UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master’s Thesis

EVs Fleet Contribution in the French Balancing Market

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Madrid, July 2015

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Abstract

Climate change concerns, sustained increase of oil price and energy security reasons have reignited interest on EVs. Nowadays, integration of Renewable Energy Sources (RES) to the existing generation mix is becoming one of the crucial mechanisms to mitigate CO_2 emissions. However, the main challenge of RES is their variable output. To cope up with the significant increase of RES and their variable output, the electricity system needs flexible generation sources more than ever. Consequently, researchers sturdily recommend the use of EVs as a good complement to the intermittent sources. Therefore, this paper deals with EVs fleet contribution in the French balancing market which is at the heart of maintaining the system balance. To scrutinize the contribution of EVs fleet in the French balancing system and quantify their financial gain, this paper used downward energy volume and downward prices obtained from 2008 to 2014. To specifically identify the financial gain of the EVs, two charging situations (charging at home and (at home and workplace)) and 3kW EVSE capacity were used. The result of the paper shows that for the EVs fleet manager, participating in the balancing market with charging facility at home benefits more than having charging facility at both home and workplace which is directly related to the battery's state of charge.

Keywords: *Electric Vehicle, RES, Balancing Market, France, Downward Balancing Service.*

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To write this thesis it demands basic understanding of electricity and how electricity market works. In the absence of the basic knowledge of electricity and its operation, it would have been impossible to come up with the results obtained. Consequently, I would like to thank Comillas Pontifical University (Spain) and Paris-Sud University (France) for the two years of formal educational training that equipped me with the necessary theoretical and practical knowledge to prepare this Master's thesis.

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Madrid, Spain

Table of Contents

Content Page

Abstract ... i

Acknowledgement ... iii

Table of Contents ... iv

List of Figures ... vii

List of Tables ... viii

Acronyms ... ix

Chapter One ... 1

1. **Introduction** ... 1

1.1 Background and Problem Statement ... 1

1.2 Objectives of the Paper ... 2

1.2.1 General Objective ... 2

1.2.2 Specific Objectives ... 2

1.3 Organization of the Paper ... 2

Chapter Two ... 3

2. Review of Related Literature ... 3

2.1 Introduction ... 3

2.2 Characteristic of Electricity ... 4

2.3 Electricity Balancing Management Services ... 4

2.3.1 Reserve and Balancing Services ... 4

2.3.2 Physical Notification and Procurement of Reserves ... 6

2.3.3 Remuneration for Balancing Service ... 6

2.4 The Structure of French Electricity Balancing Market ... 7

2.4.1 Introduction ... 7

2.4.2 Who Manages French Balancing Service? ... 7

2.4.3 Réseau de Transport d'électricité (RTE) ... 7

2.4.3.1 Overview of RTE Changes (2000-2015) ... 7

2.4.3.2 Balancing Providers ... 8

2.5 Type of Balancing Mechanism ... 8

2.6 Imbalance Settlement Pricing ... 9

2.7 European Energy Policies and Promotion of EVs ... 10

2.7.1 Europe 2020 Growth Strategy ... 10

2.8 A Brief History of Electric Vehicles ... 11

2.8.1 EVs Participation in the BM ... 11

2.9 Vehicle to Grid (V2G) ... 11

2.9.1 Conventional View ... 12

2.9.2 Contemporary View ... 12
2.9.3 Benefits of EVs ... 13
2.10 Charging Types and Possibilities ... 14
2.10.1 Charging Types ... 14
2.10.2 Chagrining Possibilities ... 14
2.11 Power Market and EVs Participation ... 15
2.12 Challenges of EVs to Participate in Balancing Market ... 16
2.12.1 Balancing Providers ... 16
2.12.2 Minimum Amount and Pricing ... 16
Chapter Three ... 18
3. Methodology of the paper ... 18
3.1 Study Area ... 18
3.2 Data Type and Source ... 18
3.3 Modeling and Assumptions ... 18
3.3.1 Technical Characteristics ... 18
3.3.2 State of Charge of the Battery ... 18
3.3.3 Non Technical Characteristics ... 19
3.3.4 Trip characteristics ... 19
3.3.5 Charging Situations ... 20
3.3.6 Financial Gain ... 20
3.3.7 Modeling and Programming ... 21
3.3.8 Elements of the Main Model ... 21
3.3.8.1 Step by Step Description of the Model ... 21
3.3.8.2 Weekly Gain Analysis ... 22
3.3.8.3 Price Matrix ... 22
3.3.8.4 Price Availability Indicator ... 22
3.3.9 The First Loop (Opportunity Identification) ... 22
i) Identification of Timeslots ... 22
ii) Identification of Prices ... 22
3.3.10 The Second Loop (State of Charge Characterization) ... 23
3.3.11 The Third Loop (Balancing Market Participation Decision) ... 23
4. Results and Discussions ... 25
4.1 Introduction ... 25
4.2 Home Charging Simulation Result ... 26
4.3 Home Charging Gain Allocation ... 28
4.4 Home and Workplace Charging Simulation Result ... 30
4.5 Home and Workplace Charging Gain Allocation ... 31
4.6 Comparison of the Two Cases ... 32

5. Conclusion 35
6. Challenges Faced and Limitation of the Paper 35
6.1 Challenges Faced 35
6.2 Limitation of the Paper 36
References 37
ANNEXES 40
ANNEX A Gain Calculation 40
ANNEX B Balancing Complete Cycle and Balancing Offer 40
ANNEX C Distribution of EVs Travel per Day 41
ANNEX D Simulation Result (2008-2014) 41

List of Figures

Figure 1: Structure of EU Electricity Market……………………………………………..4
Figure 2: Global EV Sales and EV Market Share……………………………………...13
Figure 3: Conventional view……………………………………………………………..15
Figure 4: Concept of V2G………………………………...…………………………...16
Figure 5: Components of V2G…………………..……………………………………..17
Figure 6: Opportunities for Deployment of Charging Stations and their Possible Charging Capacities……………………………………………………………………………………19
Figure 7: Histogram of the Departure Time from Home to Workplace…………………..24
Figure 8: Framework of the Model……………………………………………………...30
Figure 9: Home Charging Total Gain, Energy from Market and Gain from Balancing Market..32
Figure 10: Energy share between BM and Purchase as a Function of the Energy Use (% of total battery capacity) per Round Trip……………………………………………………33
Figure 11: Energy share between BM and Purchase as a Function of the Energy Use (% of total battery capacity) per Round Trip...…………………………………………………34
Figure 12: Energy from BM and Market (Home Charging)………………………………35
Figure 13: Home and workplace Charging Total Gain, Energy from Market and Gain from Balancing Market………………………………………………………………………..37
Figure 14: Energy from BM and Market (Home and Workplace Charging)……………..37
Figure 15: Energy from BM and Market (Home and Workplace Charging)……………..38
Figure 16: Energy from BM and Energy Market Comparison...…………………………..40
Figure 17: BM Gain, Energy Purchase and Total Gain Comparison……………………...40
Figure 18: Revenue Comparison………………………………………………………...41

List of Tables

Table 1: Types of Balancing Service……………………………………………………………...7
Table 2: Imbalance Prices in the French System……………………………………………12
Table 3: Evolution of the K Factor and Price Charged …………………………………….12
Table 4: Cost of Charging in the Base Case (without participation in the balancing Market)……..31
Table 5: Home Charging Average Values...………………………………………………….35
Table 6: Home and Workplace Charging Average Values…………………………………39
Table 7: Summary of Gains…………………………………………………………………...41

Acronyms

BM-Balancing Mechanism
BR - Balance Responsible Party
CRE - Commission Régulation de Energie
DC – Direct Current
DST – Daylight Saving Time
DSO- Distribution System Operator
EBM - Electricity Balancing Mechanism
ECWBM – Electricity Cost without Balancing Market
ENTO - European Transmission System Operators
EV - Electric Vehicle
EVSE – Electric Vehicle Supply Equipment
EWEA - European Wind Energy Association
GBM – Gain from the Balancing Market
IVC – Internal Combustion Vehicle
PV - Photo Voltaic
RTE - Réseau de Transport d'électricité
RES - Renewable Energy Sources
SOC – State of Charge
TG –Total Gain
TSO – Transmission System Operator
V2G -Vehicle to Grid

Chapter One

1. Introduction

1.1 Background and Problem Statement

Climate change concerns, sustained increase of oil price, improvement on battery technologies and energy security reasons have reignited interest on EVs. Consequently, significant number of automotive industries have started manufacturing different Electric Vehicles (EVs) along with their product lines by believing that EVs are economically affordable, technically feasible and environmentally friendly (Johansen, 2013).

In the last few decades, climate change has been one of the most discussed agendas of our time. To combat this problem, mega regional and international organizations have been designing and implementing long term policies. Among others, EU member countries have developed climate and energy package with plans and targets to be achieved till 2020. Member countries have started integrating renewable energy sources (RES) to their generation mix at a remarkable pace. Among the renewable energy sources, wind and PV are dominating the share and are expected to be the most crucial energy mix of the future (Tuffner and Meyer, 2011). On top of this, countries are aggressively promoting the use of EVs as a means of transportation.

France one of the European Union member countries has significantly increased the share of RES to the generation mix. The share of Wind has increased from 630 MW in 2013 to 9,285 MW in 2014 (EWEA, 2015). The installed capacity of PV reached 5,439 MW in 2014 and more PV sources will be installed in the coming years (RTE, 2015).

However, one of the major challenges of wind and PV energy sources is variability of their output as they are subject to natural fluctuations (Lauby et al., 2009; Komor, 2009; Tuffner and Meyer 2011). Consequently, considerable disturbance in the balance of power between generation and consumption could arise (Tuffner and Meyer, 2011; Makarov et al., 2009).

Since electricity cannot be stored in large quintiles, the balance between generation and consumption should be maintained all the time. To ensure continuous and secured supply of electricity, TSO in liberalized power sector use Balancing Mechanisms to manage imbalances that could happen in the system. To mitigate the imbalance, flexible alternative source of generation, demand side management and storage units are indispensable (Halamay, 2010; Ortega and Krischen; 2009, Tuffner and Meyer, 2011).

For this purpose, researchers sturdily recommend participation of EVs either to manage their consumption patterns and act as a load (Roscoe and Ault, 2010) or to inject power back to the system and act as a flexible source of generation (Kempton and Amardeep, 2006; Short and Denholm 2006; Kempton et al., 2008).

Despite EVs potential as source of energy and their positive contribution, they could also be a source of disturbance to the system if their consumption is not properly managed. To clarify how EVs could be a source of disturbance, let’s considers the following example. In France at the end of 2014 there were around 31,000 EV stock (Global EV Outlook, 2015) if we allow all these EVs to charge at the same time and at the peak hour, with no doubt they create additional stress to power system. In order to take EVs as an opportunity and not as an additional burden to the system, incentivizing the way they interact with the grid is quite important. This could be done by creating a favorable condition to participate in the balancing market in either upward or downward balancing services.

Studies show that private vehicles are in use only for one hour per day and they are parked for the remaining hours either at home or work (Codani et. al., 2014; Kempton and Amardeep 2006). This indicates that 95% of the day EVs are parked and stay idle. From these underutilized hours, huge flexible potential source of energy could be exploited if EVs are incentivized to participate in the upward balancing service. To make some Euros out of this service, EVs can charge their battery when the price of electricity is low and discharge to the grid when the price is high.

Regarding the charging behavior, EV owners charge their vehicles based on their trip characteristics without considering the possible participation in the balancing market. To roughly show how the EV owners charge their vehicles, let us consider a simple case. Let's assume that the average daily distance an EV travels is 24 kms and that the battery capacity is 24 kWh. As assumed in this paper on working days (from Monday to Friday) EV trips are restricted to working commuting trips (From home to office and office to home). Once the battery is fully charged an EV owner can use it for three to four days. Even when we consider relaxed charging an EV owner can charge three times per week including the weekends (Monday and Wednesday for the working days and Friday for the weekend).

It is clear that EVs have a huge potential to participate in all of the balancing market offers with either by providing additional service to the system (upward) or taking advantage of their charging patterns without giving additional service to the system (downward). However, this paper tries to take advantage of the "dump type of charging"[1] and incentivize the EV owners to manage their charging patterns according to the system need.

1.2 Objectives of the Paper

1.2.1 General Objective

As the title indicates the main objective of this paper is to investigate the contribution of an EV Fleet in French balancing market.

1.2.2 Specific Objectives

Keeping the general objective in mind, different objectives have been derived and addressed in this paper. Therefore, the main specific objectives of the paper are;

1. To quantify the financial gain of the EVs fleet considering two cases
2. To calculate the cost saving of the EVs Fleet

1.3 Organization of the Paper

The following parts of the paper are organized in four main chapters. The second chapter explains the theoretical and empirical foundation of the topic under study. The third chapter portraits and answers methodological questions of where this study is conducted, how the objective is addressed and what type of data have been used. The fourth chapter presents the simulation results and discussions. Lastly, general conclusion, challenges and limitation of the paper are presented.

[1] Charging based on the daily trip characteristics of an EV owner. Considering 95% of the time without

Chapter Two

2. Review of Related Literature

2.1 Introduction

Before introduction of liberalization to the power sector, countries were operating their activities in a vertically integrated manner. However, due to economic and non economic reasons, countries have been engaged in revolutionizing their power industry since the late 1980s. Right after this date, many developed and a few developing countries have made enormous changes to their power industry. One of the notable changes observed in the last thirty years is the introduction of competition to bring about a remarkable efficiency on the operation of the sector. Consequently, the power sector is classified as regulated activities (Transmission and Distribution) and deregulated activities (Generation and Retail).

Ever since the introduction of market liberalization, companies and consumers have been reaping the benefits of decentralized operations. Among other things, the introduction of wholesale market to ensure sufficient supply of electricity to final consumers is worthwhile element to mention.

To meet the daily demand and keep the electricity supply secured, many of the liberalized electricity markets are organized in a sequence of activities ranging from a forward bilateral contracts market (long term) to financial derivatives market and ancillary services (short term)(MIBEL, 2009). The structure of electricity market in many of EU member countries can be represented as follows.

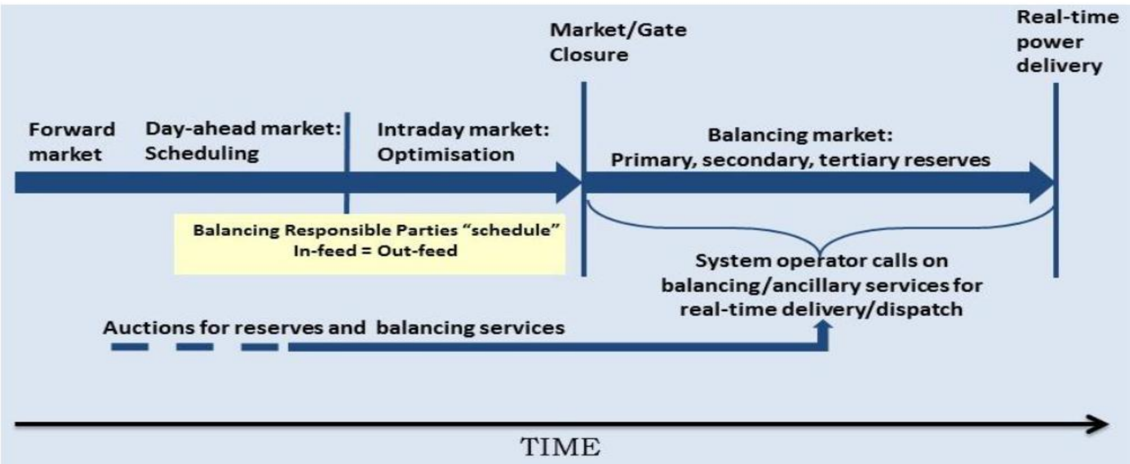


Figure 1: Structure of EU Electricity Market (Source: Bright K., 2014)

Based on the time horizon, electricity wholesale market in EU can be categorized in to long-term and short term contracts. Long-term market arrangement encompasses contracts that demand years to weeks to realize. Short-term electricity market on the other hand encompasses contracts ranging from days to hours that mainly occur in day ahead (D-1), intraday (D) and real time operations. Market participants through Balancing Responsible Parties can manage their offer updates and modifications till the gate closure. Once the gate-closure is closed it is the system operator who has full authority to modify the amount submitted by market participants considering the actual system balance.

2.2 Characteristic of Electricity

Electricity has several technical and non technical characteristics. Leaving the technical characteristics aside, electricity as a commodity is undifferentiated, non-storable and suitable for trading with bounded transmission capability.

Fungible and undifferentiated- the final electricity delivered to final consumers is the same irrespective of the input used (hydro, Gas, Coal, wind, solar etc.). This strengthens that unit difference doesn't exist between generation types. Furthermore, it is suitable for trading though with a limitation in transmission, for instance, electricity produced in France couldn't be traded in Japan or US.

Non-storability- electricity unlike other agricultural commodities can't be stored in large quantities. As a result, it should be consumed as soon as it is produced. To realize the instant consumption and production in all time periods, long term and short term electricity marketing arrangements are important. *In this paper, therefore, short term balancing marketing arrangements which are at the heart of electricity balancing process have been addressed.*

2.3 Electricity Balancing Management Services

As mentioned above, one of the unique characteristics of electricity as a commodity is non-storability. Due to this, electricity should be consumed as soon as it is produced. To keep secured electricity supply the balance between generation and consumption should be maintained in all times. Different researchers use different terms and classifications to the types of services associated with balancing management; ancillary services, reserve and balancing services (Batlle, 2013) or frequency response, fast reserve and operating reserve (www.ricardo.com).

Moreover, different regions use different types and classification of balancing services. For instance in US frequency reserve, regulating reserve, ramping reserve, load following reserve and supplemental reserve (Milligan et al., 2010) and Europe-oriented classification frequency control (primary, secondary and tertiary), and black start capability (Batlle, 2013) are common.

Ancillary services- are those services associated with automatic provision of energy to maintain the system balance with in different time horizons. Ancillary services can be classified as primary (30 seconds), secondary (5-15minutes) and tertiary (above 15 minutes).

Ignoring the differences in naming and classification of the response types and for the purpose of this paper, the general services can be broadly classified as frequency response, fast reserve and short term operating reserve which is in line with the classification outlined by the Ricardo strategic, technical and environmental consultancy group (www.ricardo.com). *Therefore, in this paper balancing and reserve services will be addressed with greater detail as they are the hub of the study.*

2.3.1 Reserve and Balancing Services

Electricity balancing as part of the power sector is a process of balancing electricity supply and consumption through the Transmission System Operators (TSOs). TSOs access sufficient amount of energy to meet the imbalance that could occur in transmission system. To achieve this, TSOs use Balancing Energy (through market participants) or reserve energy dimensions.

Unlike ancillary services, reserve and balancing services are not automatically managed, ordered and delivered. They are managed through the TSO and delivered upon instruction of TSO. The main purpose of these services is to cater the required energy whenever there are huge generation losses due to outage or huge demand forecasting errors that could create significant imbalance in the system.

There is similarity in the general purpose of the services in all liberalized markets. However, some differences exist on response time, type and application of the services among countries. Therefore, the following table portraits the myriad of services that exist across European countries. To point out the difference, minimum time of response and type of services are considered.

Table 1: Types of Balancing Service

	Minimum service time (Form dispatch to full delivery)	Type of Service		Countries
1.	<5 minutes	**1.**	Fast reserve	Italy, England and Wales
		2.	Emergency reserve	Poland
		3.	Secondary reserve	Hungary
		4.	Operating reserve	Ireland
2.	<15 minutes	**1.**	Fast disturbance reserve	Denmark
		2.	Regulating reserve	England and Wales, Italy,
		3.	Fast reserve	France, Sweden
		4.	Minute reserve(+/-)	Germany, Luxembourg, Hungary
		5.	Hourly reserve	Poland
		6.	Secondary regulation/reserve	Greece, Belgium,
3	<30 minutes	**1.**	Tertiary reserve/operating	Belgium, Ireland, Portugal, Greece
		2.	Supplemental fast reserve, decremental reserve	France
		3.	standing reserve	England and Wales
4.	<1 hour	**1.**	Regulation Power	Denmark
		2.	Reserve market	Italy
		3.	Contracted power reserve	Slovenia
5.	>1 hour	**1**	Replacement reserve	Ireland, Belgium, Poland, France
		2.	Standing reserve	Portugal, Greece
		3.	Energy balancing trading	Switzerland, Slovenia

(Source: European Transmission System Operators)

The above table indicates that balancing and energy reserve mechanisms vary across countries though the objective is the same all over. The difference is not only on the time scale and type of the mechanism but also on physical notification and remuneration for the service.

2.3.2 Physical Notification and Procurement of Reserves

The main role of TSO is to secure the system through technical and marketing arrangements. Leaving the technical aspects aside (frequency and voltage control, and congestions reduction), physical notification and procurement of reserves will be addressed with more emphasis as the objective of the paper is to investigate the contribution of EVs to the balancing market which is more of economic analysis than technical one.

In liberalized electricity market, balancing mechanism is renowned way to procure reserve and balancing services through organized marketing arrangements. TSOs arrange and organize the balancing mechanism. Depending on the rolling time market participants (generation and demand) submit their physical position in day ahead or intraday till the get-closure.

The market participants (generation and demand) should notify their physical position to the transmission system operator so as to manage the imbalance. The sequence of activities starts from day-ahead where the physical position of the market participants is merely indicative. The market participants can modify or update their position till the gate-closure of the dispatch day. But in practice the concept of gate-closure varies from country to country. The rolling time ranges from 15 minutes (Netherlands), half an hour (England and Wales), one hour (Sweden) to a fixed time in the operation day (Germany, France and Spain) (Batlle, 2013). Moreover, the time between the gate-closure and the next operation period varies as well ranging from 1 minute (Sweden) to 3 hours in France before the next relevant time period (ENTO 2003; Batlle, 2013).

Once the participants submit their final physical position there is no way to modify the position after the gate-closure. However, the physical position of the participants could be modified by the TSO according to the actual power need in the real time to the extent of asking for more power from the participants. The payment for the accepted bids may vary from one country to another. Some countries like Spain, Netherlands and Norway consider marginal price (the last price of accepted bid) (ENTO, 2003) or bid price such as in France (RTE, 2012) as a way to pay for the bids.

2.3.3 Remuneration for Balancing Service

Remunerating market participants for the service they provide is important tool to encourage and motivate the actors to provide the required quantity of energy continuously. Depending on the nature of the electricity system remuneration mechanisms for balancing services could be utilization or availability based.

Utilization based – this type of remuneration is based on the amount of energy delivered and is paid for the metered MWh.

Availability based – In this type of remuneration, the payment could be made for the contracted amount or for holding the service.

2.4 The Structure of French Electricity Balancing Market

In the above parts the general introduction of electricity market, types of balancing management, types of balancing services, physical notification and remunerations have been addressed. The stake of this paper is, however, to analyze the contribution of EVs to the French balancing market and calculate the financial gain of the EVs fleet. Therefore, bird's eye view of the French balancing mechanism helps to identify the gaps that affect or opportunities that encourage the EVs to participate in the market. Therefore, this part shades light on the structure of French balancing mechanism by stressing on market participants, responsible body, types of balancing mechanism, pricing, characteristic and types of bid offers.

2.4.1 Introduction

Like many other balancing mechanisms, the French balancing market ensures the balance between electricity generation and consumption in real time. The mechanism also takes care of congestion in the country's electricity system. In the early 2003, the Balancing Mechanism was launched with a set of governing rules under the approval of French Energy Regulatory Commission (CRE). Since then, the mechanism has proved itself as one of the effective bodies that works for betterment of the sector and it has been striving to achieve secured electricity supply in the country.

2.4.2 Who Manages French Balancing Service?

Pursuant to the law of February 2000, when there is mismatch between generation and consumption due to random incidents like generation outage, demand forecasting error or demand increase, RTE is a responsible body to call for generation to produce/reduce or for the demand to reduce/increase their consumption (RTE, 2015).

2.4.3 Réseau de Transport d'électricité (RTE)

RTE is the Transmission System Operator in France. Since it was founded in 2000, it has been improving the quality of electricity service by developing smart ways of operations and introducing innovative marketing tools to the operation of the system. RTE has done a good job in providing reasonably lower cost of electricity to the end users by maximizing its transmission system. It has also created Interconnection with neighboring countries and remarkable flexibility to integrate new energy mix to the system (RTE, n.d.).

2.4.3.1 Overview of RTE Changes (2000-2015)

RTE was founded as regulated monopoly with the roles of maintaining, operating and expansion of transmission so as to reach electricity to final consumers with fair and equitable manner.

Ever since RTE was founded, it has entertained a number of changes. Some of the notable changes and key dates are; balancing mechanism limited to minimize the gap between projection and supply (2000); electricity exchange (2001); grid reinforcement program (2002); birth of the balancing mechanism asking market participants to respond quickly (2003); legal structure (2005); market coupling (2006); CORESO technical coordination center (2007); demand side management (2014) and recently capacity mechanisms are under preparation (RTE, n.d.).

Due to the difficulty to store electricity in large quantity, system operators have been searching for a mechanism that could maintain the balance of production and consumption in real time operation. In response to this, RTE introduced balancing mechanism in 2003 so as to maximize the technical and economic efficiency of the transmission system. This method helps the operation of system to deal with imbalances that could happen in the system due to demand and generation variations. In times of random events that could adversely affect the balance of demand and generation, RTE can organize a bid and offer through balancing mechanisms.

2.4.3.2 Balancing Providers

Deregulation of electricity sector has benefited consumers from choosing suppliers to participating in the balancing market. Since July 2007, consumers have been able to choose their suppliers (RTE, n.d.). Through the Balance Responsible Entity, both generation and consumption of electricity can participate in the balance perimeter.

In line with the legal and technical requirements, generations can produce additional power so as to fill the imbalance of power in the system. Moreover, consumers (demand) are given an option to respond to minimize the imbalance by adjusting their consumption and to take advantage of their flexibility.

When balancing mechanism was launched in 2003, generation companies, industrial consumers, and inter-connection bidders were the main providers (Valentin, 2004). However, due to environmental concerns and deployment of renewable energy sources, novel and flexible actors will join the provision of power for balancing market in the coming few years. Kempton and Kubo (2000) indicate that EVs are the future participants of balancing market due to their flexibility. Therefore, this fact will be true soon when the rules are designed in favor of small and flexible participants for instance EVs.

2.5 Type of Balancing Mechanism

To maintain secured production and consumption of electricity, RTE proposes a mechanism in permanent and transparent call of bids. The balancing mechanism is open to everyone that is able to provide a reserve in a real time to keep the demand and supply balanced (upward or downward offers). In some cases RTE can call for offers that take into consideration the technical conditions, economic precedence and any other aspects that are crucial to evaluate the system. To remunerate offers RTE uses payments based on bids (RTE, 2012).

Imbalance in the system could arise in generation or demand side. To keep the system balanced and the supply of electricity secured, RTE uses either of the following offers.

Upward offer- is needed when the consumption is higher than generation. This could occur when one or more generators face outage problems. To keep both sides balanced, RTE could call generators to increase production, ask for more imports or call consumers (aggregators) to reduce their demand.

Downward offer- is needed when the production is higher than consumption. This could occur when consumption of electricity is reduced in the demand side or generation is increased. To do this, RTE could call for generators to reduce production or demand to increase consumption or export to nearby countries.

The main focus of this paper is to identify the opportunities and calculate the financial gain of EVs from participating in the downward balancing market. Of course many researchers have investigated the potential of EVs to participate in both upward and downward regulation market

(Kempton, 1996; Kempton and Kubo, 2001; Kempton and Tomi´c, 2005; Short and Denholm, 2006; Roscoe and Ault 2010). However, in this paper participation of EVs in downward balancing market is addressed as it helps to achieve a couple of objectives at a time (revenue from participation and saving of charging cost for the end users).

2.6 Imbalance Settlement Pricing

Pricing of balancing mechanism takes into account the overall picture of the system, not based on a single shot of the system. Due to this, the pricing reference system is set for each half an hour which is applicable for managing the imbalance. The upward and downward prices are set on the basis of Epex spot prices. The prices for the imbalances are remunerated based on the following formulas.

Table 2: Imbalance Prices in the French System

	Upward balancing	**Downward balancing**
Positive imbalance	Epex spot price	AWPd(1+k)
Negative imbalance	PMPh *(1+k)	Epex spot price

(Source: RTE)

Positive balance - when injection (generation) is higher than withdrawal (consumption) in this case RTE remunerates the Balance Responsible Entity
Negative balance - when extraction (consumption) is higher than injection (generation) in this case Balance Responsible Entity (BR) remunerates RTE.
PMPh - is the weighted average of offers (system buying price)
AWPd - is the weighted average of offers (system selling price)
K - is a coefficient and aimed at equalizing the imbalance account (varies from year to year)
Epex Spot Price - is a power spot price for trading in France, Germany, Austria and Switzerland.

Table 3: Evolution of the K Factor and Price Charged

Year		**Value of K**	**Year**		**Price charged**
1.	Before July 2004	**0.2**	**1.**	Before March 2005	**0.11/MWH**
2.	July 2004 - March 2005	**0.18**	**2.**	April 2005 – January 2009	**0.09/MWH**
3.	April 2005 – July 2006	**0.15**	**3.**	February 2009 – December 2012	**0.11/MWH**
4.	July 2006 - April 2010	**0.05**	**4.**	From January 2013 onwards	**0.15/MWH**
5.	April 2010- June 2011	**0.12**			
6.	From July 2011 onwards	**0.08**			

(Source: RTE)

2.7 European Energy Policies and Promotion of EVs

For the last few years European Commission has been designing polices and directives that promote green and sustainable source of energy that are expected to significantly mitigate air pollution in the region. Some of the policies that have relationship with EVs are briefly discussed below.

2.7.1 Europe 2020 Growth Strategy

Europe 2020 is European Union’s growth strategy to be achieved till the year 2020. The strategy has five main ambitious objectives (social, education, innovation, climate change and employment). Of the five strategies climate and energy package is devoted to mitigate climate change through deployment of Renewable Energy Sources. By the year 2020 EU member countries are committed to achieve;

- ✓ 20% reduction of green house gas emissions
- ✓ 20% energy efficiency
- ✓ 20% deployment of RES

In addition to this ambitious strategy, a number of directives and regulations have been forwarded. To mention some, directives 2009/33 which promotes green energy for transportation to reduce pollutants and enhance air quality. European strategy for clean vehicles and energy efficiency (2010) promotes R&D, network standardization, and charging infrastructure development. Therefore, the above stated directives, policies and regulations contributed to the deployment of EVs for the last few years. Due to the commitment of the countries the number of EVs is increasing from year to year though the growth is not satisfactory yet. According to EV global outlook (2015), the global number of EVs sold from 2010-2014 and EV market share by country are presented below.

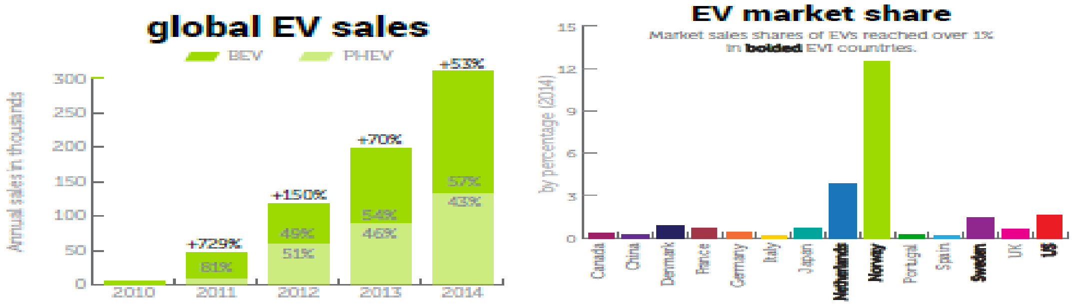


Figure 2: Global EV Sales (left) and EV Market Share (right) (Source: Global EV Outlook, 2015)

The above figures indicate that the global EV sales have increased enormously from 2010 to 2014. However, the target set to be achieved till the year 2020 particularly for EU member countries seems to be unachievable. The main reason is people tend to prefer the conventional vehicles due to lack of break through technological innovations and cost characteristics of the EVs. Therefore, this paper tries to assess the financial gain of EVs from participating in downward balancing mechanism and in turn to incentivize consumers to buy EVs that could contribute for the electricity system security and climate change of our planet.

Due to introduction of Renewable Energy Sources (RES) scholars and researchers are expecting some new actors to participate in the balancing market. For instance, EVs can participate in the balancing market either to inject power (Kempton, 1996; Kempton and Kubo, 2001; Kempton and Tomi´c, 2005; Short and Denholm, 2006,) or to shift their consumption patterns from the peak hours to off peak (Roscoe and Ault, 2010). *Therefore, this paper tries to address participation of EVs in downward balancing market by managing their consumption (charging) patterns to get revenue out of it.*

2.8 A Brief History of Electric Vehicles

The history of EVs dates back to the early of 1830s when Robert Anderson developed electric powered prototype. Few years later, the first EV that had a DC motor was invented. After showing remarkable progress, the first EV joined the New York taxi fleet at the end of 19th century (Anderson and Anderson, 2012). At the turn of 20th century car manufactures provided EVs along with steam and Internal combustion vehicles (Battery University, n.d.). The first half of 20th century was the time of boom and bust for the EV industry, where the historic EVs production hit its peak (30,000) and at the end of 1940s cheap petroleum cars started to dominate the market and forced EVs to get out of the market. Consequently, ICVs have dominated the automotive industry for the last 100 years.

During the 20th century, researchers, engineers, business consultants and experts have been cheering automotive manufacturers to manufacture EVs along with their product line. However, the attempt was not successful (Donald and Perez, 2015).

Environmental concerns and persistent increment of oil price have contributed to the resurgence of EV in the past 40 years. Moreover, public and private sectors have shown interest on electrification of vehicles (Anderson and Anderson, 2012). However, a number of technical and non-technical improvements are needed to penetrate and dominate the market share in the near future.

2.8.1 EVs Participation in the BM

How can EVs participate in the balancing market as a new source of power? EVs can participate in the balancing market in either of the offers (upward or downward). Upward offer – EVs are expected to provide additional power to the system when the generation is lower than the consumption. In the Downward offer – EVs are expected to consume power (charge) when the system has excess power. Therefore, through Vehicle to Gird (V2G) EVs can participate in the balancing market.

2.9 Vehicle to Grid (V2G)

The concept of vehicle to gird has been studied by a number of researchers and institutions to analyze the contribution of EVs to the electric system and to calculate economic benefit of an EV fleet from participation in a balancing market (Kempton and Letendre, 1996; Kempton and Kubo, 2000; Kempton et al., 2001; Brooks, 2002; Letendre and Kempton 2002; Kempton and Tomi´c, 2005; Kempton and Amardeep, 2006; Letendre And Denholm, 2006; Tomi´c and Kempton 2007; Kempton et al., 2008; Hidrue et al., 2011; Kamboj and Kempton, 2013; Johansen 2013; AC Propulsion; SAE International; Noel and McCormack 2014; Shinzaki, S., et al. 2015; Donada and Perez 2015; Petit and Perez n.d.). In light of the studies conducted in the area the following part of the paper portraits the concept of V2G along with related aspects.

2.9.1 Conventional View

In the conventional view vehicles are expected to get connected to their respective charging stations. For instance battery vehicles should be connected to the grid, fuel cells and hybrid vehicles should be connected to petroleum stations to produce electricity inside their tanks. Generally, in the conventional view vehicles follow unidirectional electricity flow (from the source to the vehicle) (University of Delaware).

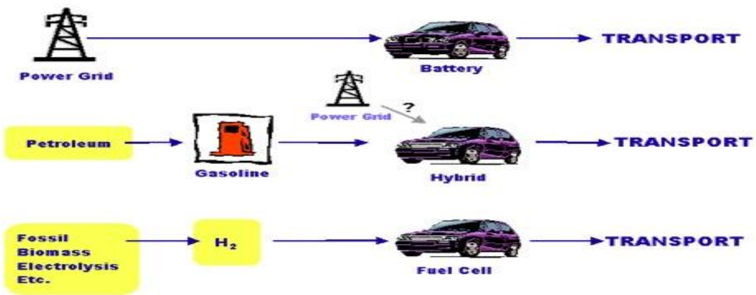


Figure 3: Conventional view (Source: University of Delaware)

2.9.2 Contemporary View

Nowadays the concept of V2G is multifunctional which encompasses bidirectional relationship of EVs and the Grid. V2G is a concept whereby vehicles (Fuel cell, hybrid or Battery) can provide power to the grid which is generated internally within the vehicles (University of Delaware and Nuvve). It is more appropriate for plug in hybrid and battery vehicles as the required devices to connect with the grid are already available. However, for the fuel cell and fuel only a direction indicator should be added to show the direction of the power flow.

For the purpose of this paper the following definition of Grid Integrated Vehicle (V2G) which is in line with the definition used by AC Propulsion and Anderson et al., 2012 is used.

Vehicle to grid *is a technology that allows EVs to charger and discharge power form and to the grid trough a bi-directional charger. The charger can serve as source of power to regulate power imbalance that could happen in the system by consuming and injecting power to the system (AC propulsion;* Anderson et al., 2012).

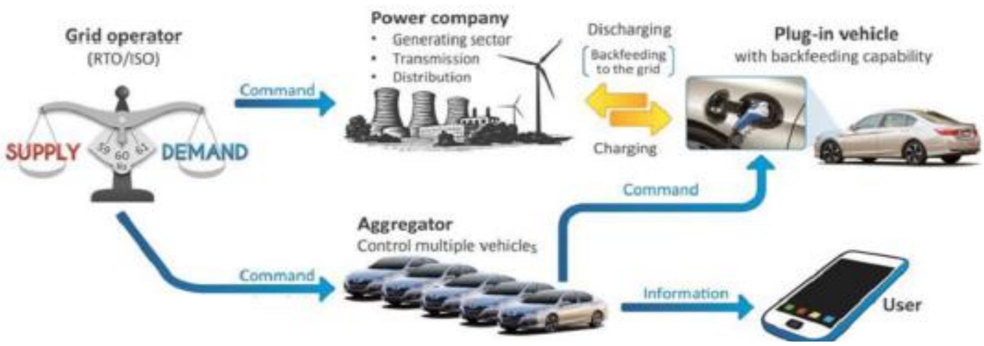


Figure 4: Concept of V2G. (Source: Satoru Shinzaki, et al., 2015)

The above figure clearly depicts that the general concept of V2G and the essential components to realize it. In order for an EV to participate in an electricity system there should be proper setup of devices to charge and discharge from and to the grid. Shinzaki et al. (2015); Kempton and Tumic (2000); and Kempton (2006) outlined that Grid Operators are those who are responsible for the balance of the system by keeping track of the daily consumption and generation. Whenever mismatches exist, they provide command to either of the sides to increase or decrease their generation or consumption based on the actual variation.

One interesting feature of EVs is their flexibility to act as a demand or generation. If the system needs more power they can inject power to the grid though with limited capacity. On the other hand, when the system has more available power they can consume power and act as a load. Therefore, in order for an EV to participate in the balancing market it has to possess bidirectional charger, of course they can use unidirectional charger which is limited to charging only and limited to downward offer in the balancing market. However, when they use bidirectional charger they can charge or discharge from and to the system. The Aggregator helps to control a large number of vehicles to accumulate the amount of power expected from each vehicle by sending information to the EV owners.

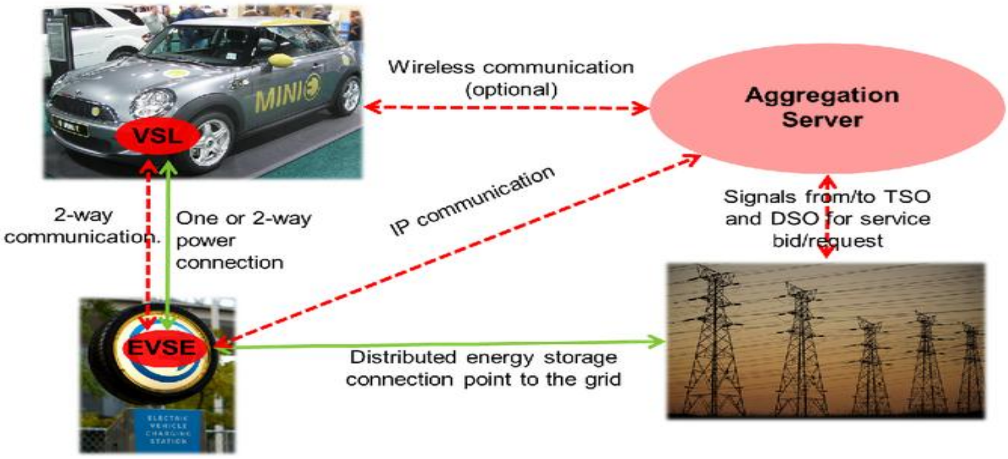


Figure 5: Components of V2G. (Source: NUVVE)

In a nutshell, the components that are essential to realize participation of EVs in the balancing market and capitalize their potential to system security are; EV (an Electric Vehicle with a battery to store power inside), aggregator (to aggregate and control multiple Vehicles), TSO (to identify the power need and communicate with market players), the Grid (to transmits power) bidirectional charger (to charge and discharge power from and to the system) and wireless communication could be used.

2.9.3 Benefits of EVs

Using EVs as main source of transportation benefits a lot for EV owners, electricity system and for the environment in general. From the final users' point of view, using EVs and charging from the grid reduce up to 60 kms that could have been used to travel to gas stations (AC propulsion, 2003). In addition to this, EVs could be used as additional sources of income for the EV owners if they participate in balancing market.

From the electricity system perspective, EVs provide clean, secured, domestic and renewable source of energy. Recently EVs have got an attention from researcher and proved that they have enormous potential for provision of balancing services either by injecting power to the grid or consuming when the system excess generation (Kempton et al., 2008). From the environmental point of view, using EVs for transportation reduces CO_2 emission and avoid cold startup which has significant impact on air pollution.

2.10 Charging Types and Possibilities

2.10.1 Charging Types

An EV without charging facility is just like a bakery without baking machine. Irrespective of the charging facilities, the current charging behavior of EV owners can be categorized in many different ways as per the characteristics and behavior of EVs and facilities. However, for the purpose of this paper, the following charging types which are quite important to roughly understand the charging types of the existing EVs are briefed.

Dumb or uncontrolled charging -this type of charging depends on the daily trip characteristics of the EV owners. EV owners charge when the battery is going to be low for the next trip most of the EV owners simply charge their vehicles without considering participation in the electricity market. According to Codani et al. (2014); Kempton and Amardeep (2006); EVs are parked for 95% of the time without giving any service. Therefore, EV owners tend to charge 2 – 3 times per week including weekends.

Delayed Charging - this type of charging involves the shifting of charging patterns based on the incentives provided by the system. For instance, EV owners can charge on the off peak as it has low cost of charging**.**

Smart Charging - unlike the above types of charging, smart charging takes control of multiple vehicles to take advantage of the charging patterns of the EVs by setting and communicating the timeslot considering the maximum capacity of the system.

Therefore, this paper takes advantage of the dumb or uncontrolled charging behavior of the EV owners and tries to incentives the EV owners to participate in the downward balancing market. Therefore, this paper calculates the financial gain of EVs fleet for changing their vehicles at off-peak without giving additional service to the system.

2.10.2 Chagrining Possibilities

Currently the share of EVs in the market is very small in most of European countries with the exception of Norway. For instance countries like Spain, UK, Portugal, Denmark and France had less than 1% of EVs market share in the year 2014 (EV outlook, 2015). Consequently, the availability of charging stations is very limited.
Most EV owners have their own charging facilities at home but it is rare to see charging stations at every corner of most cities like gas stations. Policies towards upgrading charging infrastructures are already devised and started their operation to incentivize consumers to buy EVs. However it is not yet well developed. Once significant number of EV sales is achieved there will be ample charging stations along with different charging capacities.

However, currently there are few possibilities and seems costly to have chargers with higher capacities for instance secondary EVSE at work is uncertain (Codani et al., 2014). The following figure shows the possibilities of charging stations and their respective charging capacities that would be nearly realized.

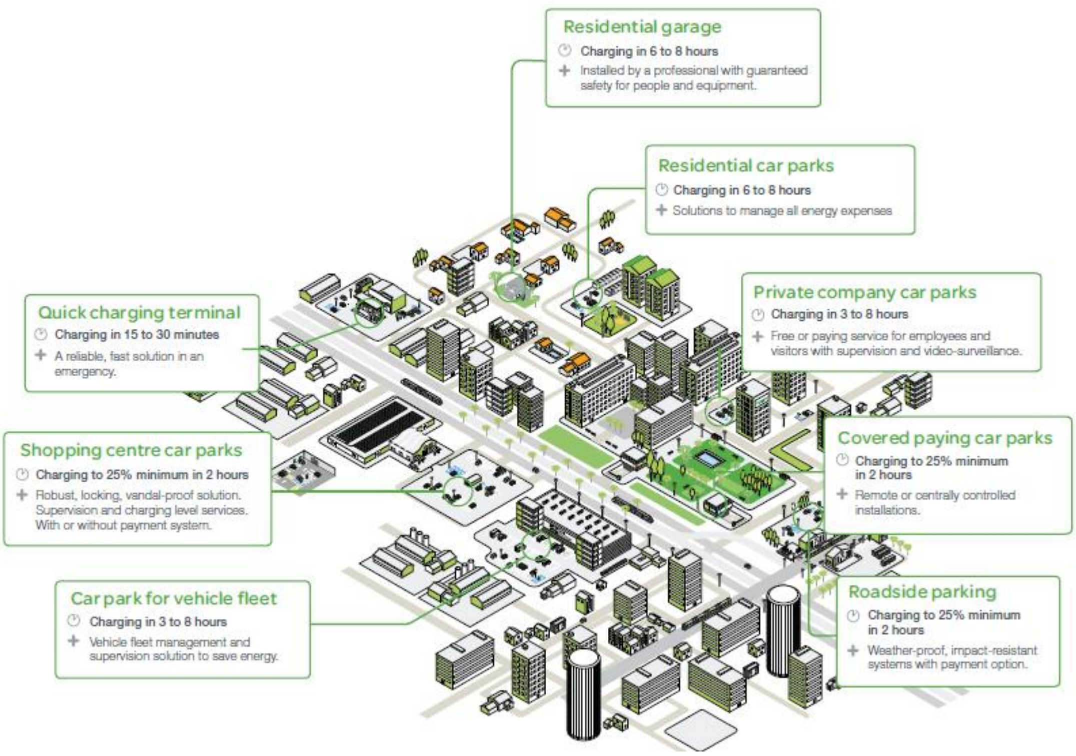


Figure 6: Opportunities for Deployment of Charging Stations and their Possible Charging Capacities. (Source: Cazals and Vidalenche, 2011)

2.11 Power Market and EVs Participation

Power market particularly electricity market can be grouped in several ways ranging from long term to short term. For the purpose of this paper the following types of power markets that have been addressed by other researchers on the area are relevant to discuss. Considering type of response, price, duration of response, type of contract and amount of power, Kempton et al. (2001) and Shinzaki, S., et al. (2015) classified and analyzed the following power markets whereby EVs can participate.

1. **Base-load power** – is a type of power where the system provides the minimum amount (base power) within a day. In order for this to be achieved giant power sources like Nuclear are more appropriate as they have lower cost per kWh. Generators which participate in this market should provide round the clock.
2. **Peak-load-** is a type of load whereby highest consumption is expected. This happens in different seasons and different times. For instance in summer, peak demand is expected use of electricity for air conditioning purposes. Where as in winter, peak demand is expected due to consumption for heating purposes. In order to meet these peak demands flexible generators like RES and CCGT are quite important.
3. **Regulation** – Is an automatic response of generators to keep the system frequency and voltage of the system constant by matching demand and generation. These services are managed and instructed by the transmission system operator.

From the above power markets, Kempton et al. (2001) and Shinzaki, S., et al. (2015) argue that EVs are not the right choice to participate in base-load power due to limited storage capacity, high cost per kWh, and limited lifespan of the storage unit. Therefore, to meet peak demand, flexible generators like CCGT with lower capital investment are needed.

Kempton et al. (2001) indicate that EVs could be appropriate to participate in Peak-load as they are highly flexible with less standby cost. However, they sturdily argue that EVs are appropriate for regulation market either in the upward or downward regulation.

Unlike the above researchers' target of study, this paper tries to investigate the contribution of EVs to the non automatic balancing services and calculate the financial gain of EVs fleet from the participation in the balancing market. Moreover, this study concentrates on the downward balancing service whereby generation is higher than the demand. *In a nutshell, unlike the above studies, this paper analyzes the participation and revenue of EVs in the off-peak demand of the French electricity system*.

2.12 Challenges of EVs to Participate in Balancing Market

Like many other technologies EVs path to participate in the balancing market doesn't seem smooth and free of challenges. The EVs challenges have been studied by scholars and researchers from technological, economic and political perspectives. However, in this paper technological challenges will not be discussed as the main theme of the paper is to analyze the economics of EVs and hence market related rules are addressed.

Nowadays, EVs start to catch attention of TSO due to their flexibility to provide additional service to the power system as a new source of energy. However, the existing rules are not designed to accommodate new technologies as they were designed considering the giant generations and demand. After reviewing the existing rules of French balancing market, the following three main issues could be considered as the main challenges of EVs to participate in the balancing market.

2.12.1 Balancing Providers

Currently very giant generations and industrial consumers are the main providers of balancing management. The existing rule doesn't consider small players that have very small capacity to contribute to the system. Due to this, the minimum amount to participate in the balancing market seems ideal and unachievable at this time as the EVs are at their infant age of resurgence. Therefore, it is not easy to aggregate a large number of vehicles to meet the minimum requirement.

2.12.2 Minimum Amount and Pricing

Since the main players are the giant demand and generation the minimum amount to participate in the balancing market is 10 MW. This could create a challenge for EVs fleet manager to coordinate the huge number of EVs as a single vehicle is able to contribute less than 20 kW.

In addition to the minimum amount to participate in the market the pricing is also set considering the capacity if the giant players. Pricing in French balancing market is therefore, for MWh not for kWh.

It seems the pricing system and minimum amount are designed considering who the main players are. However, when the system market allows small players to participate in the market for sure considerations will be taken in pricing and minimum about to bid. As of the existing rules, it seems challenging for EVs to participate in the market. In the near future hopefully the rules will be designed to enhance small players like EVs to be one the actors in the French balancing market.

Chapter Three

3. Methodology of the Paper

In this part of the paper, the methods and tools that have been used throughout the itinerary of the research are explained. Generally, this part briefs out the study area, type of data, assumptions made on the technical and non technical characteristics of the EVs fleet, objective function and brief explanation on how the model was programmed.

3.1 Study Area

This study was conduct in France considering the Electricity of the country in general. French Electricity market was liberalized in 2000 by unbundling the operations of the sector to regulated and competitive ones. As time passes on several changes have been made to the operation of sector. Therefore, the target of the study was the French balancing market and assessed the potential financial gain of EVs fleet from participation in the liberalized downward balancing market.

3.2 Data Type and Source

The main objective of the paper was to assess the financial gain of EVs fleet in the French balancing market. To achieve this objective, downward offer prices and energy volumes that have been observed from 2008-2014 were used. The data were collected from RTE (Transmission system operator of French) website (http://www.rte-france.com/).

In addition to the price and energy volume of the downward balancing market, information about the EVs trip patterns and distance distribution was collected from *Ministry of Ecology, Sustainable Development and Energy.*[2]

3.3 Modeling and Assumptions

To scrutinize and estimate the contribution of EVs fleet to the system, understanding the technical and non technical characteristics of the vehicles is at the heart of the model. Therefore, the technical and non technical assumptions that we have made to calculate the EVs fleet contribution in the system and their potential revenues are discussed below.

3.3.1 Technical Characteristics

Technical characteristics of the vehicles explain the capacity of the vehicles to store power inside their batteries which in return determines the capacity of the vehicles to store and reuse electricity when it is needed. For this study purpose, it is assumed that all vehicles have battery capacity of 24kWh which is in line with the assumptions made by other researchers (Petit and Perez, 2014). In addition to the battery capacity, 3 kW charging capacity is considered.

3.3.2 State of Charge of the Battery

For the battery safety and technical reasons 5% and 95% minimum and maximum state of charge are considered respectively. To determine the fraction change of SOC we developed the following formula;

$$SOCt = \frac{EVSEC * hour}{BC} \quad (1)$$

Where SOCt is State of charge at t time duration

EVSEC - Electric Vehicle Supply Equipment Capacity

BC - Battery Capacity

For each 30minutes and considering 3kW EVSE, the fraction of charge for an EV will be

$P\ 30\ minute = \frac{3*.5}{24} = 0.0625$ and the SOC at time t would be $SOC(t+\delta t) = SOCt + P\delta t$ (2)

[2] *For more information see annex C*

For instance when a vehicle leaves Monday morning at 8:30am the state of charge would be 24 kWh and after returning from work at 5:30pm, the SOC would (24-4.8)=19.2 kWh. Therefore, the state of charge at 6:30pm would be;

$$SOC(5:30 + 1hour) = SOC6:30pm \ = SOC5:30pm + 3kWh * 1 = 19.2kWh + 3kWh = 22.2kWh$$

In addition to the fraction of charge, we programmed the model not to allow charging beyond its capacity. For example, on Monday evening it is not possible to charge the whole night as the battery gets full within few hours. Considering the above example, it is impossible for the EVs fleet to participate in the downward balancing market for more than 2 hours.

3.3.3 Non Technical Characteristics

These characteristics elucidate trip behavior of the vehicles. It includes, when EVs depart from home, how long do they stay at work, for how long they can charge, when they get back home etc. more specifically the following non technical assumptions are made.

3.3.4 Trip characteristics

The general trip characteristics of the EVs are assumed to be similar in the weekdays (from Monday to Friday). On the other hand, weekend trip patterns of the EVs are not included in the study due to lack of organized data about weekend trip patterns.

The average distance an EV commutes for the roundtrip per day is 24 kms which is in line with the assumption made by P. Codani et al. (2014), and an average of one hour travel time (30 minutes from home to work and 30 minutes from work to home). Therefore, the following patterns about when the EVs leave home, reach workplace, depart from workplace and reach home back are observed.

$t0 - departure\ from\ home$ – (the time when vehicles leave their home)
$t1 - arrival\ at\ work$ – (the time when vehicles arrive at work)
$t2 - departure\ from\ work$ – (the time when vehicles leave workplace)
$t3 - arrival\ at\ home$ – (the time when vehicles reach home)

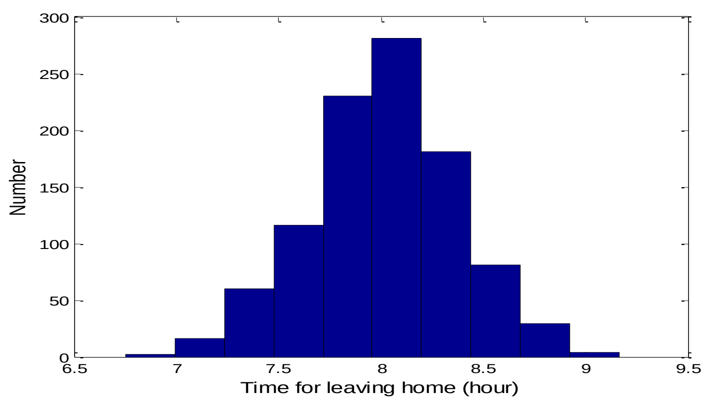


Figure 7: Histogram of the Departure Time from Home to Workplace

The above figure portraits the departure of EVs from home to work. Very few vehicles leave home before 7am and after 9am. But most of the vehicles leave home between 7:45am and 8:45am. Due to this fact the reference time for departure from home to office is considered to be 8:30am. And hence, vehicles are expected to reach office after an average of 30 minutes travel (9am).

3.3.5 Charging Situations

Depending on the market price and availability of charging stations and on theoretical basis, EVs can charge their battery at any time and place. In the future when EVs dominate the automobile market, a number of charging types and possibilities will be in place. Studies indicate that there are myriad of charging possibilities ranging from quick charging terminals (15-30minutes) to very slow residential garages (6-8 hours) (Cazals and Alenche, 2011). However, to calculate the potential financial gain of the EVs fleet, only the following two cases are considered in this paper.

i. **Home Charging –** as indicated above due to cost reasons home charger capacity is limited to 3kW. In addition to this, all existing EV owners have charging facility at home. Therefore, the first case tries to calculate the potential financial gain of EVs assuming that they are able to charge at home during the night like what most EV owners are doing currently. Therefore, the total available hours to charge their battery is limited to the number of hours starting the EVs stay home. In this case their availability to provide downward balancing service will be limited to 15 hours (from 5:30pm-8:30am).

ii. **Home and Workplace Charging –** in this case optimist assumption is made where EVs can charge at home and workplace. Therefore, the number of hours the EVs fleet that can participate in the balancing market is almost the whole day except the time they use to travel. In this case the number of possible hours that the EVs can participate in the market is much higher than the other first case. Therefore, the total available hours for the EVs fleet to participate in the downward balancing market is 23 hours.

In both case the EVs can't participate in the balancing market when they are traveling either from home to workplace or workplace to home (typically around 8:30am-9:00am and 5:00pm-5:30pm).

It is obvious that the wholesale revenue varies along hours in a day, days in a week, seasons in a year and with market conditions. For instance, hourly prices are different for peak hour and off peak hour of a day, weekdays and weekends, winter and summer. Market price of inputs could have also a significant impact on the price of electricity (price of oil, coal etc). Therefore, to grasp better information about the financial gain of the EVs fleet the analysis is made considering the downward balancing prices of French balancing market from 2008-2014.

3.3.6 Financial Gain

To quantify the financial gain of EVs from participation in downward balancing market, 1000 EVs have been considered as a fleet. Calculation of the financial gain is done based on the relationship of downward price and downward energy volume for each week. In order to facilitate quantification of the financial gain we programmed the model in MATLAB.

3.3.7 Assumptions about the Aggregator

Assumptions are quite useful tools to analyze a specific situation with greater detail and better focus. Therefore, in this paper the following assumptions are made about the aggregator.

The aggregator is perfect and not that much giant enough to be able to influence the market price and exercise market power. Therefore, in the French Energy Market it is impossible for the aggregator to exercise market power and raise revenue. This assumption is made considering the possible impact that the aggregator could have compared to the French Electricity industrial structure. Moreover, there is perfect information flow between the three players (the Aggregator, Electricity Market and EVs).

3.3.7 Modeling and Programming

Optimization of the financial gain is made considering the best price in the downward balancing market and availability of timeslot in which the vehicles can participate in the market. It creates a vector by selecting the best price (from the available 48 half hourly prices) for all days except for 26-oct-08, 25-oct-09, 31-oct-10, 30-oct-11, 27-oct-13, 28-oct-12 and 26-oct-14 which they have 50 half hourly prices per day due to Daylight Saving Time (DST) that forces the clock to delay one hour.

We consider weekly approach where each Monday morning the vehicles have full battery capacity, therefore, the state of charge on Monday morning before they depart to work is 100%. In every Sunday the vehicle owners charge their vehicles at the expense of themselves. Consequently, we set the price for Sundays to be zero and there is no possibility to participate in the balancing market till Monday. Moreover, the prices for Christmas holidays are set to zero. Since the analysis is made on weekly basis we set the first Monday of the year and the last day of the year before Christmas due to this 50 yearly weeks are considered.

3.3.8 Elements of the Main Model

3.3.8.1 Step by Step Description of the Model

To optimize the best opportunity along with the best possible prices and sufficient SOC, the main function contains three basic elements.

The first function lays the foundation for the whole optimization and holds the other two elements (SOC and possibilities to participate). Therefore, the first element devotes to extract the best prices and opportunities in weekly basis. To do this, we programmed the model; when the state of charge should be at its full capacity, number of time slots available for charging, availability of time slots before departure to work and after arriving home.

Moreover, we modeled the program to identify the best prices and possible time slots to participate in the balancing market from Monday evening (t3[3]) to Saturday morning (t0[4]). After identifying the possibilities and best prices, it transforms the 50[5]*6[6] matrix in to a vector then the prices will be sorted in descending order.

---

[3] The time when vehicles reach home after work which is assumed to be at 5:30pm
[4] The time when vehicles depart home for weekend trip which is assumed to be at 8:30pm
[5] Half hourly daily prices
[6] The number of days from Monday to Saturday

3.3.8.2 Weekly Gain Analysis

The gain for every Monday is done on weekly basis. To calculate the financial gain of the EVs Fleet, the following data are crucial.

3.3.8.3 Price Matrix

```
Function [ B ] = table_price ( price , power)
```

[B] is a price matrix that matches available power with their corresponding prices. Hence, the matrix will have either zero or non zero values. When there is available power the values inside the matrix will be different from zero otherwise the values remain zero. Therefore, the Price matrix is a function of available power in each time slot and the corresponding prices.

3.3.8.4 Price Availability Indicator

```
function [ B, Monday, last_day ] = table_indicater_price ( A , Year)
```

The price availability indicator shows us the availability of prices from Monday to Friday. It is a function of the price matrix [B] which is the same as "A" of the right hand side of the above equation, and Working days in each week. To exclude the Sundays from financial gain calculation we set the price of all Sundays to be zero.

```
B(:,sunday+k*7)=0
```

After programming all the relevant aspects, the gain optimization was developed based on the following three main loops.

3.3.9 The First Loop (Opportunity Identification)

This loop is by far the main loop that holds the other two loops. It identifies the best opportunities to participate in the market. To do this we programmed it as follows.

i) Identification of Timeslots

```
t0 = floor(data_EV(1,index_EV)/30)
```

Last time slot of availability before departure to work

```
t4 = ceil(data_EV(4,index_EV)/30);
```

First time slot of availability after arrival at home

```
Nb_slot_EV = floor(data_EV(5,index_EV)*5/W_30min)
```

Number of 30min slots that are required to charge the EV during the week

ii) Identification of Prices

After identifying the half hourly prices from Monday to Saturday morning, the half hourly prices are transformed in to a vector of prices and then sorted in descending order.

```
px3_week = reshape(px_week,50*6,1);
```

The matrix 50*6 is transformed in to a vector

Once we programmed and identified the available timeslots and prices, the next step is to identify the first and second best prices.

```
best = indx_w(1:Nb_slot_EV);
```

List (index) of the weekly best prices for (the first best)

```
others = indx_w(Nb_slot_EV+1:end);
```

List (index) for the other prices (the next best)

3.3.10 The Second Loop (State of Charge Characterization)

After identifying all the possible price and availability combinations, the next step is to characterize how the SOC works. As a result, we programmed the maximum SOC to be 95% and minimum state charge to be 5%. The program doesn't allow an EV to charge beyond 95% and below 5% of the SOC.

The second loop of the model deals with characterization of the State of Chare of the EVs. Once we identified the opportunities to participate in the market in terms of power availability and prices, the next step is to identify the EVs available battery space to accommodate additional charging.

To identify the available space after consuming for a round trip of a given day, we programmed the SOC as follows

```
SOC_week(index_EV) = SOC_week(index_EV) - data_EV(5,index_EV)
```

For technical and efficiency reasons the EVs batteries cannot be charged above 95%. Therefore, to identify the possible time slots for charging before the next departure we programmed the SOC as follows.

```
Nb_slot_charge = floor((0.95 - SOC_week(index_EV))/W_30min)
```

After identifying the available space and the time slots the next step is to calculate the revenue from charging in the balancing market.

```
gain(index_EV) = gain(index_EV)+ sum(px3_week(indx_day(1:Nb_slot_charge)))*W_30min*C_bat*1e-3/rendt
```

The above formula tells us the revenue of an EV which is a function of the number of EVs, the best price, available time slots, battery capacity for minimum of 30 minutes and its efficiency.

3.3.11 The Third Loop (Balancing Market Participation Decision)

This element of the model emanates from the first two loops which deals with optimization of participation of the vehicles considering the available timeslots, best prices and the nature of SOC. Therefore, in this loop identification of the minimum required amount for the round trip is identified.

```
minSOC = min([(1+security)*data_EV(5,index_EV) 1])
```

The above formula explains the minimal SOC for leaving in the morning in each day. Moreover, if there is no enough energy in the battery i.e SOC_week(index_EV) < minSOC we will search for the highest price in the balancing market during night. However if there is no enough opportunity to charge from the balancing market the owners should purchase from the energy market.

Nb_slot_charge > 0   therefore the cost of energy purchase would be

```
Energy_purchase(index_EV) = Energy_purchase(index_EV) + Nb_slot_charge*W_30min*C_bat*energy_price/rendt;
```

Considering the above three elements, the total gain of the EVs fleet was calculated based on the following formula.

$$TG = (GBM - EM) + (EVPBM * BC * EP * NDW * \frac{NM}{EC}) \quad (3)$$

Where **TG** is the total gain

GBM – gain from the balancing market (kW * price) expressed in Euros

EM – electricity purchased from the market to fill the battery (kW * price)

EVPBM – electric vehicles participated in the balancing market per week (numbers)

BC - battery capacity for daily round trip(kW)

EP – energy price (Euros)

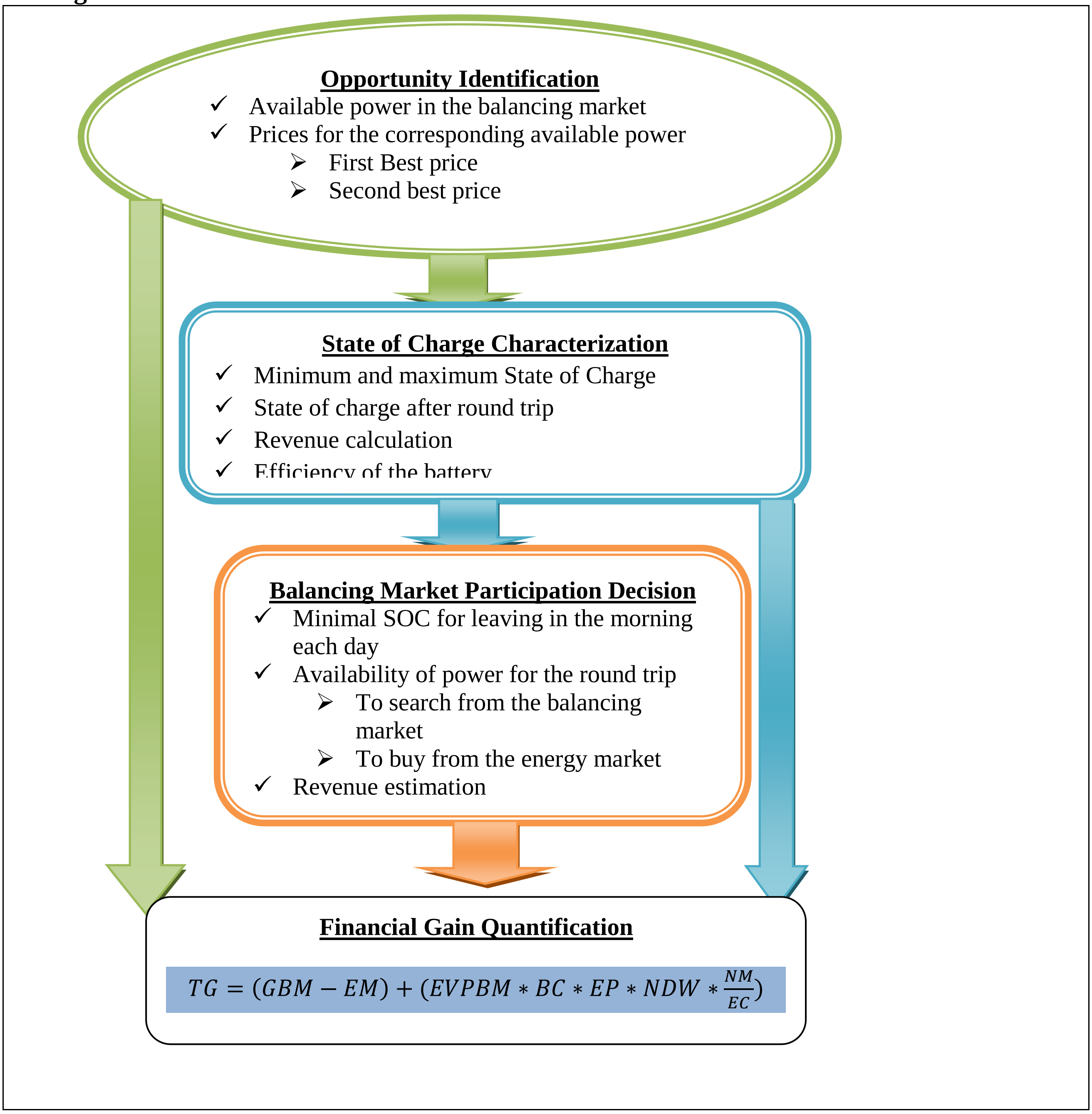
NDW – number of working days per week

NM – number of Mondays

EC – efficiency of the conductor (percentage)

Therefore, based on the above formula we determined the total gain of an EV per year which is expressed in Euros.

Figure 8: Framework of the Model



Chapter Four

4. Results and Discussions

4.1 Introduction

This part of the paper discourses the result of the simulation about the financial gain of the EVs fleet from the downward balancing market. We considered two different charging situations (home charging and home and workplace charging).

To calculate the potential financial gain of the EVs fleet we modeled it considering the relationship of the time that the EVs are available for the balancing market and price of the downward offer. To fully understand the gain of the EVs fleet from participation in the balancing market, it is better to see the overall cost that an EV could have incurred without participating in the downward balancing market.

If the battery is charged at its full capacity and we assume we can use it till it gets zero, it is possible to travel for a maximum of 120kms (with a mean consumption of 0.2 kWh/km). However, due to safety and technical reasons we assume maximum and minimum utilization of the battery. We put a constraint not to charge more than 95% at full power and a charge is mandatory if the remaining capacity is less than the energy required for the next trip and a security margin (chosen equal to the next trip and hence a capacity twice of the next trip is required.

$$\textit{Total Cost} = \textit{Average daily consumption} * \textit{average yearly energy price} * \textit{num. of working days per year}$$

Considering the total available working days in a year by excluding weekends and two weeks of Christmas holiday, the average yearly total cost of charging an EV from 2008 to 2014 is represented below.

Table 4: Cost of Charging in the Base Case (without participation in the balancing Market)[7]

Year	Average yearly Electricity tariffs in €/MWh	Average daily consumption in kWh	Number of working days	Average yearly consumption In MWh	Total cost in Euros
2008	89	5.5	250	1.53	**137.2**
2009	90.7	5.5	250	1.53	**138.8**
2010	93.4	5.5	250	1.53	**144**
2011	95	5.5	250	1.53	**146.5**
2012	96.9	5.5	250	1.53	**149.4**
2013	101.8	5.5	250	1.53	**157**
2014	104.3	5.5	250	1.53	**160.8**
	Average Cost				**147.7**

In the above table, rough calculation of the charging cost for an EV owner has been made to estimate how much money an EV owner would pay if it was from his own pocket. In the above calculation, some simplifications are made (the same number of days for each year, the same daily consumption). The average yearly electricity tariffs in off-peak are calculated from the present tariffs (2015) and successive increases since 2008 has been observed. Other things remain constant, the cost of charging increased constantly from year 2008 to 2014. This indicates the cost of charging is proportionally related to the price of electricity. *The higher the electricity price the higher the charging cost. Therefore, on an average basis, an EV owner would have paid 147.7 Euros per year if it were from his pocket.*

[7] The calculation is done considering the French tariffs in off-peak-hours (typically from 10pm to 6am) and 90% efficiency of the EVSE is assumed.

4.2 Home Charging Results and Discussions

To scrutinize the potential financial gain of the EVs fleet we considered two different charging situations (home charging and home and workplace charging).

In this case we assumed the vehicles are able to charge only at home with charging capacity of 3kW. To have a better picture of the vehicles trip patterns, let's recall the departure and arrival time of the vehicles from the previous part.

$t0 - departure\ from\ home$ (the time when vehicles leave home)
$t1 - arrival\ at\ work$ (the time when vehicles arrive at work)
$t2 - departure\ from\ work$ (the time when vehicles leave workplace)
$t3 - arrival\ at\ home$ (the time when vehicles reach home)

Therefore, availability of the vehicles for the balancing market is limited to the night time only which is from t3 - t0. However, from Saturday (t0) to Monday (t0) there is no possibility to participate in the balancing market. On Sunday, EV owners charge their vehicles at the expense of themselves from their pocket to get full and ready for Monday morning. On Monday morning (at t0) the vehicles will have fully charged battery. Since workplace charging facility is not considered in this case, the vehicles couldn't participate in the downward balancing market during the day time (t0 – t3). After running the simulation, the following home charging results are obtained.

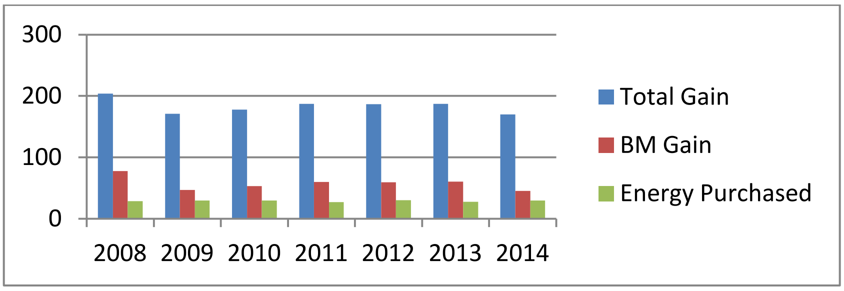


Figure 9: Home Charging Total Gain, Energy from Market and Gain from Balancing Market

The above figure 8 depicts the total gain, gain from balancing market and energy purchased from the market. The total gain of an EV is determined by the amount of energy purchased from market, energy obtained from the BM and prices of both markets. Due to these determinant factors, variations in the total gain are observed. As it can be seen from the figure above, relatively higher and lower amount of gains have been observed in 2008 and 2014 respectively. For the years 2011, 2012 and 2013 relatively moderate gain has been obtained.

The main reason for the gain difference observed above is due to the difference between the amount of energy reaped from the market and the energy purchased from the electricity market. Therefore, in 2008 relatively very high amount of energy is extracted from the BM with small amount of energy bought from the energy market. On the other hand, in the year 2014 relatively small amount of energy is extracted from the BM. Due to this , the total gain varies among the years. Other things remain constant, the larger the share of energy from the BM, the higher the total gain.

From the above three figures, one can infer that, participating in the balancing market helps the EV owners to achieve a couple of objectives at a time (saving the charging cost and reducing the amount of energy purchase from the market).

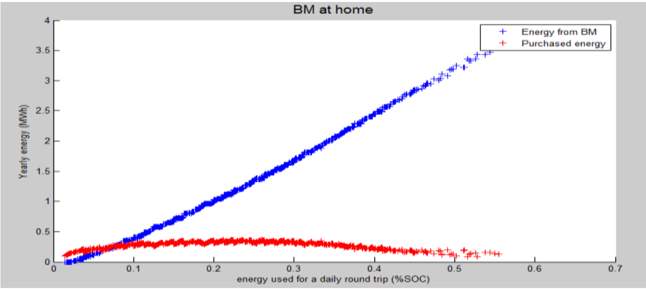


Figure 10: Energy Share between BM and Purchase as a Function of the Energy Use (% of Total Battery Capacity) per Round Trip

Figure 9 shows the relationship of the State of Charge and gain from balancing market. If the vehicles use their battery less than 7% of the SOC they always have to buy from the energy market. This is due to the fact that the amount to be charged is less than the fraction of charge needed to participate in the balancing market. Recalling the fraction of charge formula $\left(SOCt = \frac{EVSEC*hour}{BC}\right)$ from the previous chapter (equation 1), the fraction of charge for half an hour considering 3kW charging capacity is, ($3 *. \frac{5}{24} = 0.0625$). If the vehicles need energy less than the minimum fraction of charge they tend to charge from the energy market.

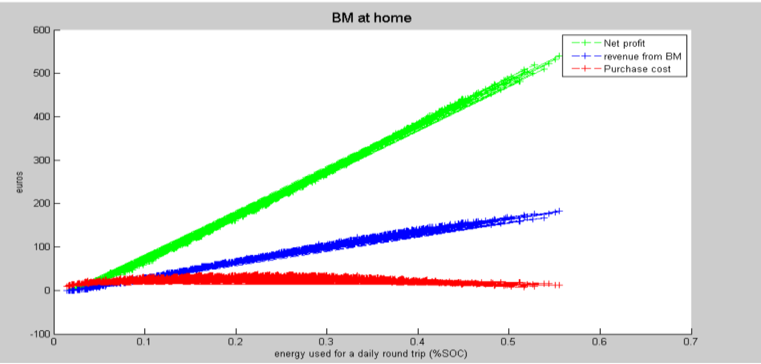


Figure 11: Energy Share between BM and Purchase as a Function of the Energy Use (% of Total Battery Capacity) per Round Trip

The figure above indicates utilizing the batter below 8% of its capacity leads to higher energy purchase from the market and utilizing beyond 8% of the SOC creates more opportunity to participate in the balancing market. As it can be seen from figure 10, below 8% utilization of the SOC, the energy purchased is above the total and balancing market gains. However, beyond 8% utilization of the SOC, the BM gain starts to exceed the energy purchase and total gain increases significantly.

In a nutshell, the longer distance the vehicles travel, the higher the consumption of energy, the more space to charge, and the more opportunity to participate in the balancing market and the higher the total gain to reap. Therefore, from the above figures (Figure 9) one can infer that the total gain is directly related to utilization of the battery.

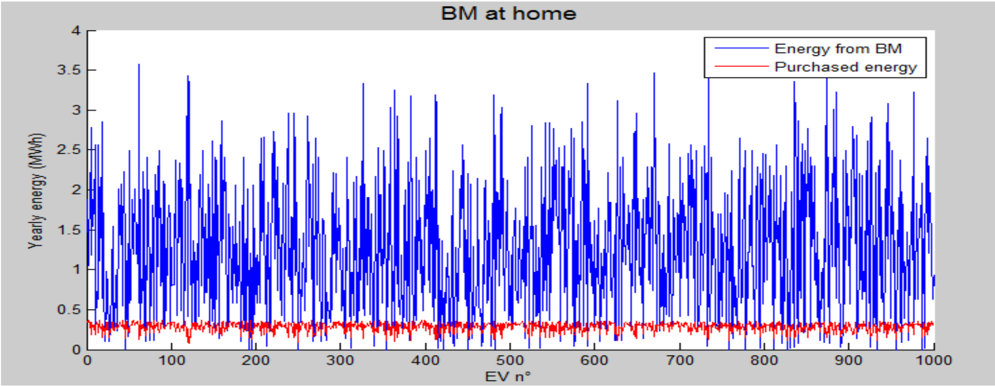


Figure 12: Energy from BM and Market (Home Charging)

The yearly share of energy consumption per vehicle is presented in the figure above. The blue and red lines indicate energy obtained from the BM and energy market respectively. As indicated in the figure the lion's share of the energy consumptions came from BM with highest value of 3.57 MWh. On the other hand, the amount of energy bought from the market accounts for less than 0.4 MWh per year. Therefore, as significant amount of energy is obtained from the BM, the total gain of an EV owner is expected to be attractive.

4.3 Home Charging Gain Allocation

When the EVs participate in the balancing market, they make money out of it in addition to the energy cost they save. But in order to participate in the balancing market there should be an intermediary (aggregator in this case) that communicates with the EV owners whenever there are opportunities to participate in the balancing market. Therefore, reasonable way of sharing the benefit between the EV owners and the aggregator is worthwhile to consider. Since it is difficult to measure the fairness of gain allocation especially in this paper, it is better to consider three different allocations that indicate optimist (60/40), pessimist (40/60) and neutral (50/50) positions from the EV owners' perspective.

To estimate the average yearly gain of an EV, average values of Total gain, balancing market gain and Energy purchase are used. The Energy cost without BM (ECWBM) is the amount of money that would have been paid in the absence of Balancing Market.

Table 5: Home Charging Average Values

S.no	Description	In Euros
1.	Average gain from BM (AGBM)	**57.5**
2.	Average Energy Purchase (AEP)	**27.6**
3.	Energy Cost Without Balancing Market (ECWBM)	**147.6**
4.	Average Total Gain (ATG)	**177.7**

$$\text{Total Gain} = \text{GBM} - \text{EP} + \text{ECWBM} \quad (3)$$

Where ECWBM - Energy cost without BM

TG - Total Gain

EP - Energy Purchased

GBM – Gain from the Balancing market

Therefore, using GBM, EP and ECWBM values from the above table, TG is

$$\text{TG} = 57.5 - 27.6 + 147.6 = 177.7$$

Considering the three gain allocation ways, the net gain per EV and the overall net gain of the EVs fleet are illustrated below.

Equal share (50/50) - in this case the amount obtained from the balancing market is shared equally to the EV owners and the aggregator. An EV owner will get half of the gain from the balancing market. Therefore, the total financial gain of an EV considering half of the gain from the BM and cost saving would be.

$$NGPV = \frac{GBM}{2} + ECWBM - EP \quad (4)$$

Where NFPV- Net Gain Per Vehicle
GBM – Gain from Balancing Market
EP - Energy Purchase

$$Net\ Gain\ per\ Vehicle = \frac{Gain\ from\ the\ Balancing\ Market}{2} + Energy\ Cost\ Without\ BM - Energy\ Purchase \quad (5)$$

$$Net\ Gain\ Per\ Vehicle = \frac{1}{2} * 57.5 + 147.7 - 27.6 = 148.8\ Euros$$

The overall financial gain of the EVs fleet per year would be;

$$EVs\ Fleet\ Overall\ Gain(EVFOG) = NetGain\ per\ Vehicle(NGPV) * Numberof\ EVs(NEVs) \quad (6)$$

$$\boldsymbol{EVFOG = 148.8 * 1000 = 148,800}\ \textbf{Euros per year}$$

The gain of the aggregator is limited to the gain from the balancing market and the energy saving gain is allocated to the EV owner only. Therefore, considering the 50/50 share the aggregator's gain is half of the gain from the balancing market which is 28.75 Euros.

In favor of the aggregator (40/60) – assuming that much work is done by the aggregator, therefore, lion's share of the gain goes to the aggregator. In view of this, An EV owner will get two fifth (2/5) of the gain from the balancing market. Therefore, the total financial gain of an EV considering two fifth of the gain from the BM and cost saving would be.

$$Net\ Gain\ per\ Vehicle = \frac{2}{5}(Gain\ from\ the\ Balancing\ Market) + Energy\ Cost\ Without\ BM - Energy\ Purchase \quad (7)$$

$$Net\ Gain\ Per\ Vehicle = \frac{2}{5} * 57.5 + 147.7 - 27.6 = 143.1\ \text{Euros per year}$$

The overall financial gain of the EVs fleet per year would be;

$$EVs\ Fleet\ Overall\ Gain(EVFOG) = NetGain\ per\ Vehicle(NGPV) * Numberof\ EVs(NEVs)$$

$$\boldsymbol{EVFOG = 143.1 * 1000 = 143,100}\ \textbf{Euros per year}$$

In this case the aggregator's gain is 2/5 of the gain from the balancing market which is 23 Euros.

In favor of the EV owner (60/40) – now more of the gain goes to the EV owner. Therefore, unlike the second approach, in this approach EV owners get lion's share of the gain. An EV owner will get two fifth (3/5) of the gain from the balancing market. Therefore, the total financial gain of an EV considering three fifth of the gain from the BM and cost saving would be.

$$Net\ Gain\ per\ Vehicle = \frac{3}{5}(Gain\ from\ the\ Balancing\ Market) + Energy\ Cost\ Without\ BM - Energy\ Purchase \quad (8)$$

$$Net\ Gain\ Per\ Vehicle = \frac{3}{5} * 57.5 + 147.7 - 27.6 = 154.6\ \text{Euros per year}$$

$$\boldsymbol{EVFOG = 154.6 * 1000 = 154,600}\ \textbf{Euros per year}$$

In this case the aggregator's gain is 3/5 of the gain from the balancing market which is 34.5 Euros.

In a nutshell, if we consider EVs that participate in the balancing market through home charging only, the overall benefit of the EVs fleet lies between 143,100 and 154,600 Euros per year. In an individual basis an EV owner reaps a benefit of at least 143.1 Euros per year.

4.4 Home and Workplace Charging Simulation Result

Unlike the previous case, this case considers charging both at workplace and home. The number of hours that the EVs will be available for the balancing market is much higher than the previous case. The vehicles can participate in the balancing market almost the whole day except the travel time. In terms of hours, the vehicles can participate in the balancing market for about 23 hours (from t1 to t2 and t3 to t0) in the working days.

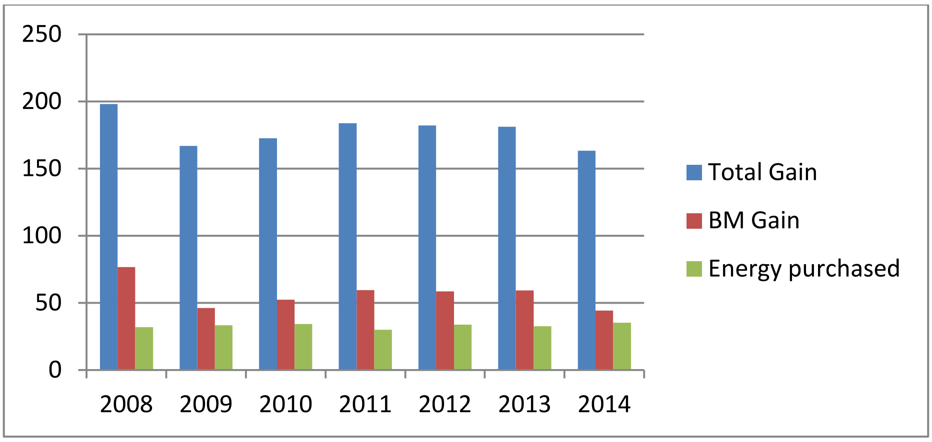


Figure 13: Home and Workplace Charging Total Gain, Energy from Market and Gain from Balancing Market

The above Figure 12 depicts the total gain, BM gain and energy purchased in the market. When the vehicles are able to charge at home and work the total gain ranges from 163.15 to 198.1 Euros. The total gain is similar with the previous case, but in this case the total gain value is below 200 unlike the previous case.

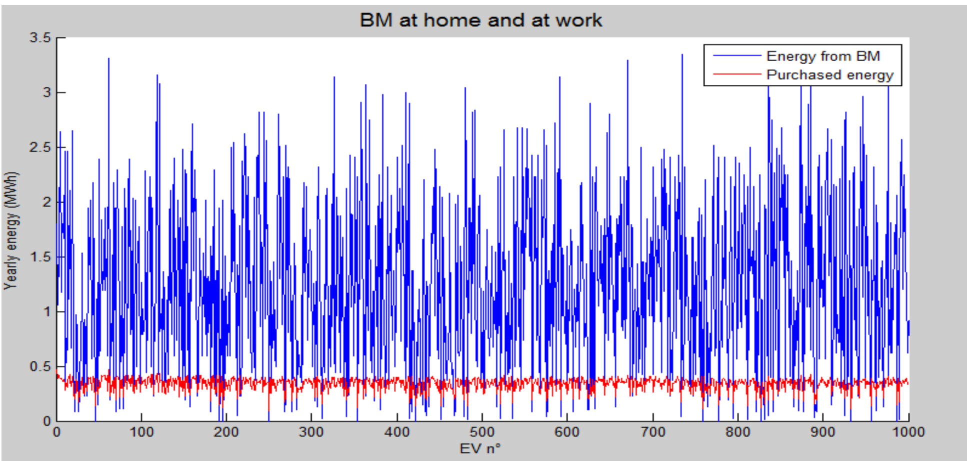


Figure 14: Energy from BM and Market (Home and Workplace Charging)

The share of energy consumption when the vehicles are able to charge both at work and home is also similar with the previous case. The lion's share of the energy consumption comes from the balancing market with maximum of 3.3 MWh/year which lower than the previous case. The amount of energy purchased from the energy market is a bit higher than the previous case. The reduced amount of energy from the balancing market is due to the fact that the vehicles can charge at work and need small amount of energy when they get back home. As already briefed in the previous case, SOC utilization has positive effect on the total gain. Therefore, when the vehicles charge both at home and work, they have lower utilization of SOC as they are able to recharge it in either of the places.

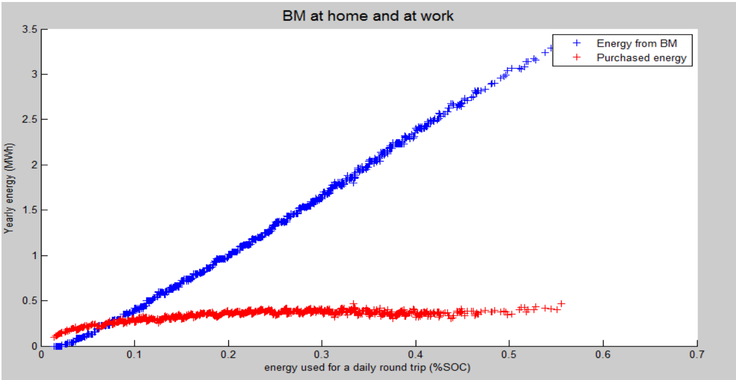


Figure 15: Energy from BM and Market (Home and Workplace Charging)

The above figure 14 depicts that, at some point (below 7% of SOC) the energy purchased from the energy market is higher than the amount of energy obtained from the balancing market. This is due to the fact that, to participate in the balancing market an EV should be able to charge for at least 30 minutes. If an EV is unable to charge for 30 minutes it should charge from the energy market. Therefore, when the energy used for daily trip approaches to zero the energy from the market exceeds the energy from the balancing market.

4.5 Home and Workplace Charging Gain Allocation[8]

Participating in the balancing market in is not free of cost. Like any other services it costs money. The question is then how much does it cost to get the service? What is the fair share for both players (EV owner and Aggregator)? Allocating the gain obtained from the balancing market in fair and reasonable manner is quiet curial. However, it is not easy to determine the right share of the pie to the right player. For simplicity three different approaches of allocating the gain are considered.

Equal share (50/50) – in this case it is assumed that both the aggregator and the EV owners contribute equally and they deserve to share the pie in equal manner. The new values in this case are;

Table 6: Home and Workplace Charging Average Values

S.no	Description	In Euros
1.	Average Gain from BM (AGBM)	**62**
2.	Average Energy Purchase (AEP)	**42.9**
3.	Energy Cost Without Balancing Market (ECWBM)	**147.6**
4.	Average Total Gain (ATG)	**167**

[8] For more information see case 1 gain allocation

The net gain of an EV owner is therefore;

$$NGPV = \frac{GBM}{2} + ECWBM - EP$$

$$Net\ Gain\ Per\ Vehicle = \frac{1}{2} * 62 + 147.6 - 42.9 = 135.7\ Euros$$

The overall financial gain of the EVs fleet per year would be;

$$\boldsymbol{EVFOG = 135.7 * 1000 = 135,700}\ \textbf{Euros per year}$$

In favor of the aggregator (40/60) – assuming that much work is done by the aggregator, therefore, lion's share of the gain goes to the aggregator. In view of this, An EV owner will get two fifth (2/5) of the gain from the balancing market. Therefore, the total financial gain of an EV considering two fifth of the gain from the BM and cost saving would be.

$$Net\ Gain\ Per\ Vehicle = \frac{2}{5} * 62 + 147.6 - 42.9 = 129.5\ \text{Euros per year}$$

The overall financial gain of the EVs fleet per year would be;

$$EVs\ Fleet\ Overall\ Gain(EVFOG) = NetGain\ per\ Vehicle(NGPV) * Numberof\ EVs(NEVs)$$

$$\boldsymbol{EVFOG = 129.5 * 1000 = 129,500}\ \textbf{Euros per year}$$

In favor of the EV owner (60/40) – now more of the gain goes to the EV owner. Therefore, unlike the second approach, in this approach EV owners get lion's share of the gain. An EV owner will get two fifth (3/5) of the gain from the balancing market. Therefore, the total financial gain of an EV considering three fifth of the gain from the BM and cost saving would be.

$$Net\ Gain\ Per\ Vehicle = \frac{3}{5} * 62 + 147.6 - 42.9 = 141.9\ \text{Euros per year}$$

$$\boldsymbol{EVFOG = 141.9 * 1000 = 141,900}\ \textbf{Euros per year}$$

Considering the three approaches of gain allocation, the net gain of an EV from participating in the balancing mechanism lies between 129.5 and 141.9 Euros per year. The overall gain of the EVs fleet lies between 129,500 -141,900 Euros.

4.6 Comparison of the Two Cases

This part compares the results obtained by using the two cases (home charging and work and home charging).

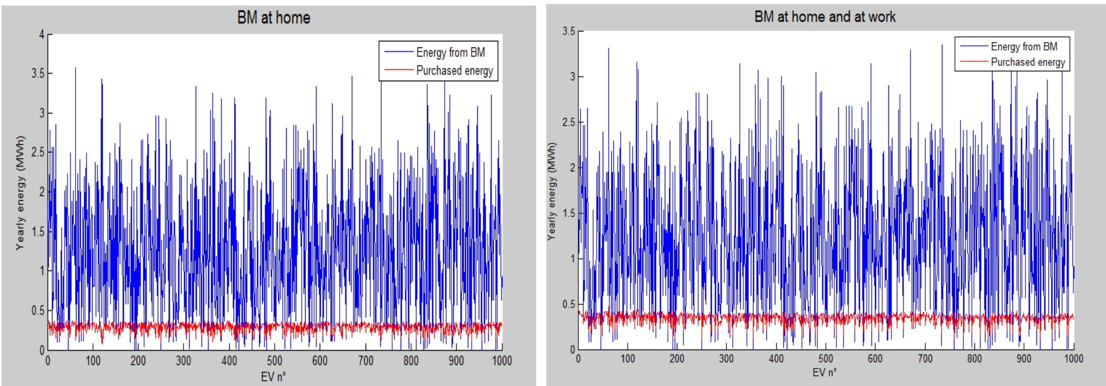


Figure 16: Energy from BM and Energy Market Comparison left (home charging) right (home and workplace charging)

The above figures show the result of the first and the second case respectively, as we can see from the figures, in the first case the highest amount of energy obtained from the balancing market is 3.66 MWh/year which is above 3.5, whereas the highest amount of energy obtained in the second case is 3.33 MWh/year which is below 3.5 w. On the other hand, higher amount of energy is purchased from the market in the second case. The relationship of energy from BM and purchase from market has a significant impact on the total gain. In the second case, the increased purchase of energy from the market reduces the amount of energy from the BM. Due to this, lower total gain has been observed in the case where charging both at home and office is possible.

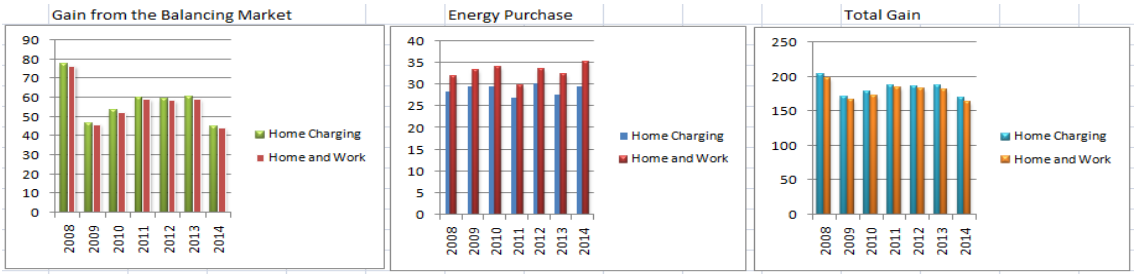


Figure 17: BM Gain, Energy Purchase and Total Gain Comparison

The following figures show comparison of energy from the balancing market and energy market for both cases. In the first picture comparison of gain from the balancing for both cases is presented. The green bar graph indicates gain from charging at home and the red one indicates gain from charging both at home and office. As a result, the gain obtained from home charging is higher than gain obtained from charging both home and office.

In the second figure, energy bought from the market is portrayed, consequently, higher amount of energy is bought when the vehicles charge both at home and work (red bar graph). The third bar graph represents the over gain of the EVs from both cases. Due to higher amount of gain from the balancing market and lower amount of energy bought from the energy market, the overall gain is higher if we considering home charging only.

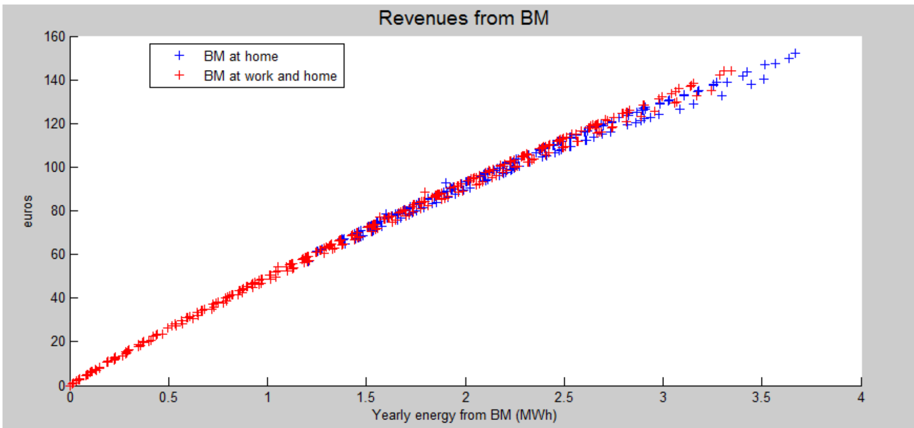


Figure 18: Revenue Comparison

As already indicated above, the total gain of an EV is determined by how much energy is obtained from the balancing market and how much is bought from the energy market. Therefore, due to the fact that relatively higher amount of energy is bought from the market in the second case (Home and work charging), the revenue from the balancing market is lower.

So far the above explanations concentrate on identifying the cost and benefit of the EVs considering the two cases in different years. Analyzing year by year is quite crucial to get ample information to draw a general conclusion about the two cases under investigation. Therefore, to have a general picture of the two cases, the following summary of cost and benefit considering the overall average is prepared.

Table 7: Summary of Gains

S.no	Description	ECWBM	Average GBM	Average EP	Net gain per EV(50/50 share)
1.	Home charging	147.6	57.5	27.6	177.7
2.	Home and Workplace charging	147.6	62	42.9	167

The above figure depicts the overall comparison of the two cases. As it can be seen from the above table, the gain obtained from home charging is a little bit higher than that of charging both at home and work place and participating in the balancing market.

Cost and gain comparison

The cost of energy without participation in the balancing market is the same for both cases it is because we assumed they travel similar distance which is around 60 kilo meters per day. Therefore, the cost that an EV would incur for purchase of energy without participating in the balancing market is 147.6 Euros. Regarding the gain obtained from the balancing market it is higher in the case of both home and work place charging the main reason behind the higher gain in the case of charging at home and workplace is due to the opportunity to participate in the balancing market during night (at home) and daytime (at work) therefore, the EV owners select the best available timeslot with higher price in any time of the day therefore they have a chance to participate during daytime when the price is high. However, for charging at home only the opportunity to participate in the balancing market is limited to night time only therefore, the EVs couldn't participate during day time even if the prices are high. Therefore, the EV owners reap higher benefit when they participate in the balancing market from home and work it is due to not they sell higher amount of energy but less amount with higher prices. On the other hand, the energy purchased to charge their battery from the energy market is higher in the case of home and workplace charging. This is due to the fact that the amount to be charged is less than the fraction of charge needed $\left(SOCt = \frac{EVSEC*hour}{BC}\right)$ to participate in the balancing market the fraction of charge for half an hour considering 3kW charging capacity is, ($3 *.\frac{5}{24} = 0.0625$). If the vehicles need energy less than the minimum fraction of charge they tend to charge from the energy market. As a result, the energy purchase is higher in the case of charging at home and workplace. Indeed, several factors could affect the price of electricity in different times in this case participating in the balancing market from both home and work place with very short distance commuting doesn't give much incentive for the EV owners since it is impossible to participate in the balancing market for less than 30 minutes. Indeed high energy prices could also affect the amount of energy purchase.

Cognizant of the above cost and benefit the overall gain is a little bit higher in the case of charging at home than charging at home and workplace. This is due to the difference between the gain from the balancing market and the energy purchase the gain obtained from the balancing market is a bit higher in the case of home and workplace charging while the energy purchase much higher in the case of home and work place, as a result the overall benefit is a little bit higher than in the case of home charging.

5. Conclusion

To estimate the financial gain of the EVs fleet from participation in downward balancing market we have modeled two different cases. The first case considers charging at home with charging capacity of 3 kWh. The second case considers flexible charging options (at home and office) with the same charging capacity. Accordingly, an EV owner that uses home charging and participates in the balancing market reaps a benefit of 177.7 Euros per year and a fleet manager with 1000 EVs would earn 177,700 Euros per year.

An EV that participates in balancing market by charging its battery both from home and workplace would earn 167 Euros per year. A fleet manager that has 1000 EVs and participates in the downward balancing market would earn 167,000 Euros per year.

It can be seen that the results are almost the same. As a battery charge 3kW*0.5h = 1.5 kWh for each 30min timeslot, an EV is available for a time slot if it can accept this amount of energy. Since the round trip length is quite short, it doesn't give additional incentive to participate in the balancing market twice a day (at home and work).

Generally, enhancing the participation of EVs in the balancing market achieves triple objectives at a time (for the end users, electricity system and the environment). From end users perspective, it creates additional income. From the electric system perspective; EVs support the system to meet demand and generation and are a good complement for variable generations. From the climate change perspectives, EVs mitigate CO_2 emission by changing the use of energy from oil to electricity.

6. Challenges Faced and Limitation of the Paper

6.1 Challenges Faced

From the commencement to the final step of this paper a number of difficulties have been faced though most of them were trivial and easy to handle. However, some (perhaps two) difficulties were crucial and worthwhile to mention in the itinerary of this paper. The first challenge was availability of documents in English. As this paper was conducted in France some and most important documents about electricity operation were available in French only and it was really difficult to fully understand the overall operation of electricity market in France. Besides, to quantify the financial gain of the EVs, programming in MATLAB was crucial but it was not easy to do it without immense involvement of senior engineers that have profound understanding of MATLAB programming.

6.2 Limitation of the Paper

Due to time and resource limitation this study is limited to specific area and topic. This research is limited to economic analysis of EVs fleet participation in the downward balancing market. Technical analysis of downward balancing and EVs is not addressed in this paper as it is beyond the objective of the paper. Since trip models are sophisticated, some assumptions are made to simplify the model. Therefore, in this paper it is impliedly assumed that some technical and non technical characteristics of the EVs (for instance charger cost, battery life and other characteristics) are assumed to have insignificant impact on the final gain.

However, with all these limitations, the result of this paper sheds light on the contribution of EVs to the balancing market that paves a way for other researchers to further investigate the topic with greater detail.

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ANNEXES

ANNEX A Gain Calculation

Home Charging

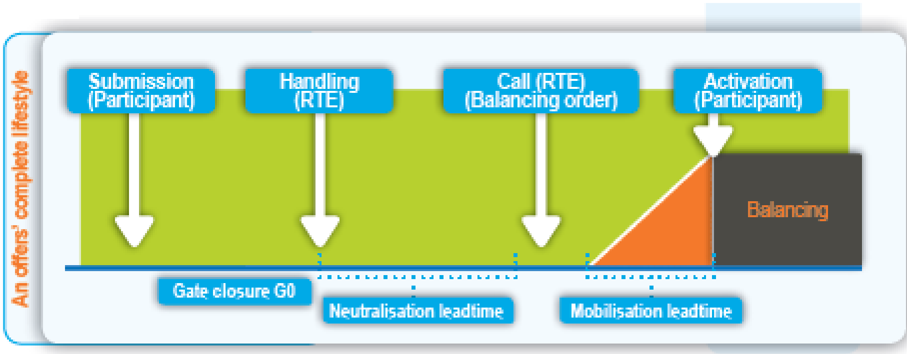
Year	2008	2009	2010	2011	2012	2013	2014	mean
BM gain	77.4	46.6	53.4	59.8	59.5	60.4	45.2	**57.5**
Energy purchase	25.2	26.4	27.6	25.7	29.4	28.2	30.9	**27.6**
ECWBM	137	138.8	144	146.5	149.4	157	160.8	**147.6**
Total gain	**189.4**	**157.5**	**169.7**	**180.6**	**182.5**	**189.2**	**175.1**	**177.7**

Home and Workplace Charging

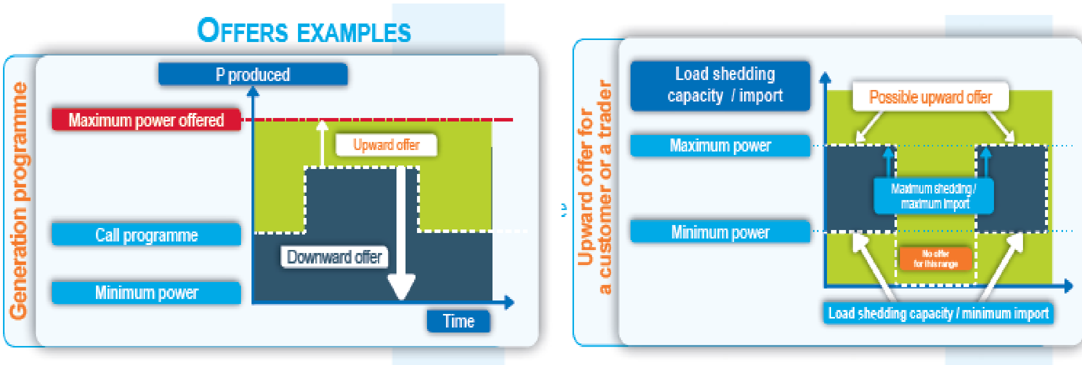
Year	2008	2009	2010	2011	2012	2013	2014	mean
BM gain	88.45	53.4	60.35	64.8	61.4	60.9	44.6	**62**
Energy purchase	44.68	42.6	39.5	41.4	41.6	40.7	49.8	**42.9**
ECWBM	137	138.8	144	146.5	149.4	157	160.8	**147.6**
Total gain	**181**	**150.6**	**164.9**	**169.9**	**172.2**	**174.2**	**156.6**	**167**

ANNEX B Balancing Complete Cycle and Balancing Offer

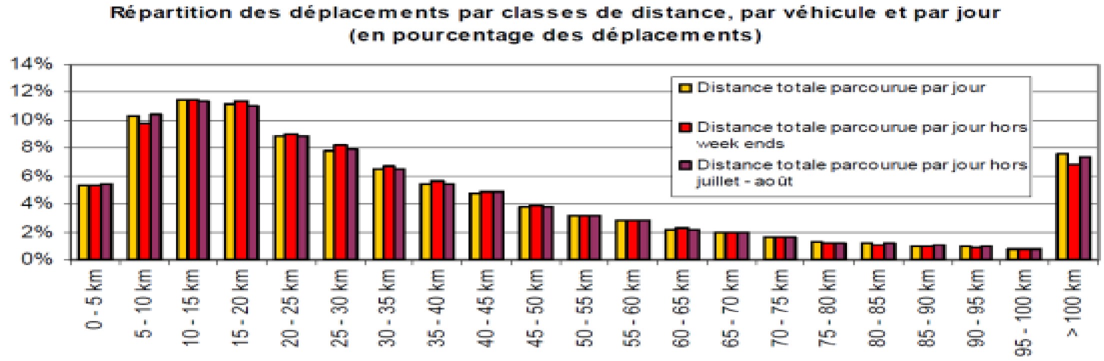
Complete Balancing Offer Life Cycle



Balancing Offer Examples



ANNEX C Distribution of EVs Travel per Day

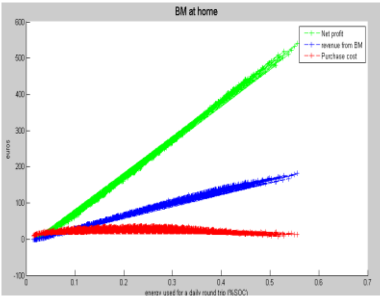


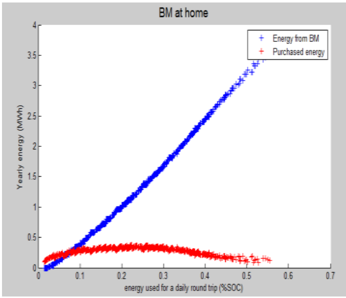
ANNEX D Simulation Result (2008-2014)

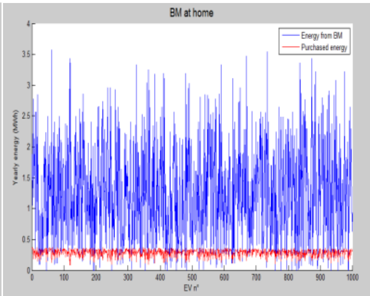
2008

Home Charging

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

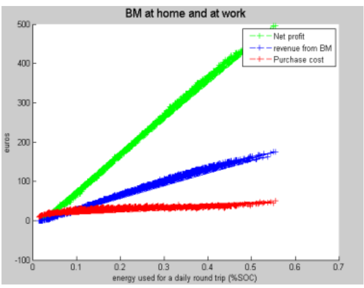


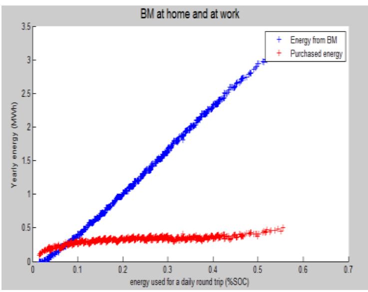


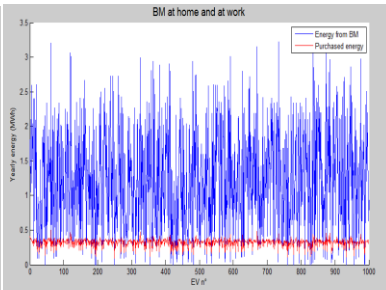


Home and Workplace Charging

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

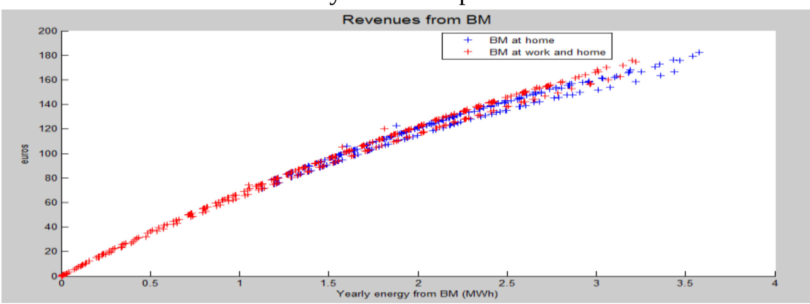






Comparison

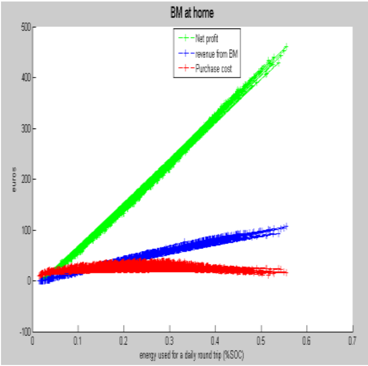
Yearly Gain Comparison

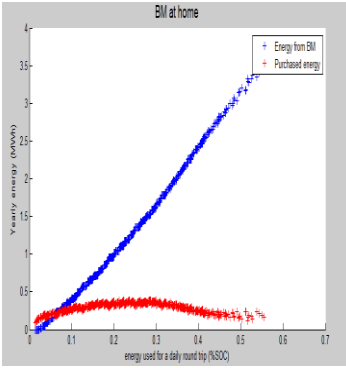


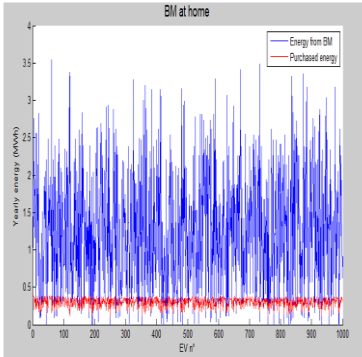
2009

Home Charging Results

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

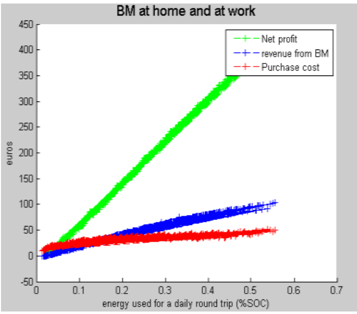


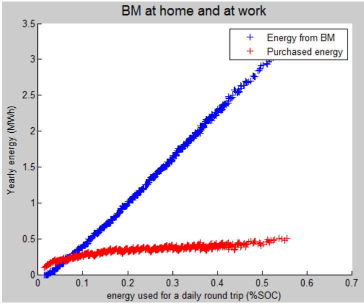


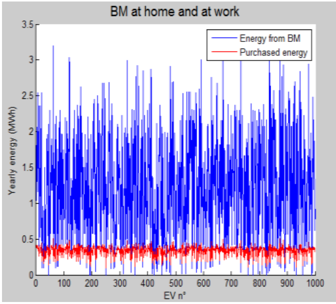


Home and Workplace Charging Results

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

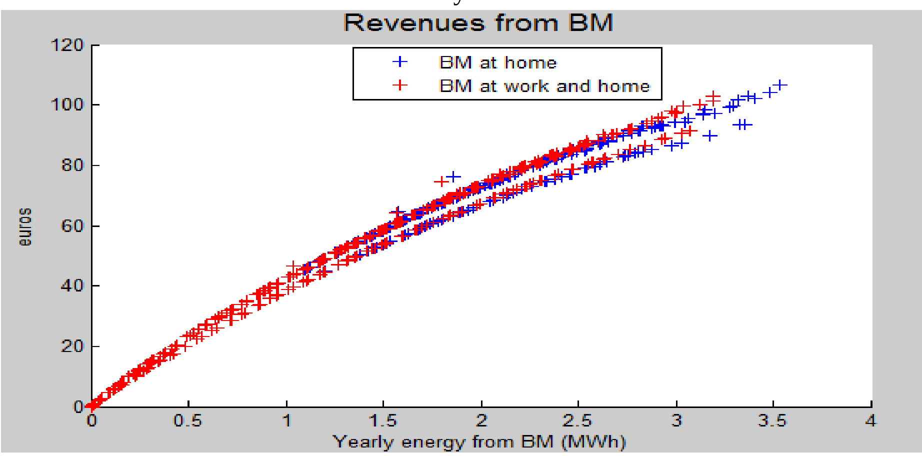






Comparison

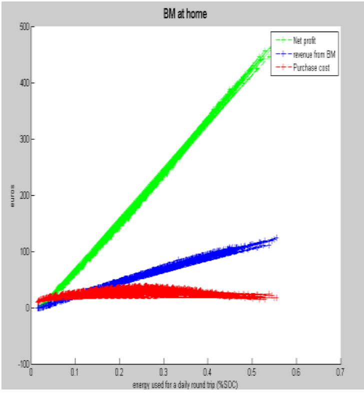
Yearly Gain

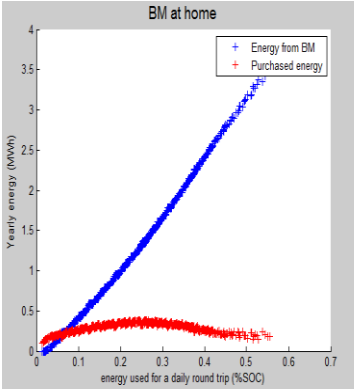


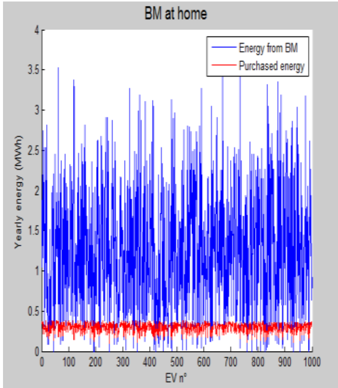
2010

Home Charging Results

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

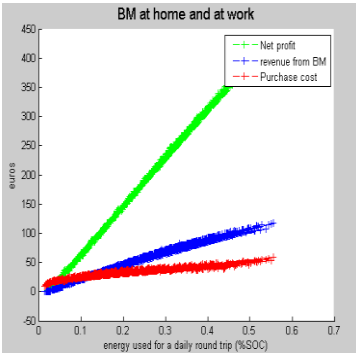


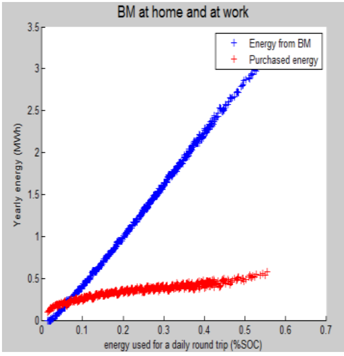


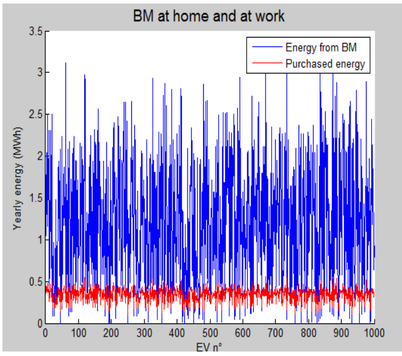


Home and Workplace Charging Results

Energy Purchase, BM gain Overall gain   Energy from BM and Market   Energy from BM and Market

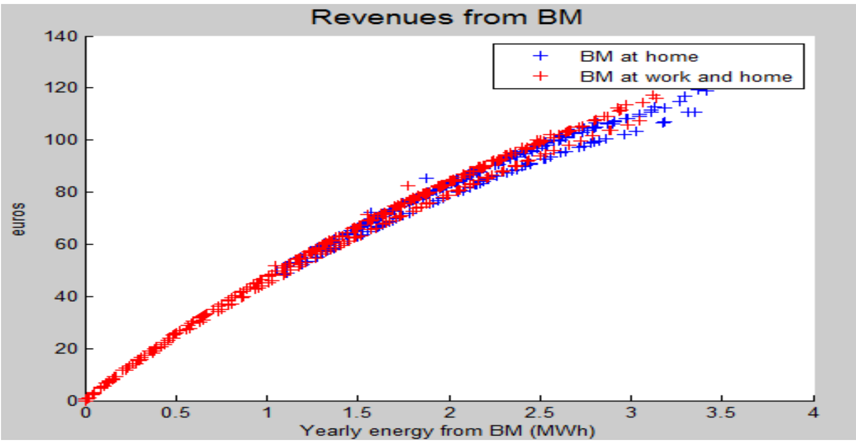






Comparison

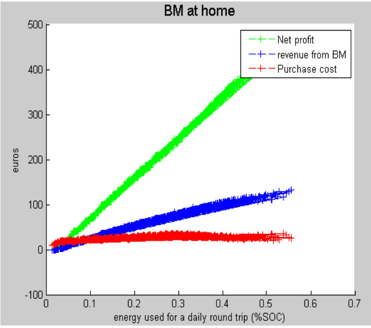
Yearly Gain Comparison

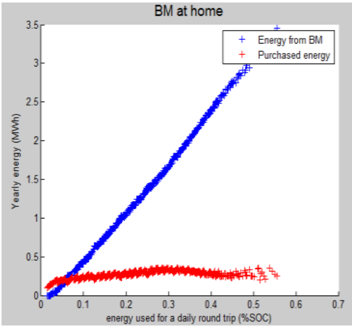


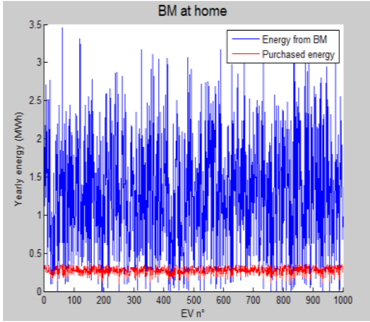
2011

Home Charging Results

Energy Purchase, BM gain Overall gain   Energy from BM and Market   Energy from BM and Market

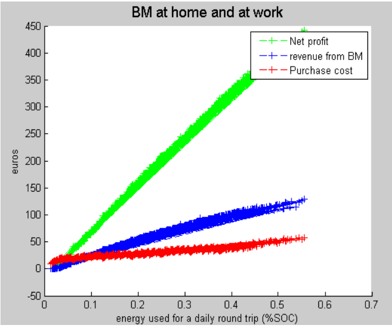


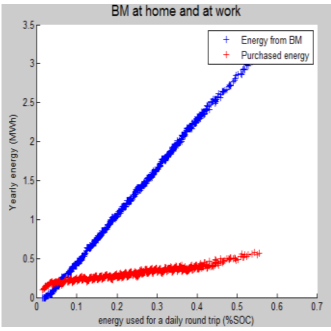


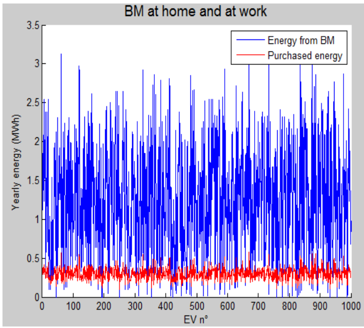


Home and Workplace Charging Results

Energy Purchase, BM gain Overall gain | Energy from BM and Market | Energy from BM and Market

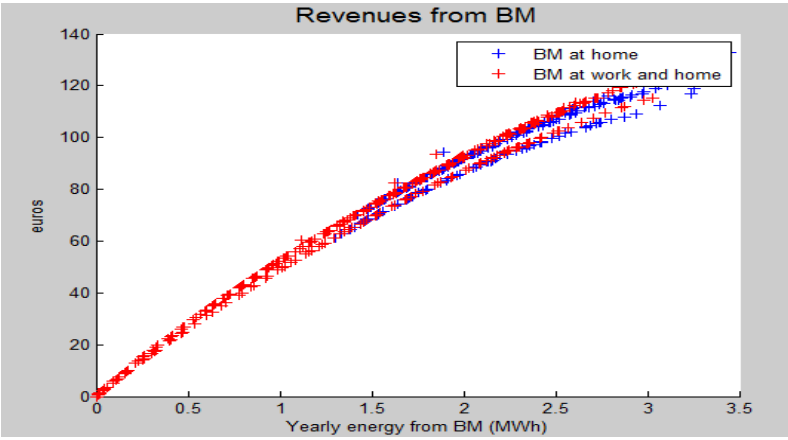






Comparison

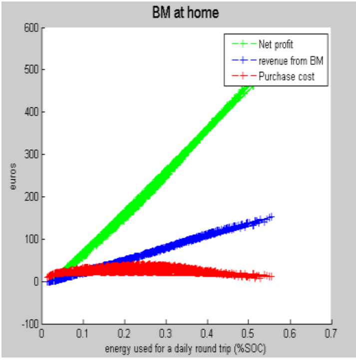
Yearly Gain Comparison

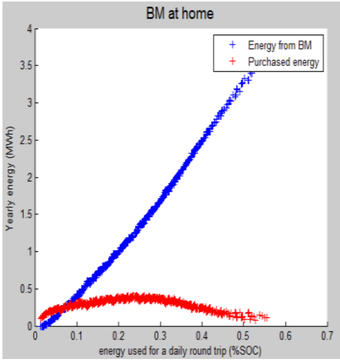


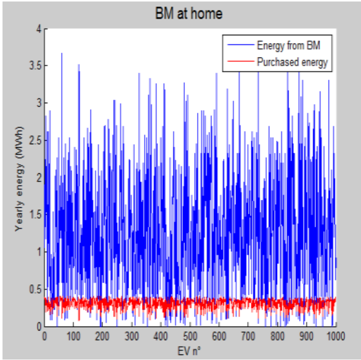
2012

Home Charging Results

Energy Purchase, BM gain Overall gain | Energy from BM and Market | Energy from BM and Market

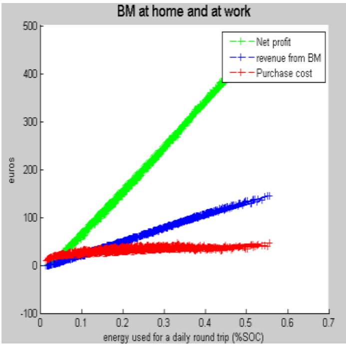


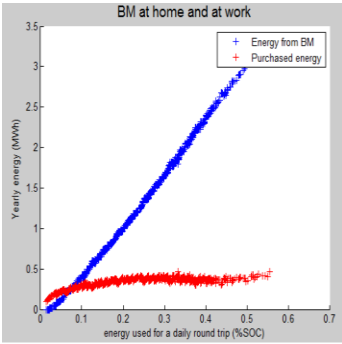


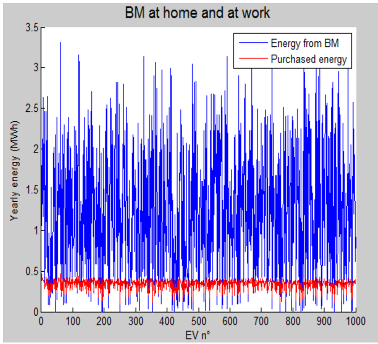


Home and Workplace Charging Results

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

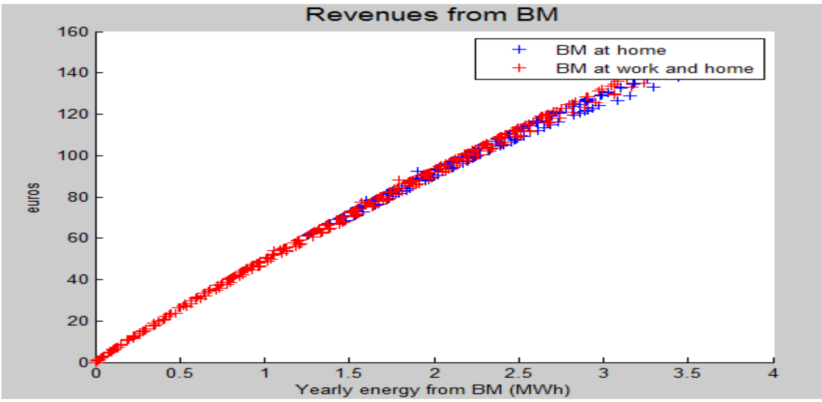






Comparison

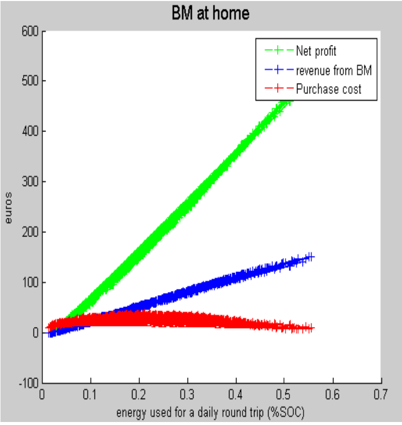
Yearly Gain Comparison

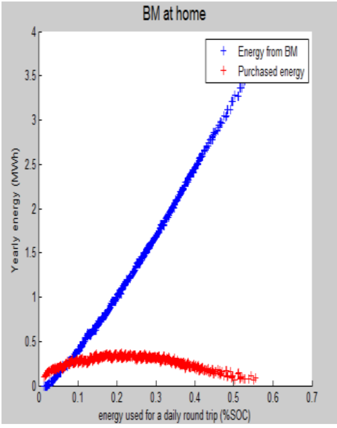


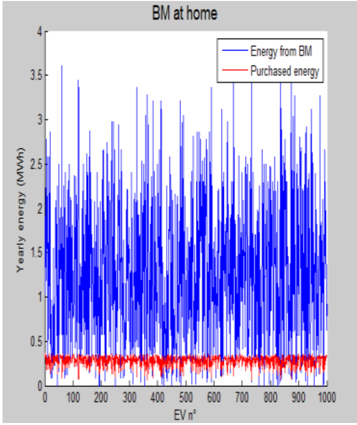
2013

Home Charging Results

Energy Purchase, BM gain Overall gain Energy from BM and Market Energy from BM and Market

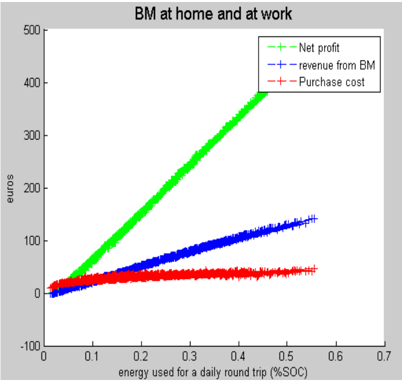


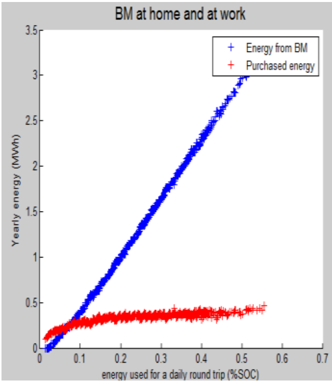


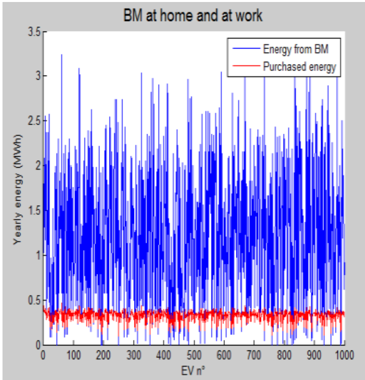


Home and Workplace Charging Results

Energy Purchase, BM gain Overall gain   Energy from BM and Market   Energy from BM and Market

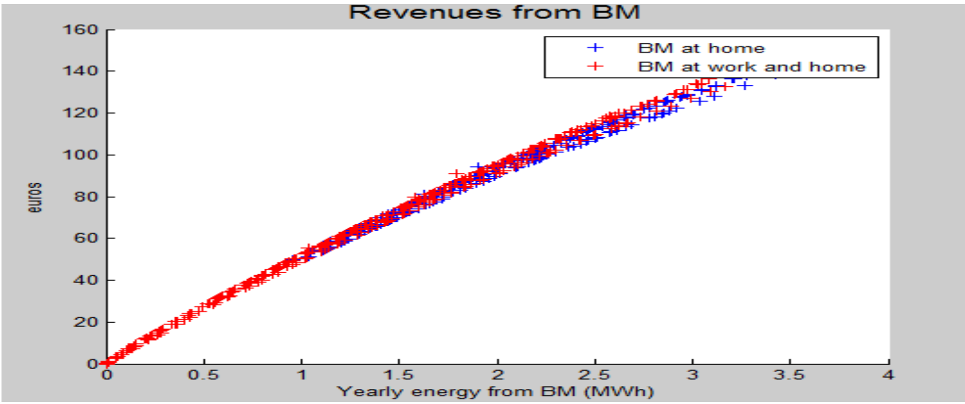






Comparison

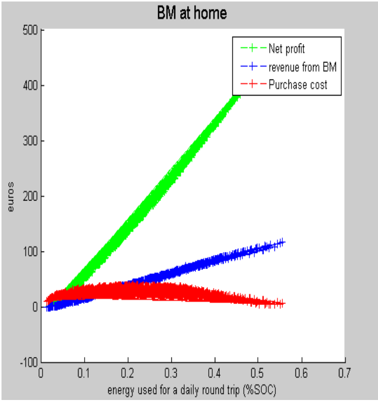
Yearly Gain Comparison

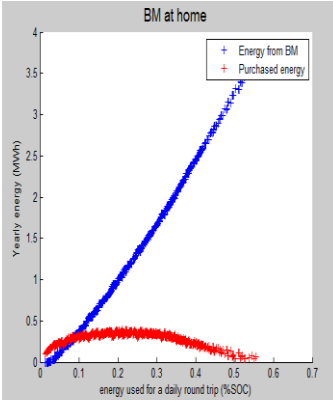


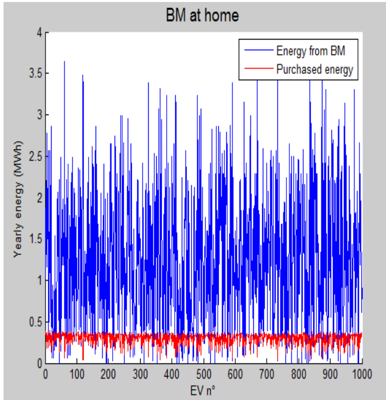
2014

Home Charging Results

Energy Purchase, BM gain Overall gain   Energy from BM and Market   Energy from BM and Market

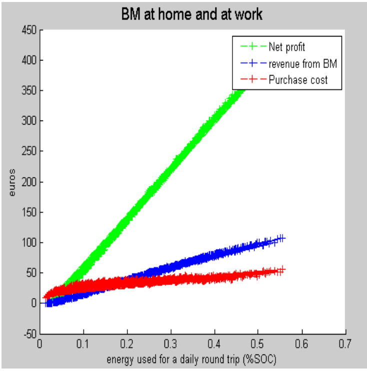




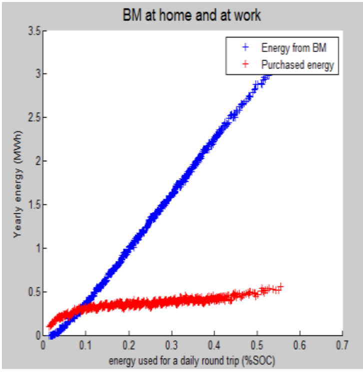


Home and Workplace Charging Results

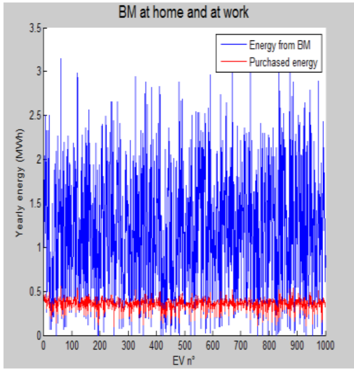
Energy Purchase, BM gain Overall gain



Energy from BM and Market



Energy from BM and Market



Comparison

Yearly Gain Comparison