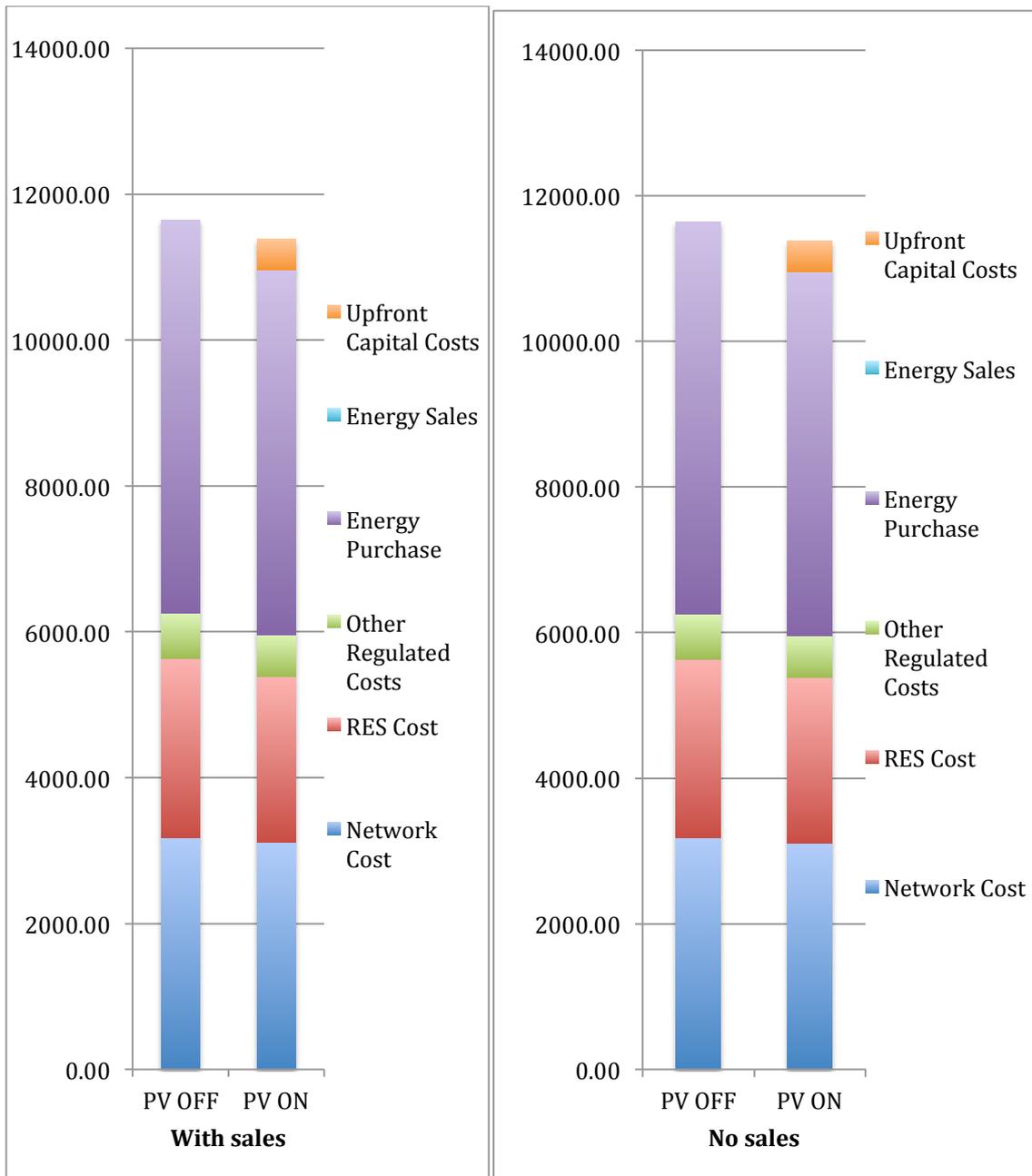


Figure XVII: Annual Cost of Activities with 35m<sup>2</sup> Area with Peak Charge Tariff for Residential Customer(\$)

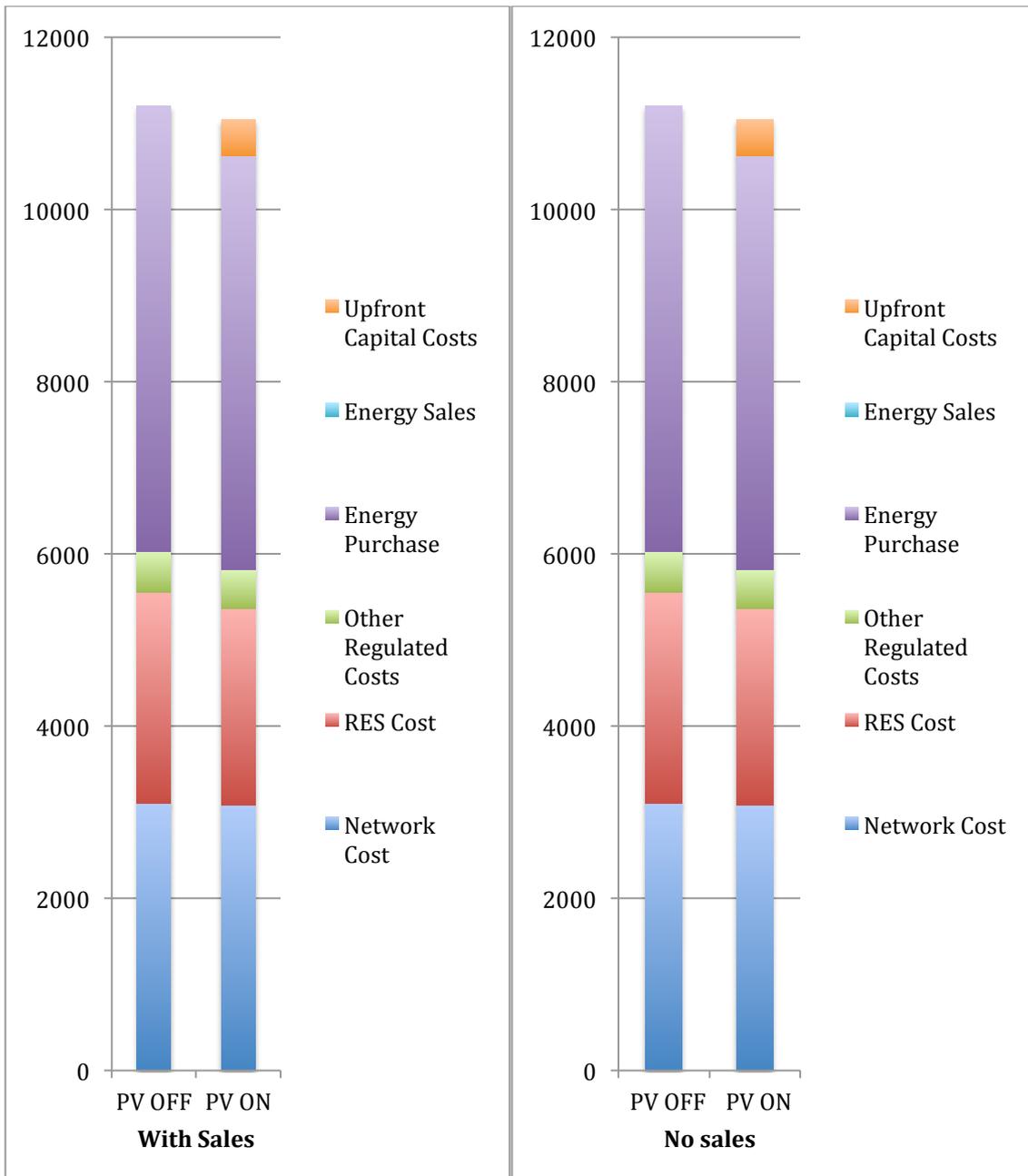


Figure XVIII: Annual Cost of Activities with 35m<sup>2</sup> Area with PCNC Tariff for Residential Customer(\$)

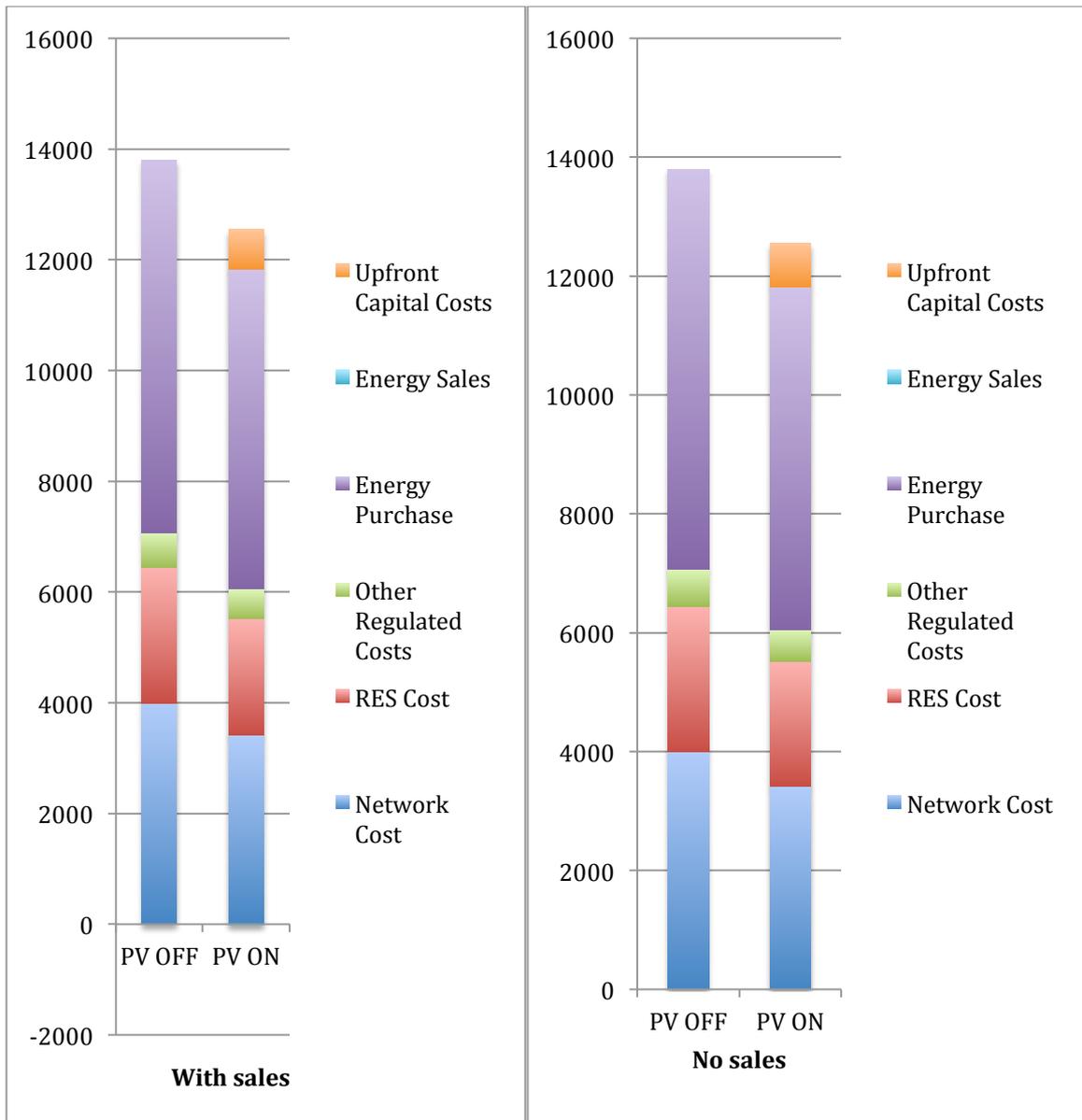


Figure XIX: Annual Cost of Activities with 70m<sup>2</sup> Area with Volumetric Tariff for Residential Customer(\$)

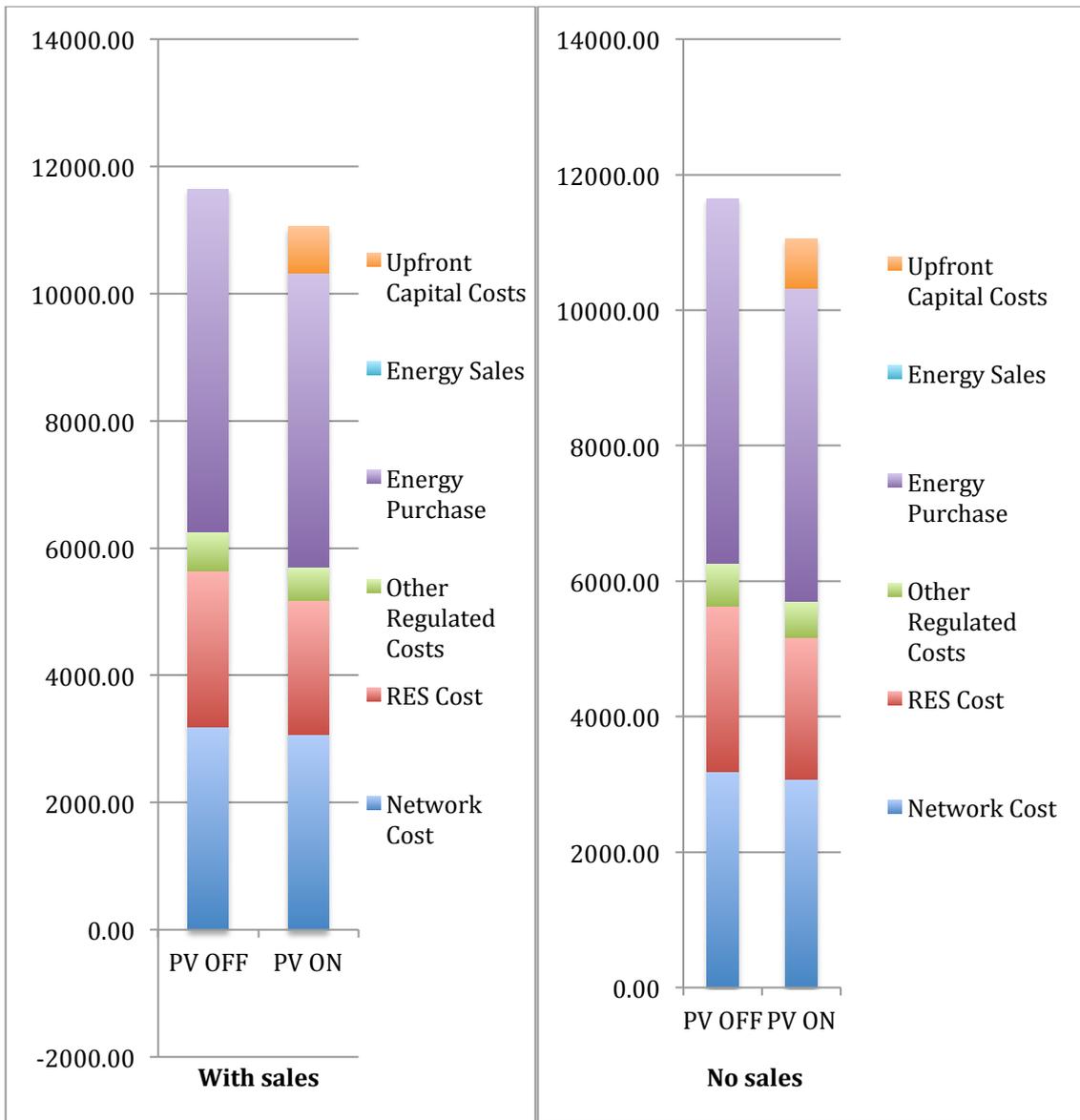


Figure XX: Annual Cost of Activities with 70m<sup>2</sup> Area with Peak Charge Tariff for Residential Customer(\$)

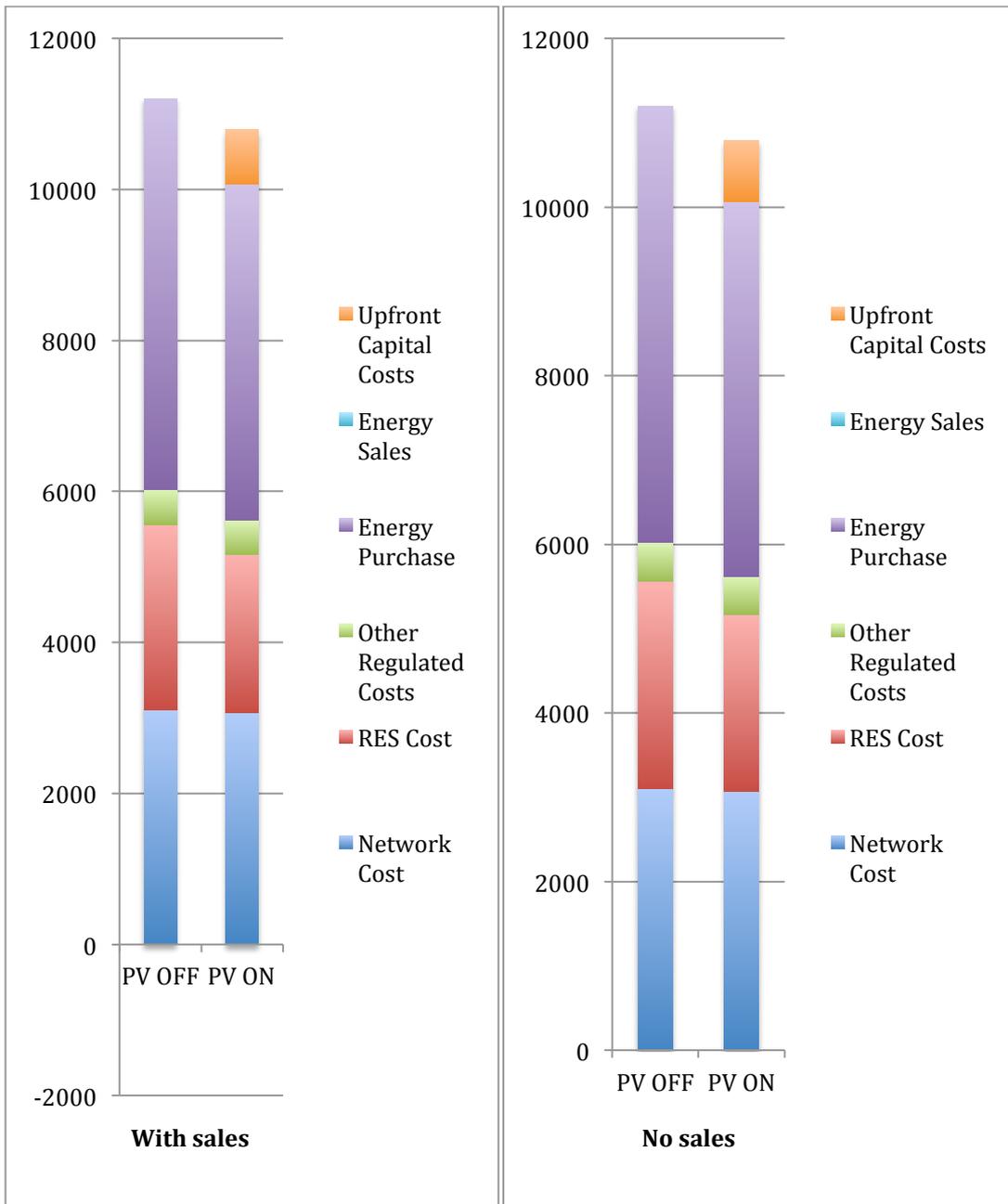


Figure XXI: Annual Cost of Activities with 70m<sup>2</sup> Area with PCNC Tariff for Residential Customer(\$)

**Annex B**

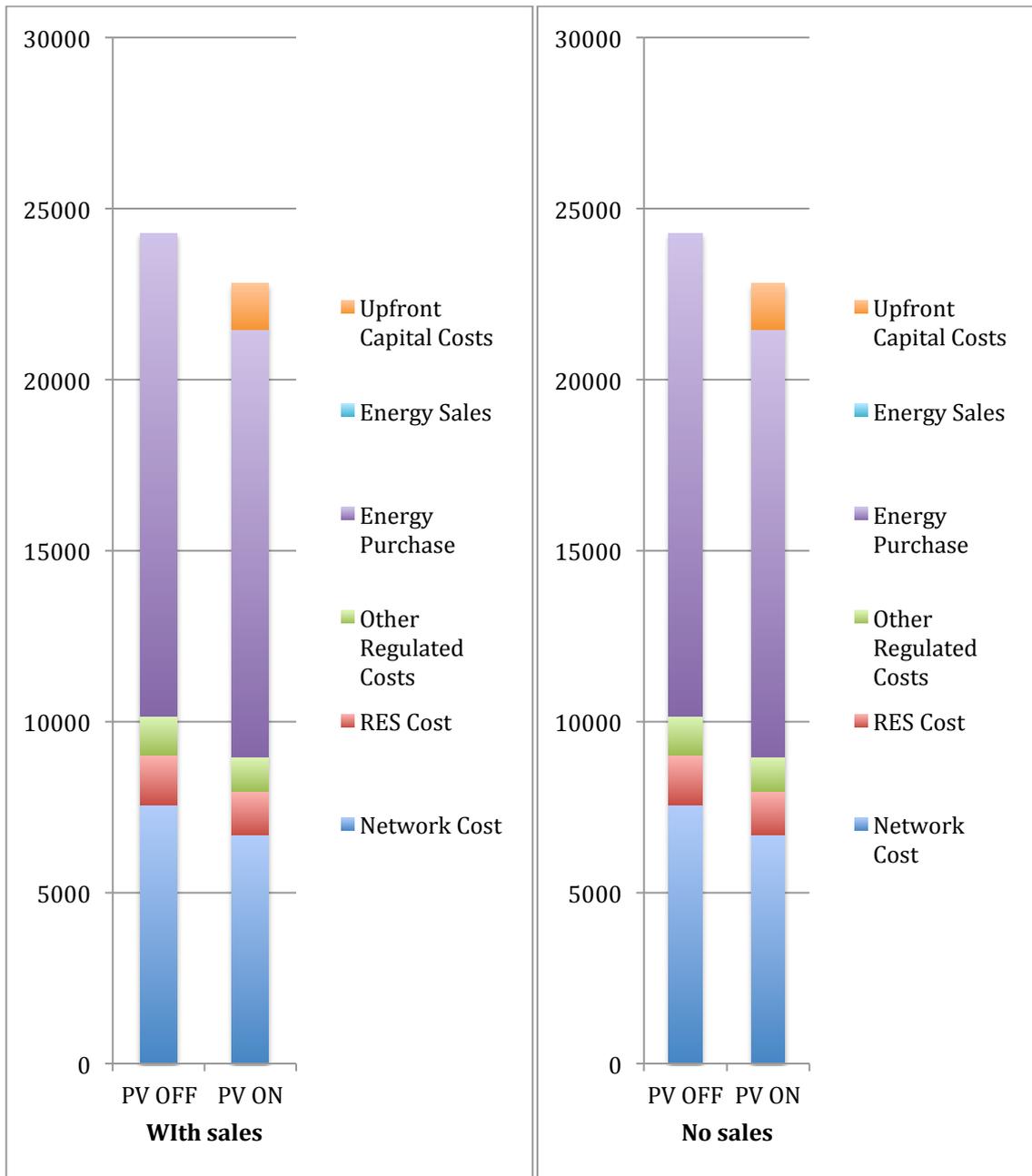


Figure XXII: Annual Cost of Activities with 140m<sup>2</sup> Area with Volumetric Tariff for Commercial Customer(\$)

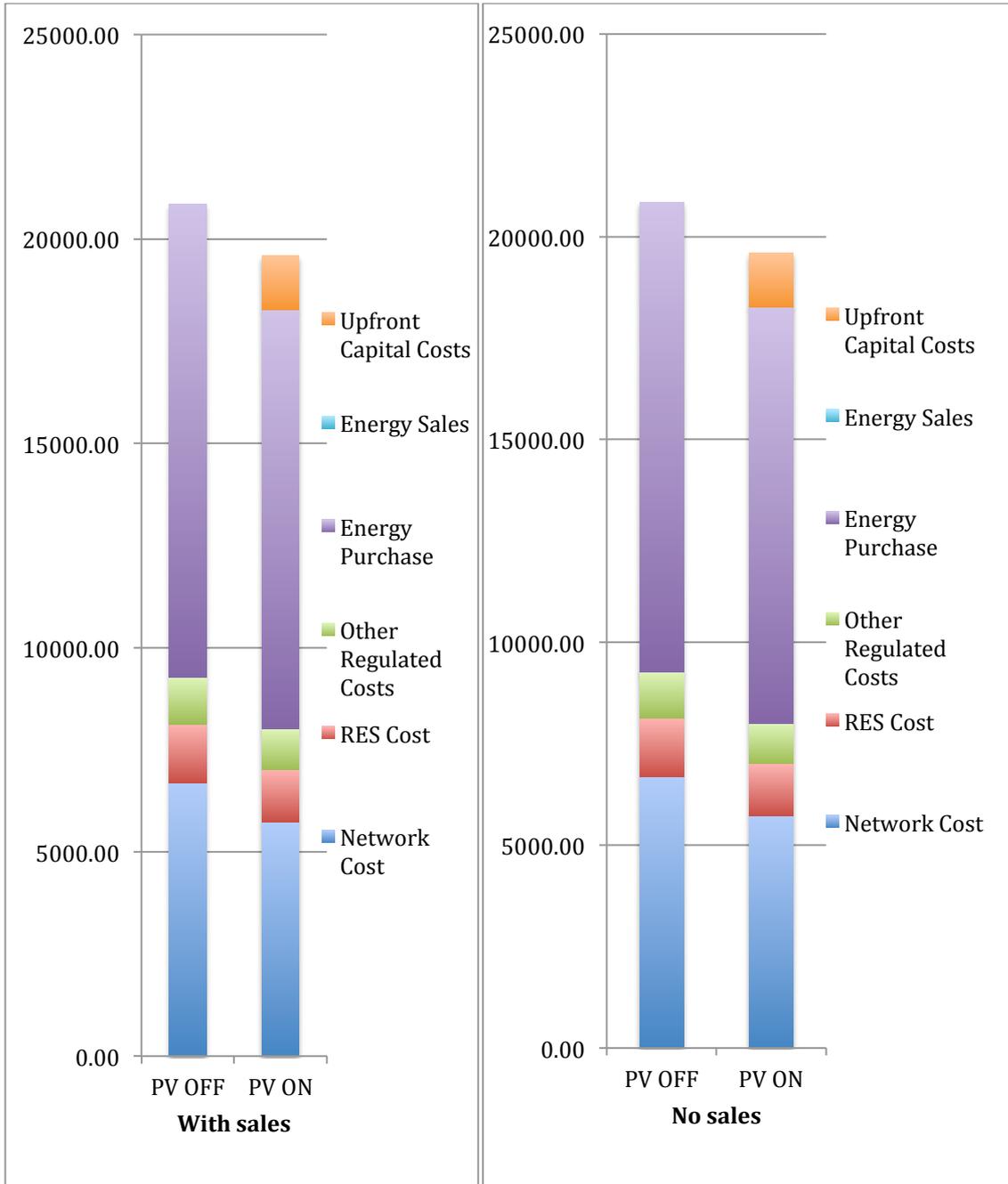


Figure XXIII: Annual Cost of Activities with 140m<sup>2</sup> Area with Peak Charge Tariff for Commercial Customer(\$)

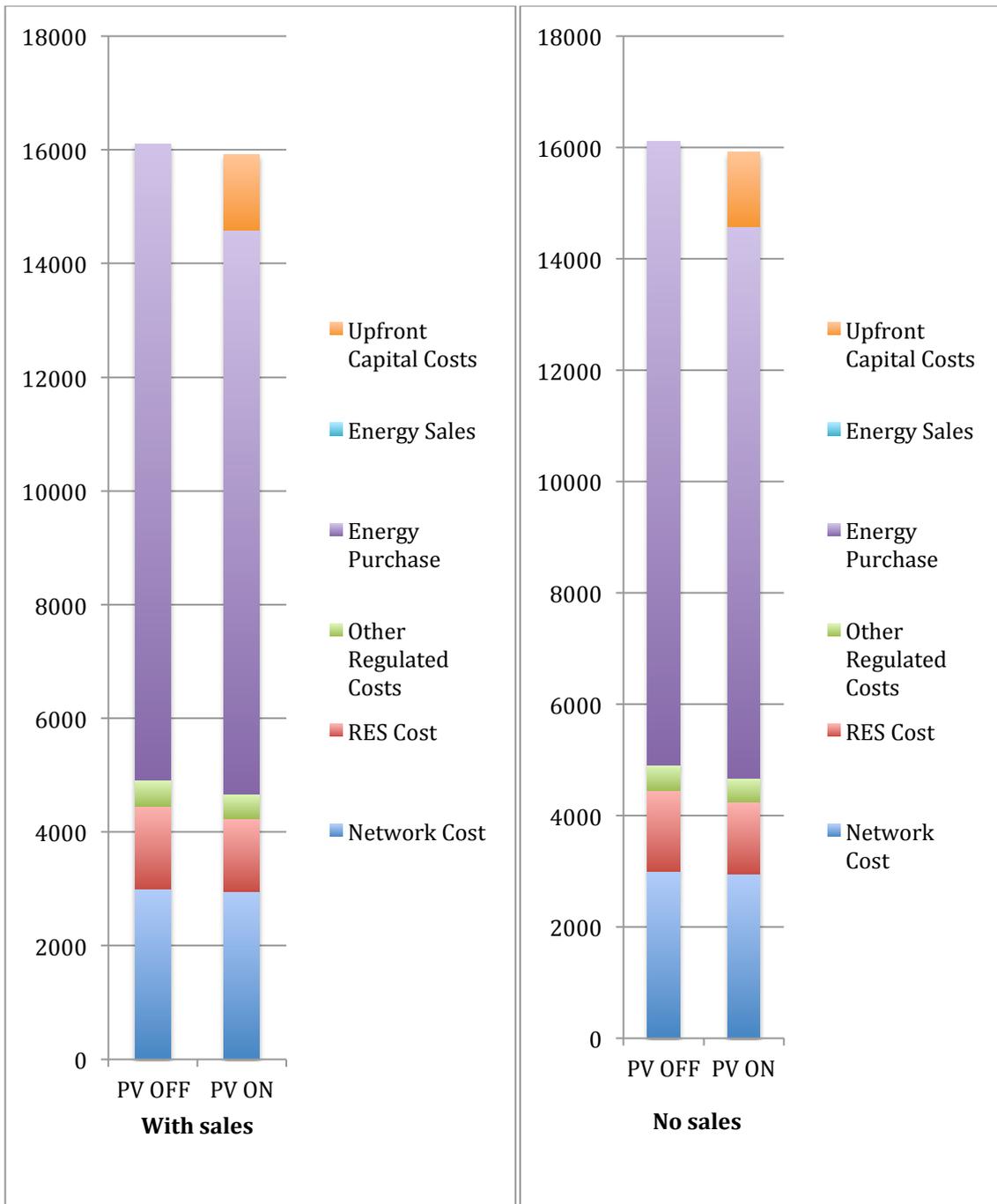


Figure XXIV: Annual Cost of Activities with 140m<sup>2</sup> Area with PCNC Tariff for Commercial Customer(\$)

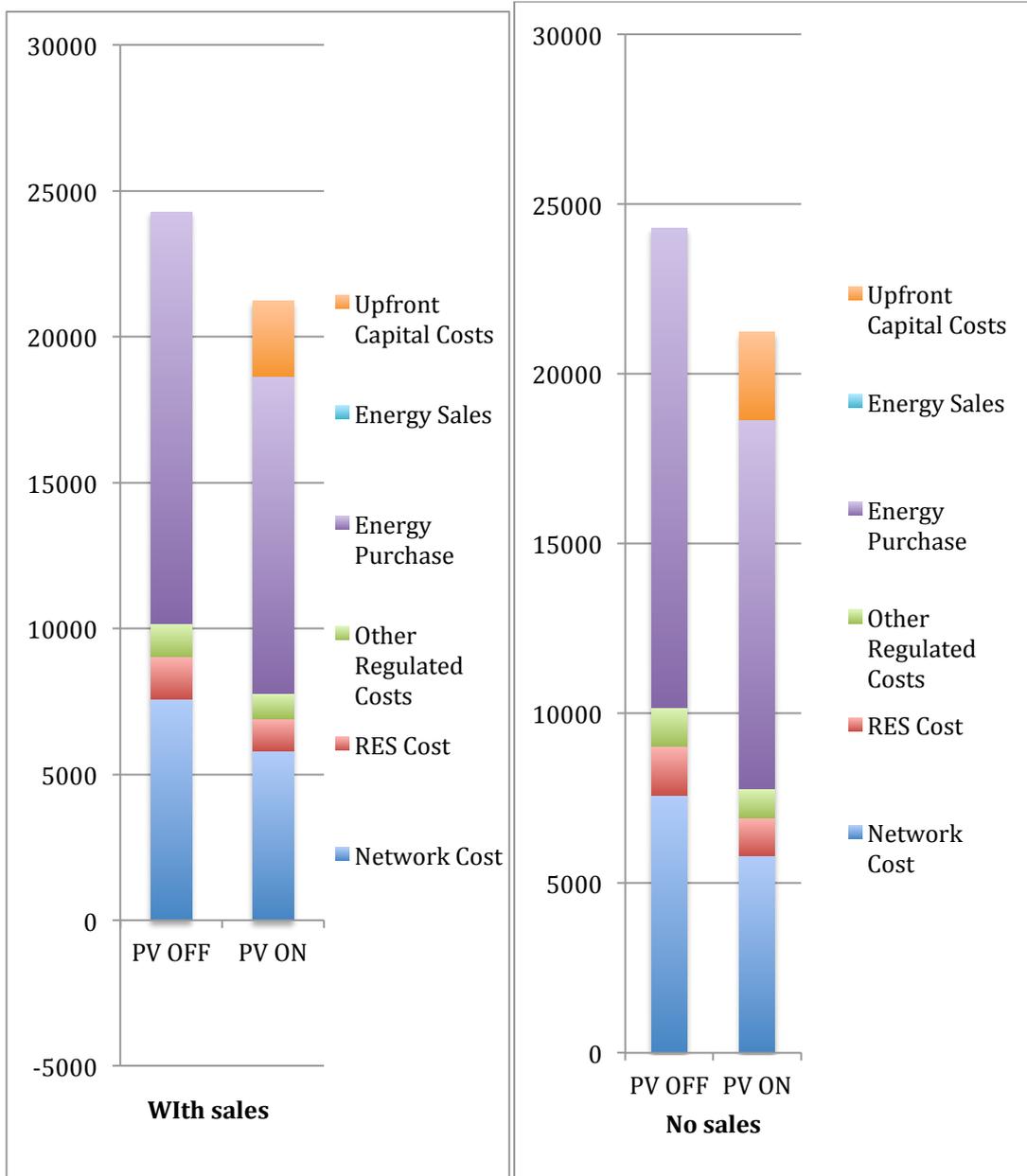


Figure XXV: Annual Cost of Activities with 280m<sup>2</sup> Area with Volumetric Tariff for Commercial Customer(\$)

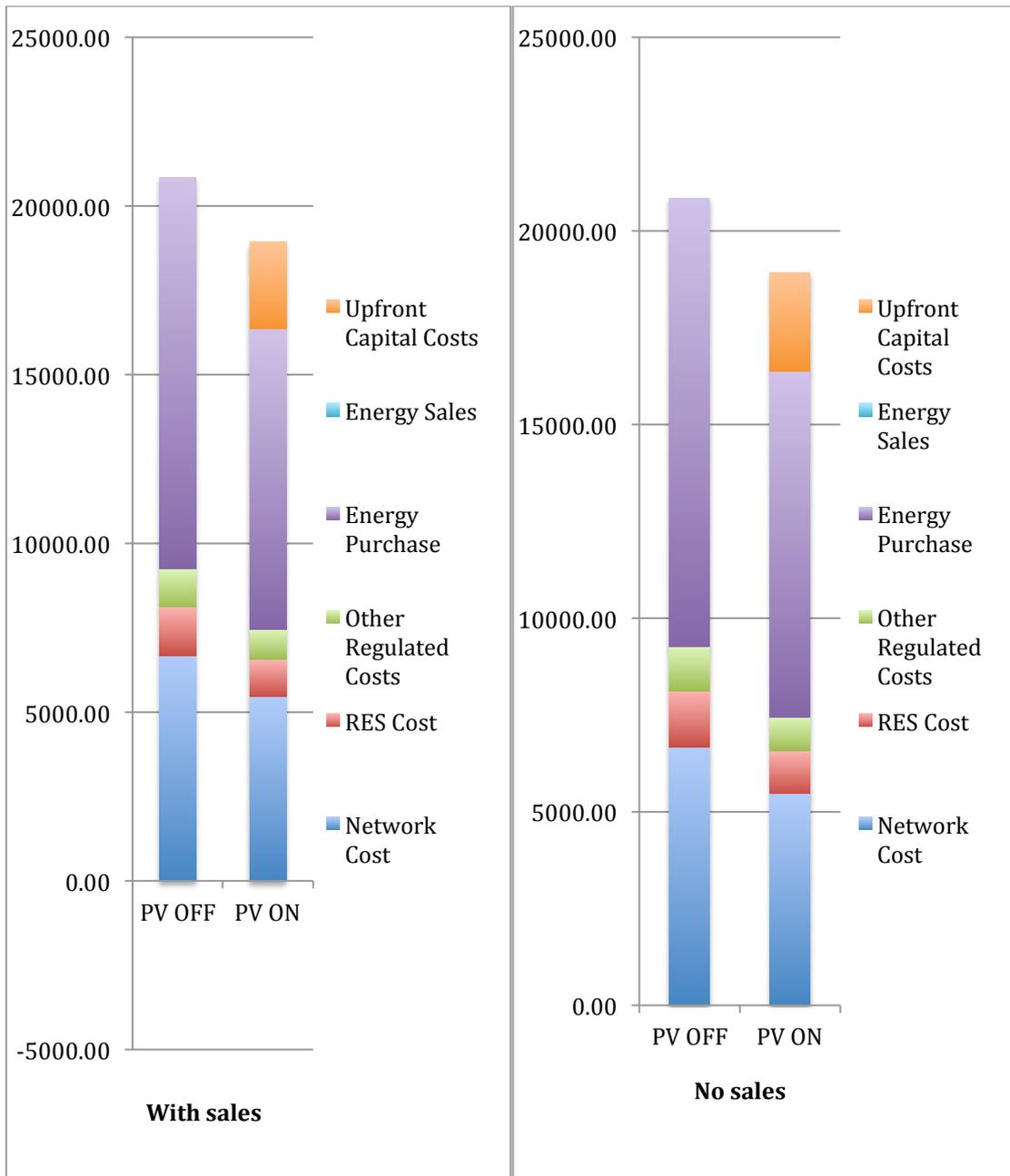


Figure XXVI: Annual Cost of Activities with 280m<sup>2</sup> Area with Peak Charge Tariff for Commercial Customer(\$)

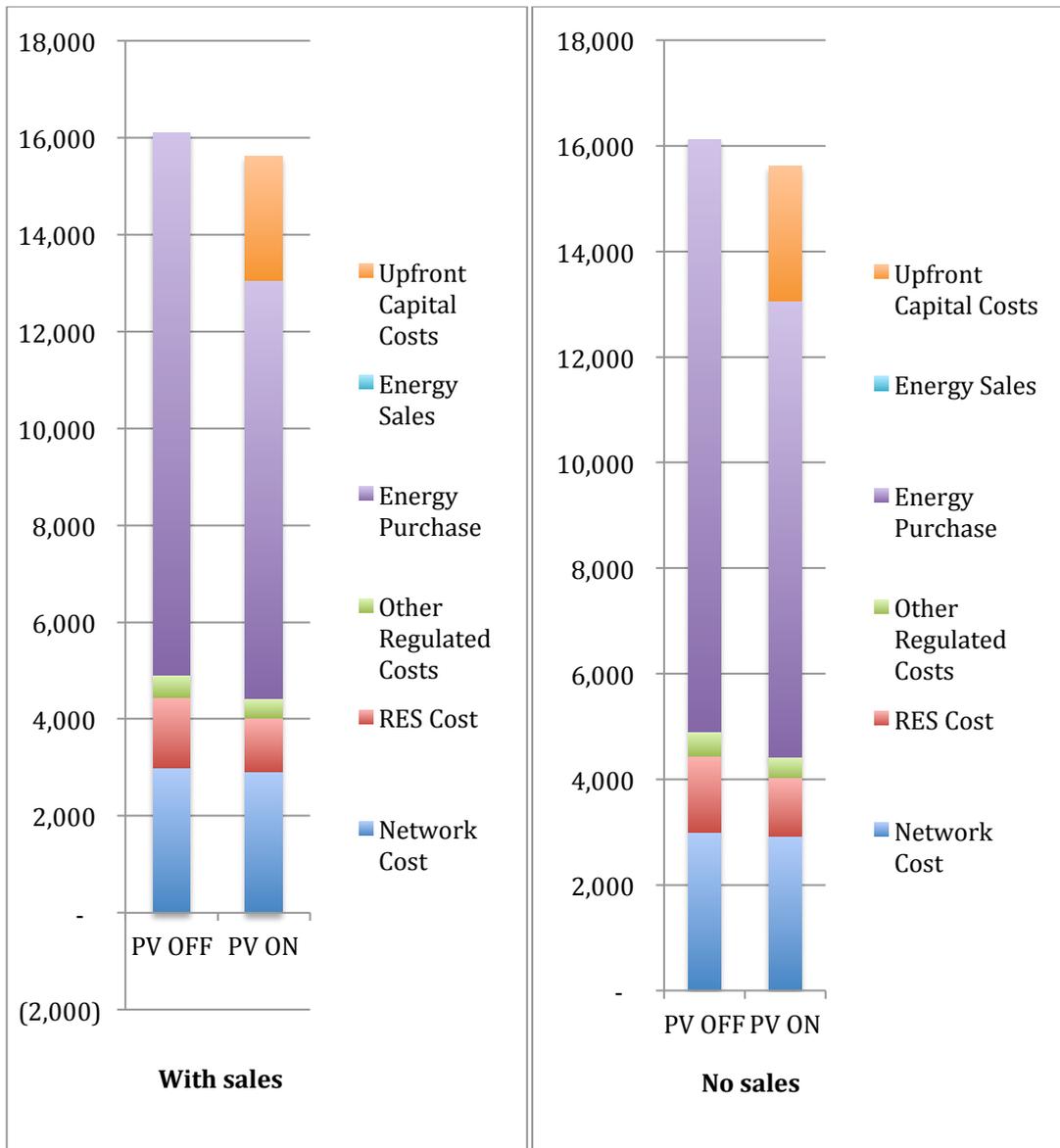


Figure XXVII: Annual Cost of Activities with 280m<sup>2</sup> Area with PCNC Tariff for Commercial Customer(\$)

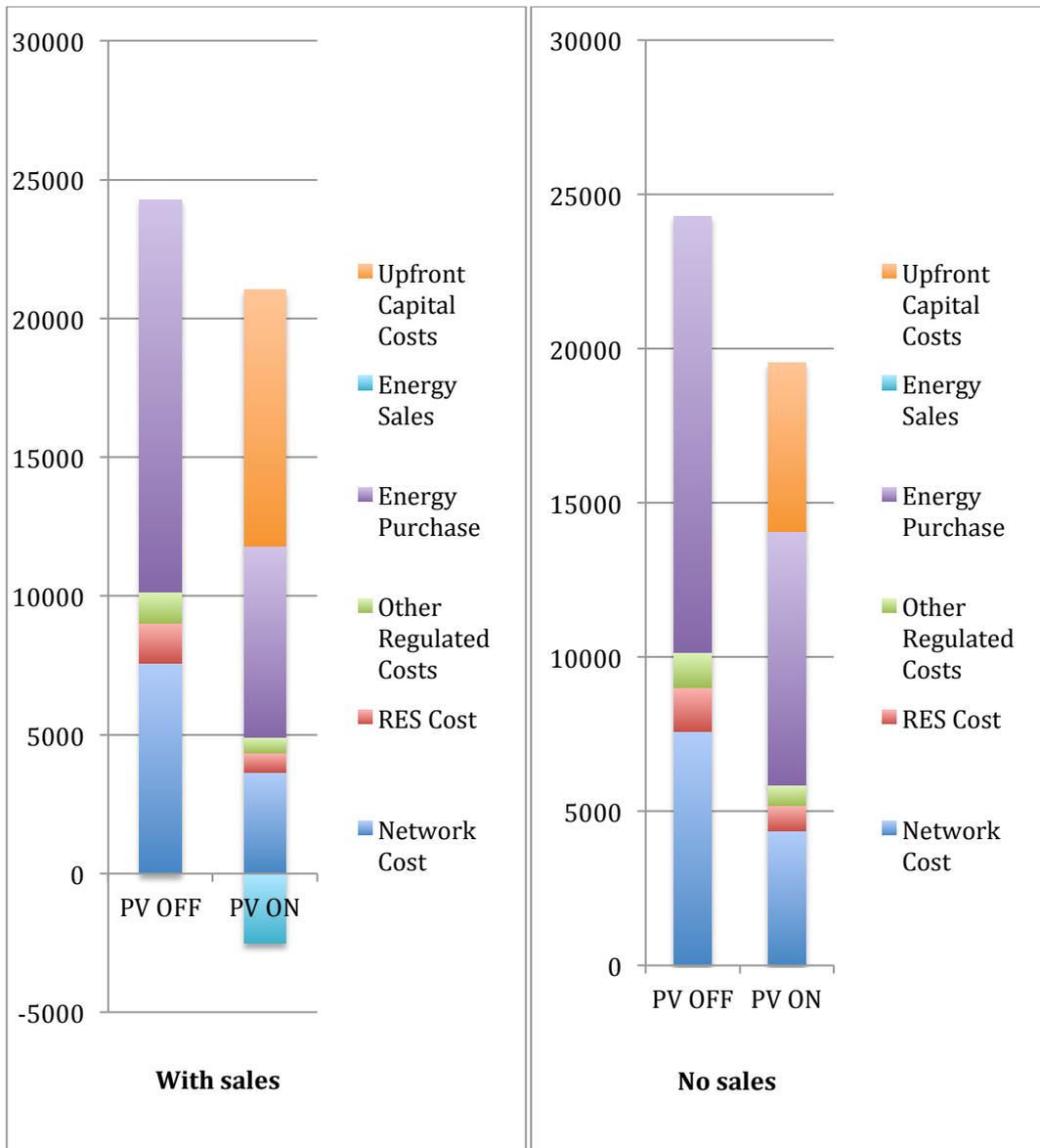


Figure XXVIII: Annual Cost of Activities with Unlimited Area with Volumetric Tariff for Commercial Customer(\$)

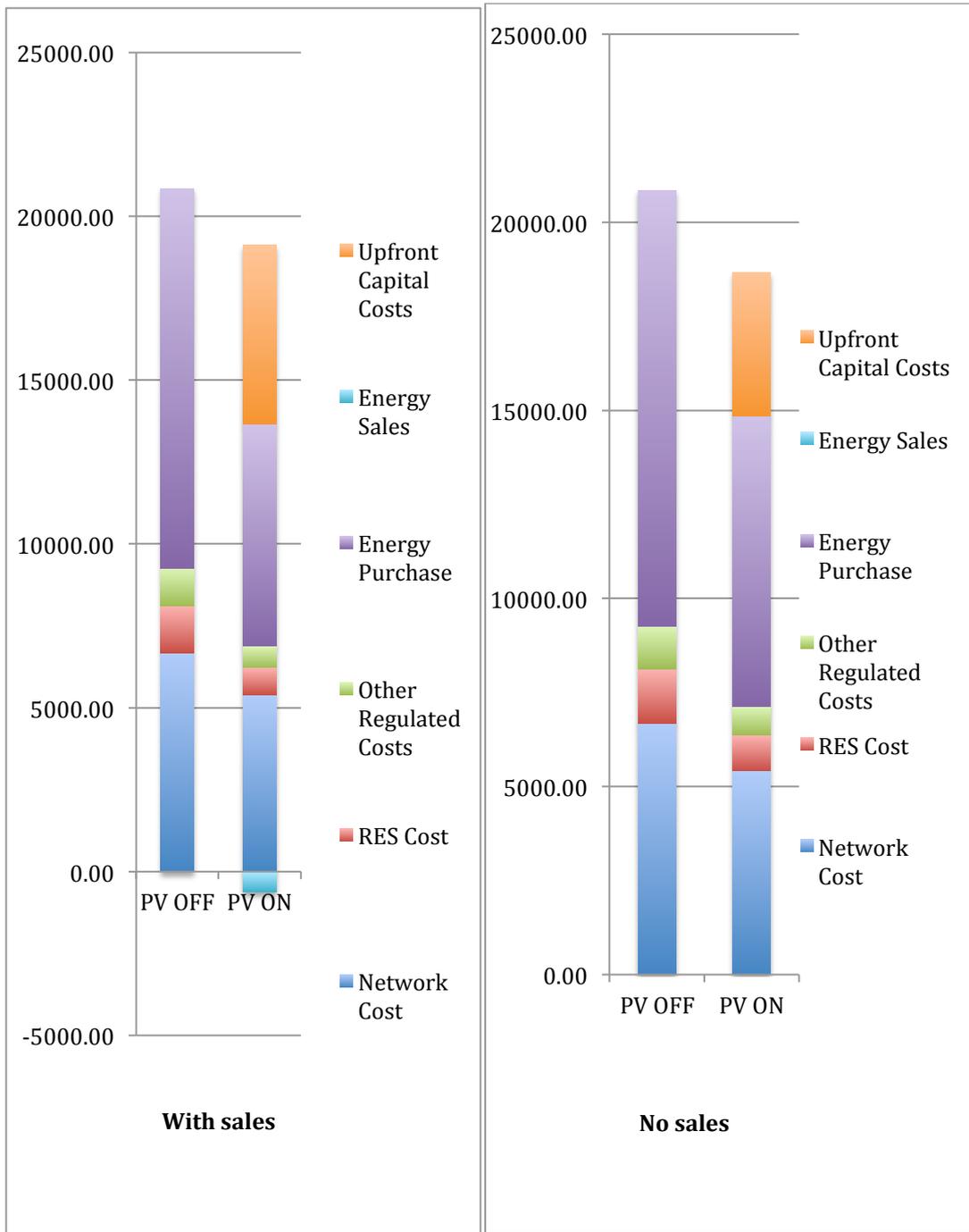


Figure XXIX: Annual Cost of Activities with Unlimited Area with Peak Charge Tariff for Commercial Customer(\$)

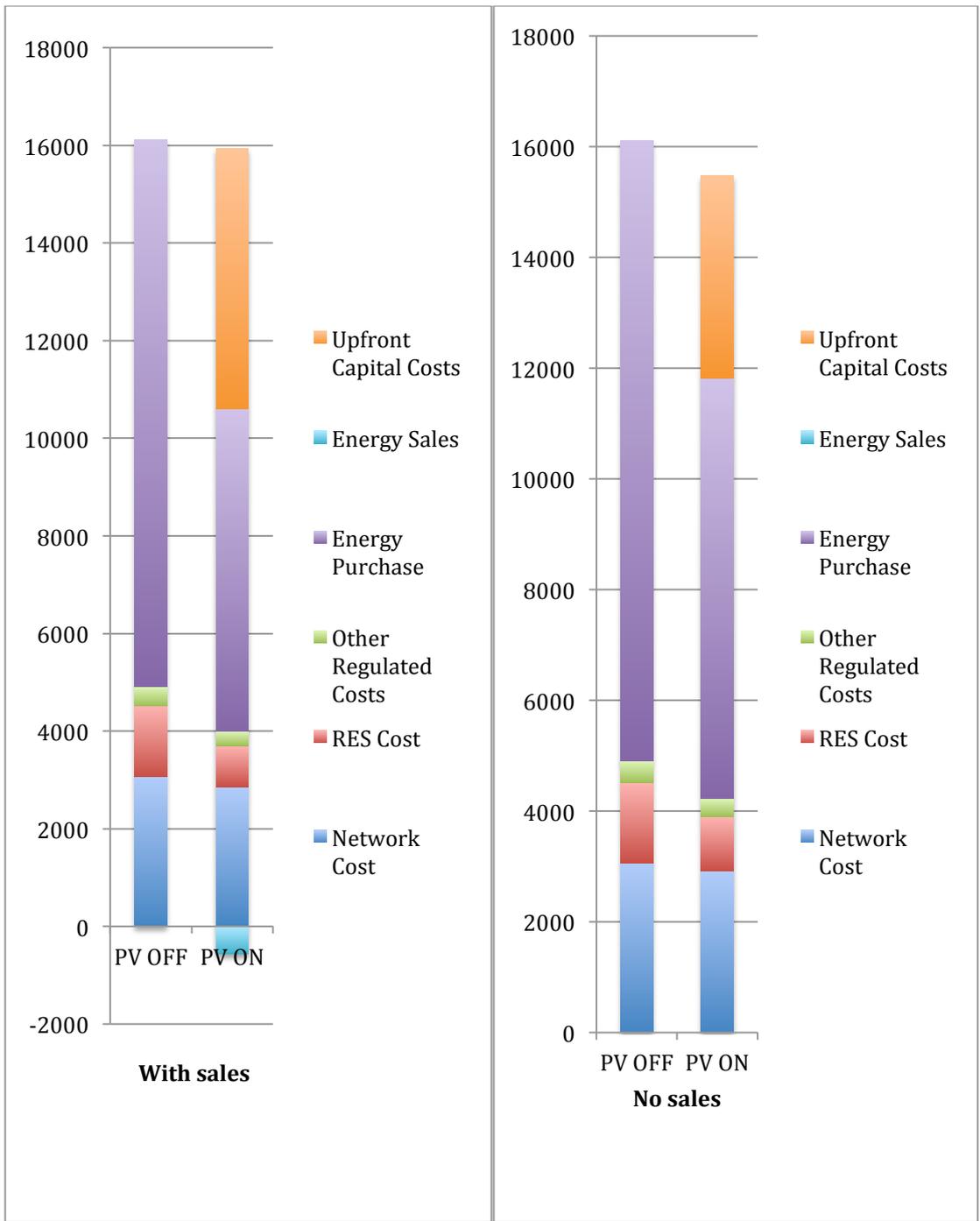


Figure XXX: Annual Cost of Activities with Unlimited Area with PCNC Tariff for Commercial Customer(\$)