Universidade do Minho
Escola de Engenharia

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Mobi-System: Towards an Information System to Support Sustainable Mobility with Electric Vehicle Integration

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My final words go to my family. In this type of work the relatives are always mistreated.

ABSTRACT

The current Thesis proposes the conceptual aspects and the preliminary prototype of a mobile information system to support information integration and manipulation towards the Electric Vehicle (EV) introduction, and the support of mobility process in urban environments, giving recommendations to drivers about EV range autonomy, charging stations, electricity market, and also as route planner taking into account public transportation, car or bike sharing systems.

The main work objective is the creation of an Information and Communication Technology (ICT) platform based on successful approaches developed in the Computer Science Area, recommender systems, cooperative systems and mobile devices, to help the driver of EV by giving real time information related with EV charging process, range autonomy, electricity market participation, and also smart mobility process in cities by giving guidance towards best route options, taking into account time travel and CO_2 emissions.

Based on the analysis of the problem a conceptual system and a prototype application were created under the designation “Mobi-System”, designed to mobile devices, with relevant information oriented to: (1) EV charging process; (2) EV range autonomy; (3) electricity market participation; and (4) mobility process in smart cities of the future. In this work it was developed an application to store data related with EV charging/discharging process, for further intelligent analysis and remote interaction with the charging system, determining a smart charging procedure, taking into account the distribution electrical system limitations, and the creation of communities with participation in the electricity market. A range estimation and representation process is introduced as part of the help process to assist EV drivers. An Aggregator system and a collaborative broker for distributed energy sources are proposed, taking into account the electricity market. A proposal for data integration of different transportation sources and a multimodal best route path are proposed based on CO_2 emissions and time travel.

Keywords: Sustainable Transportation System, Electric Vehicle, Smart Grid System, Electricity Market, Users Collaboration, Sustainable Mobility Process, User Profile, V2G (Vehicle-to-Grid) System, Range Anxiety Problem, Mobile Device, Geographic Information System, Electromobility

RESUMO

O presente trabalho consiste na concepção e discussão do sistema Mobi-System, que disponibiliza informação relevante para condutores de veículos elétricos (VE), tendo em conta os problemas dos carregamentos dos VE, a gestão da ansiedade de autonomia (range anxiety) dos condutores, a participação no mercado de energia elétrica, a integração das fontes de energia renováveis, bem como a integração de informação de transportes públicos e a criação de sistemas para gerir o problema da mobilidade sustentável em cidades inteligentes (smart cities).

O objectivo principal do trabalho é o uso apropriado de Tecnologia da Informação e Comunicação (TIC) baseada em abordagens bem-sucedidas desenvolvidas na área da informática, como os sistemas de recomendação, sistemas cooperativos e dispositivos móveis para ajudar o condutor de VE, dando informações relevantes em tempo real, orientando o condutor para os pontos de carregamento públicos, ou para o melhor caminho tendo em conta o tempo e as políticas ambientais, nomeadamente as emissões de CO_2.

Com base na análise do problema, um sistema conceitual e uma aplicação protótipo foram criadas sob a designação de Mobi-System, projetada para dispositivos móveis com informações relevantes orientadas a: (1) processo de carregamento do VE feito num local público com a orientação e a reserva de slots de carregamento, ou em casa com a programação do processo de carregamento lento, tendo em conta limitações de potência; (2) gestão assistida da autonomia dos VE; (3) participação no mercado de energia, pela criação de comunidades de condutores com capacidade de participar no mercado de energia, dado o VE poder atuar como um armazenador de energia; e (4) processo de mobilidade em cidades inteligentes do futuro, com a proposta de integração de dados de diferentes tipos de transporte, com indicação do trajeto de melhor rota multimodal, proposto com base nas emissões de CO_2 e no tempo das viagens.

Palavras-Chave: Sistema de Transporte Sustentável, Veículo Elétrico, Rede Elétrica Inteligente (Smart Grid), Mercado de Eletricidade, Colaboração entre Utilizadores, Mobilidade Sustentável, Perfil do Utilizador, Sistema Veículo-Rede (Vehicle-to-Grid System), Problema de Ansiedade de Autonomia, Dispositivo Móvel, Sistema de Informação Geográfica, Mobilidade Elétrica

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1. INTRODUCTION

Nowadays, world economy is powered by a fossil fuel based energy infrastructure. Modern transport systems account for around 30% of global energy consumption and around 60% of global oil consumption (International Energy Agency) [IEA, 2006]. Additionally, according to the Energy Information Administration, transport energy demand is forecast to grow rapidly—by 2.5% per year over the medium term [EIA, 2008]. Within the transport sector in industrialized countries, a large proportion of passenger and freight traffic is operated by road vehicles, with private automobiles accounting for nearly 80% of OECD (Organization for Economic Co-operation and Development) passenger transportation [EIA, 2008]. Moreover, road transportation relies almost entirely on oil-based fuels. This oil dependence poses challenges to the long-term sustainability and security of transport systems, particularly under the light of concerns about how long conventional oil reserves will last, and the risks of disruption of the oil supply arising from geopolitical instability, hostilities or even terrorist activity. In addition, transport has long been associated with environmental impacts, and with other problems related to safety, competition for urban space, and air, water and noise pollution. Given these linkages between transport and energy security and environmental impacts, longer-term projection trends give rise to serious concerns about the future economic and environmental sustainability of current transport systems. As a way to address these concerns, a number of new vehicle technologies based on electrically driven systems are emerging, and this subject is integrated in the sustainable development.

Sustainable development represents significant challenges to humanity. The main challenge of sustainable development is the creation of a livable future world in which human needs are met whilst maintaining the natural systems that support these needs and encompasses social, economic and environmental dimensions, which requires a long-term systematic perspective and the integration of many different elements [COM, 2007]. Critical among these elements are the global energy demand and the transportation systems, and redirecting the development of these systems into a sustainable path is becoming an increasingly important concern and policy objective [Schrattenholzer, 2004; IEA, 2001].

The current development of the global transport system, which is an important part of the overall energy system, poses a number of threats to the sustainable development. These threats include the possible impact on climate change, with long term risks. There is mounting evidence of human interference with the Earth's climate system and this has led to concerns about possible serious adverse impacts resulting from future global climate change [GroupI, 2001]. Realizing a sustainable transport system with a low impact on the global climate, but that still achieves other long-term development goals, may require profound and wide-reaching changes [IEA, 2001].

Concerning the risks to long-term security of the global energy supply, security of energy supply is seen as a more pressing concern, given the current overall dependence of OECD countries on oil supplied from politically volatile regions [IEA, 2001; EC, 2001; DOC, 1999]. The combined impact of increasing global energy demand and eventual depletion of resources poses further serious long-term challenges to maintain the access to affordable and secure sources of energy, and appropriate policy responses may also require major changes to the global energy system.

Transforming global social and economic systems, including global transport systems, from their current structure to one that is compatible with sustainable development, is likely to be a long-term process involving continual change to a range of physical, technological and institutional systems [EC, 2001].

Understanding how this long-term process might unfold may help guide policy responses aimed at achieving the long-term strategic goals of sustainable development. There is a need of study and explore the possible trajectory for the transformation of the global energy and transport system by building long-term Energy–Economy–Environment (E3) scenarios. Such scenarios are useful for enhancing our understanding of highly complex systems, such as the future development of the global transport system, and for guiding responses to long-term challenges.

In transportation systems a new reality is being introduced, the **Electric Vehicle** (EV), with several manufacturers investing in the production of this type of vehicle (e.g. Daimler AG, Toyota Motor Corp., General Motors Corp., Renault SA, Peugeot-Citroen, Volkswagen, Mitsubishi Corporation). EV sales started in 2010-2011. Simultaneously, the share of renewable energy production is increasing. Combining these two new scenarios is likely to be the first opportunity to harvest the synergies emerging from a co-evolution of vehicles and energy system. Renewable energies are not dependent on EV for their full deployment, but EV may help to increase the uptake of renewable energies, since Electric Vehicles do need renewable energy sources to realize their full benefit, reducing the greenhouse gases (GHG) emissions and the dependence on fossil fuels. Synergies may improve the business case for EV and for renewable electricity, since coordinated policy and system integration are required for harvesting these synergies. Many claim that future sustainable energy will have to rely beyond conservation and efficiency gains to: (i) the conversion of transportation vehicles, responsible today for 30% of CO_2 emissions, to EV; and (ii) the commensurate adoption of now economically competitive [Steve, 2005] clean renewable energy generation [Stern, 2006]. Also for the Portuguese case this is important, since we have a great energy dependency from the exterior, and in the last decade there was a great development on energy resources [Pinho, 2008]. This is illustrated in Figure 1-1, where is highlighted an important challenge for Portugal: the creation of a policy and system integration for Electric Vehicles based on new developments on Information Communication Technology (ICT).

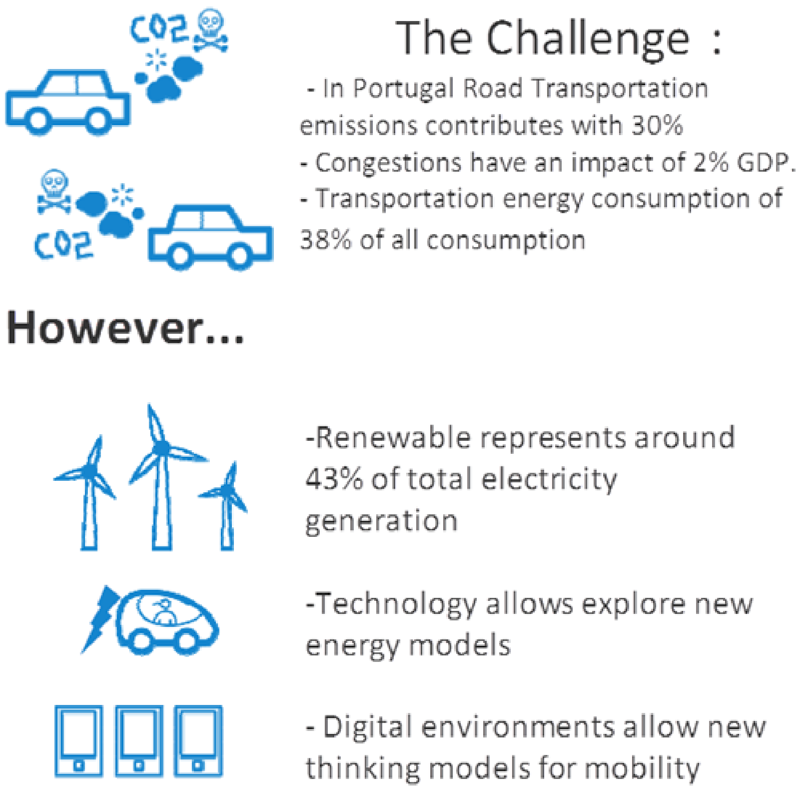

Figure 1-1: Main challenge to achieve between EV and Renewable Energy Resources, with Portuguese data from [Pinho, 2008]

Environmental concerns on affordability of energy services and supply security have pushed Europe to develop and pursue policies to increase the share of renewable energy in the electricity generation mix, to promote energy efficiency, to consider the electrification of part of the vehicle fleet, and to move towards a smart electricity grid [COM, 2007]. This strategy positions Europe at the forefront in fighting climate change, in promoting a green economy and in creating green jobs. It is a cornerstone of the EU 2020 strategy for smart, sustainable and inclusive growth. And it is a vital part of the European Union (EU) 2020 flagship initiatives: a "Digital Agenda for Europe", the "Innovation Union", and a "Resource Efficient Europe".

Currently, the transport sector is responsible for about a quarter of the EU carbon dioxide (CO_2) emissions. Car usage alone accounts for about 12% of all the EU CO_2 emissions, and road transport is responsible for 27% of energy consumption [Milkovits, 2010], [COM, 2007]. Even though modern transportation systems are becoming more fuel-efficient, they have not yet reached the level of efficiency that could substantially reduce the increasing share of the transportation sector in greenhouse gases (GHG) emissions and energy consumption.

The EU has launched a set of initiatives to address these issues. The most relevant in relation to this research topic are the:

- EU 20:20:20 Climate and Energy Initiative;
- European Green Cars Initiative [www.green-cars-initiative.eu];
- EU Transport White Paper [EU, 2011].

The first aims at reducing GHG emissions in 20% by 2020 relative to 1990, at improving energy efficiency in 20% by 2020, also relative to 1990, and at increasing the share of renewable energy to 20% by 2020 [COM, 2007]. The second supports R&D on technologies and infrastructures that are essential for promoting the use of renewable and non-polluting energy sources, and it has a clear focus on the electrification of road transport. And the third recommends an ambitious target of 60% reduction of GHG emissions from transport by 2050, relative to 1990.

Portugal and Spain intend to create the first "green car" in Iberia, hoping to generate €150 million worth of investment and 800 new jobs in the region's struggling automotive industry. The “Mobi-Green Car”, as the vehicle is named, is being developed by two automotive research centres in Portugal and Spain, using funds from both the public and private sectors [Almeida, 2008].

Under directive 2009/28/EC of the European Parliament and the Council [EC, 2009], Portugal has committed itself to a target of 31% of gross final energy consumption coming from renewable sources by 2020. In its National Energy Strategy 2020 [ENE, 2009], Portugal also sets the objectives of having 60% of electricity production and 10% of energy consumption in transport coming from renewable energy sources by 2020.

The Portuguese Electric Mobility Initiative started in early 2008 with the creation of the MOBI.E Program. This ambitious Program is based on cooperation among the different stakeholders. It aims at setting a nationwide integrated network with the focus on users and opened to every vehicle manufacturer, energy retailer and private operator. The full interoperability of services and electricity provision is ensured by a settlement system that is entrusted to a management entity, responsible for all the energy and financial flows from electric mobility network operations. With MOBI.E, any user is able to charge the batteries of the EV at any charging point of the network, regardless his or her mobility electric subscription with any retailer of electricity. The system results in transparency, low entry barriers, and competition along the value chain, and the supporting business model takes into consideration the “type” of the energy used to produce electricity, generating stimuli for the use of greener energy. This Program complete its first phase in June 2011, with the installation of 1,300 public normal charging points and 50 fast charging points in primary roads and highways, connecting 25 of the largest Portuguese municipalities. Currently, there are over 300 electric cars on the road throughout the country, and the number is projected to rise to 200,000 by 2020, in view of wide user adoption fostered by strong commitment and investments provided by the government; the public charging infrastructure may count 25,000 charging points by that time.

1.1. Context

The research work of this Thesis is conceived to the creation of a system for mobility process oriented to the user (driver), taking into account new future realities, such as the

EV integration and smart cities, resulting in a timely information system to assist driver with relevant information in order to address the following issues: EV charging, electricity market participation and sustainable mobility functions.

At the start of this research, an indication of success for this approach was the navigation systems applied on transportation systems. This situation is pointed out in Figure 1-2, where is highlighted the main problems on transportation systems, e.g., increased demand of vehicles and the limited resources on fossil fuels with increasing prices (in Europe average fuel price is around 1.5 €/liter, which means around 0.12 €/km, and taking an average daily trip of 60 km, we have around 200 €/month for fuel expenses). Also CO_2 emissions are an important issue from the transportation activity. On the other hand, in computer science the success of the utilization of mobile applications, integrated in social networks and geographic information systems, represents a huge potential for applications on these areas of transportation and electricity.

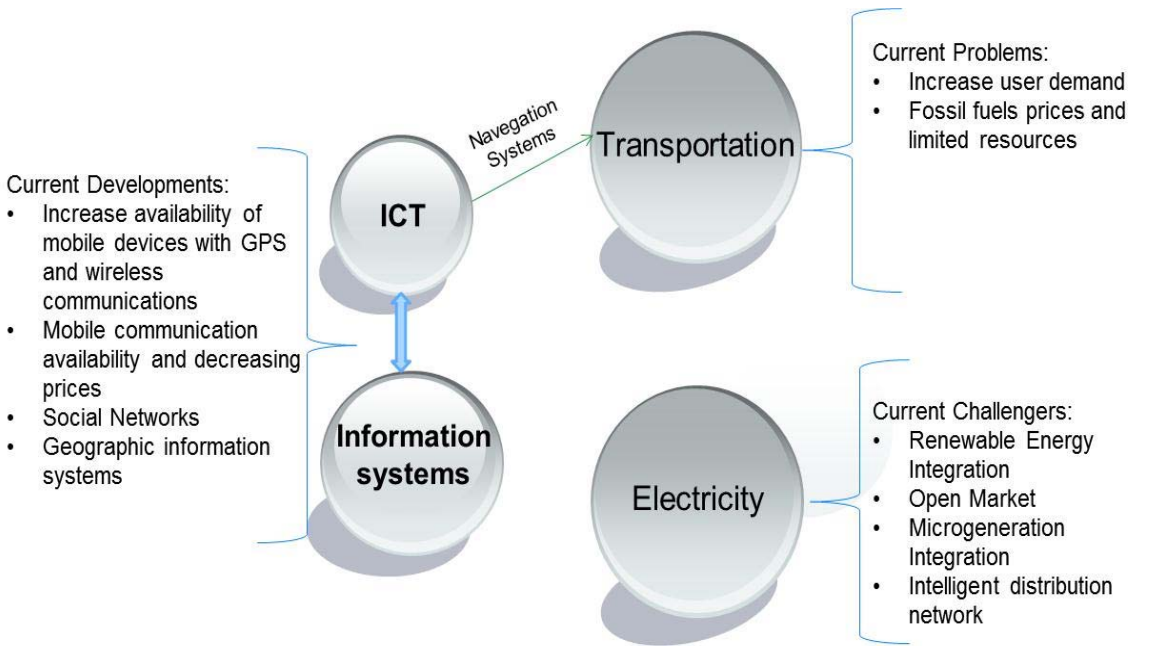

Figure 1-2: Current situation (on the start of this research project in 2008)

From this reality, Figure 1-2 shows a new scenario that is emerging in 2008, with the EV introduction, the open electricity market and the advances in renewable energy production and integration, new research challenges are being opened, where ICT (e.g., mobile devices with available GPS capacity, and usage proliferation with decreasing prices on mobile communications) and information systems can play an important role from the system information integration point of view, as well as from the point of view of driver, as shown in Figure 1-3.

This upcoming reality (suggested in Figure 1-3) will create needs for driver's relevant information (e.g., information related with transportation systems, EV charging status, electricity market and driver's guidance). This research has the goal to define a model and a prototype system to give drivers real time relevant information to promote the reduction of private energy consumption and costs, to promote EV integration and acceptance by reducing the anxiety range problem [Schott, 2009], to assist the renewable energy integration by V2G (Vehicle-to-Grid) and G2V (Grid-to Vehicle) approaches and the consequent electricity market participation. These related concepts are further discussed in the next subsection.

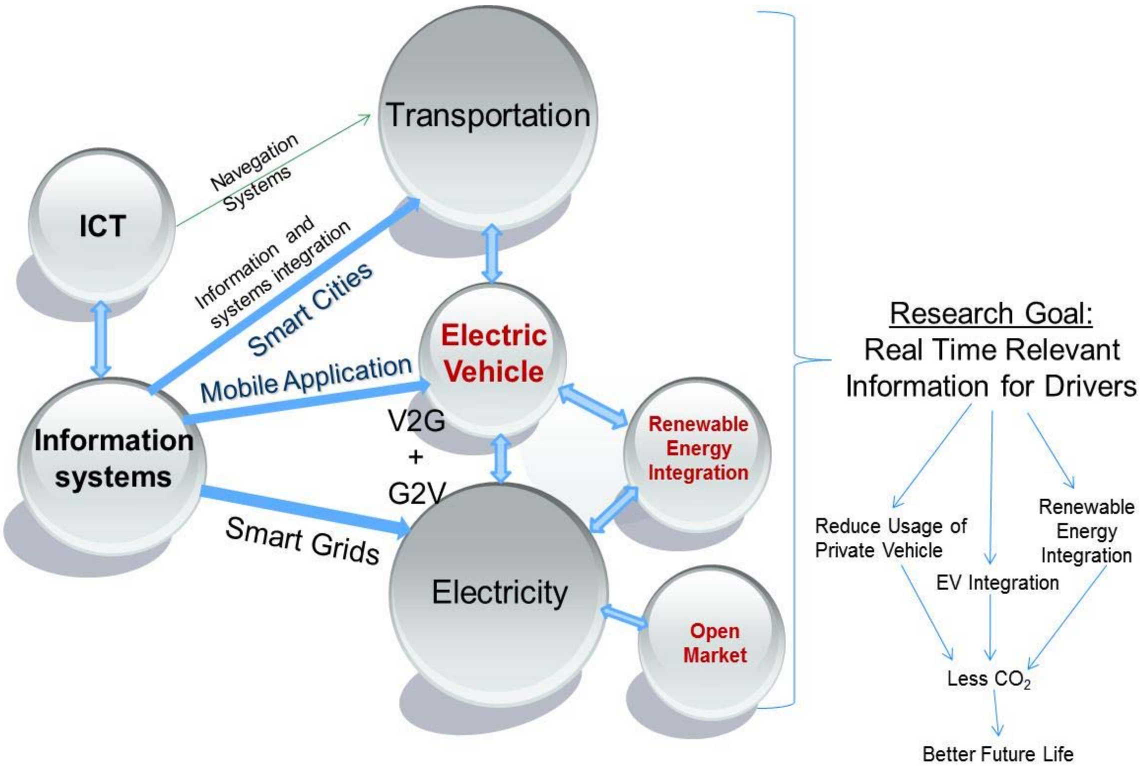

Figure 1-3: Future tendencies for current research area work

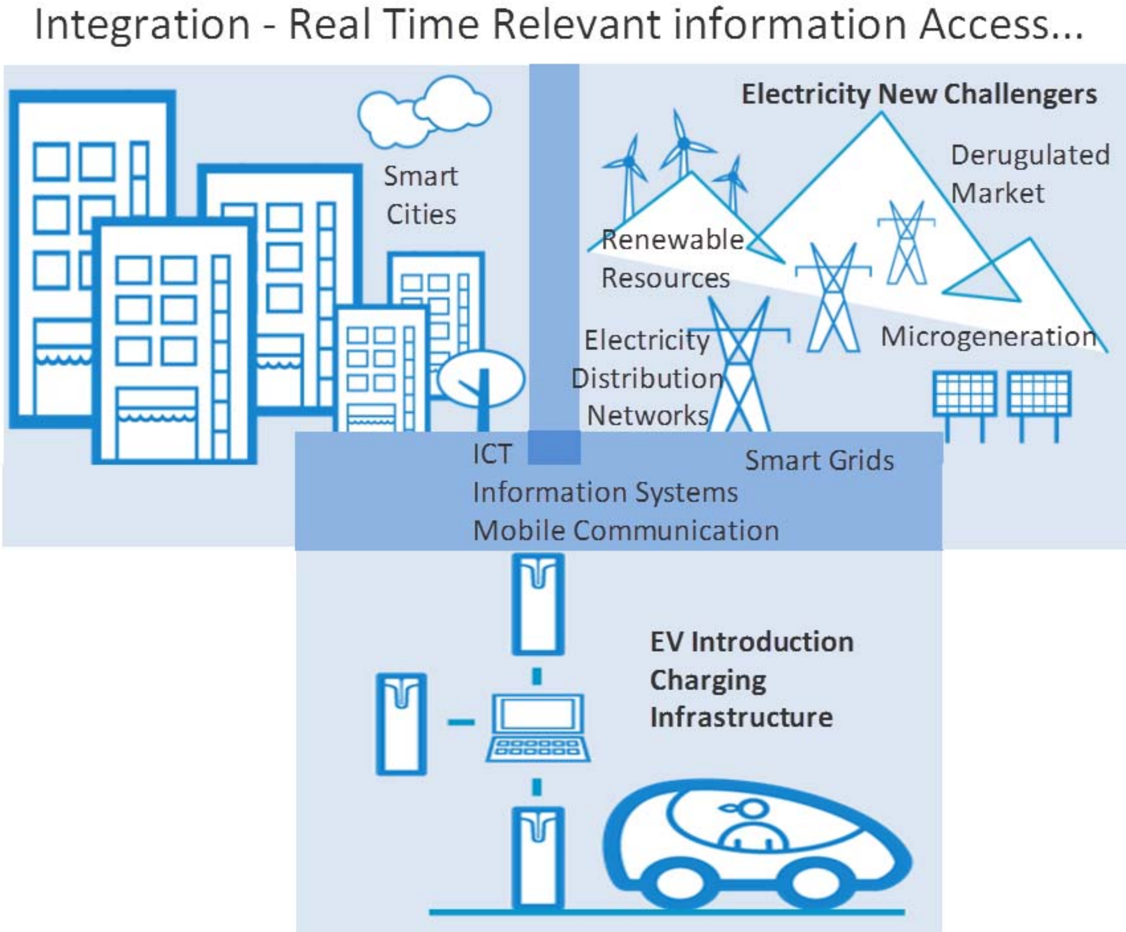

Figure 1-4: Main research goal and related areas

Figure 1-4 suggests the research context of this work, involving three new emerging paradigms: smart cities, electricity new challenges and the EV integration. This research project is located on the intersections of these emergent tendencies, where ICT, with mobile communications and information systems play an important role to support the integration and real time information access. These upcoming realities raise drivers' information needs similar to current internet users' information needs, due to information overload. Based on the author background and the potential of application of these emergent realities, the current research is oriented towards the definition of information system architecture to support the information integration on a mobile device that can feed the need of drivers' relevant real time information.

1.1.1. Smart Grids

A Smart Grid (SG) is an electrical network that can intelligently integrate the actions of all users connected to it, generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supplies.

A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to: (1) better facilitate the connection and operation of generators of all sizes and technologies; (2) allow consumers to play a part in optimizing the operation of the system; (3) provide consumers with greater information and choice of supply; (4) significantly reduce the environmental impact of the whole electricity supply system; and (5) deliver enhanced levels of reliability and security of supply [SmartGrid, 2009].

Smart Grids deployment must consider technology, market and commercial aspects, environmental impact, regulatory framework, standardization usage, migration strategy, and also societal requirements and governmental edicts. The key challenges for Smart Grids are [SmartGrid, 2009]:

- **Strengthening the grid:** ensuring that there is sufficient transmission capacity to interconnect energy resources, especially renewable resources;
- **Moving offshore**: developing the most efficient connections for offshore wind farms and for other marine technologies;
- **Developing decentralized architectures**: enabling smaller scale electricity supply systems to operate harmoniously with the total system;
- **Communications**: delivering the communications infrastructure to allow potentially millions of parties to operate and trade in the single market;
- **Active demand side**: enabling all consumers, with or without their own generation, to play an active role in the operation of the system;
- **Integrating intermittent generation**: finding the best ways of integrating intermittent generation, including residential microgeneration (e.g., Micro-Grids);
- **Capturing the benefits of Distributed Generation (DG) and storage**: DG refers to a variety of small, modular power-generating technologies that can be combined with energy management and storage systems, and used to improve the

operation of the electricity delivery system, whether or not those technologies are connected to an electricity grid;

- **New Market**: the need to handle grid congestions with market based methods; the need to reduce uncertainty and risk to businesses, making investment decisions;
- **Environment**: European and national policies encouraging lower carbon generation, new and renewable energy sources and more efficient use of heat energy;
- **Preparing for electric vehicles**: whereas Smart Grids must accommodate the needs of all consumers, electric vehicles are particularly emphasized due to their mobile and highly dispersed character and possible massive deployment in the next years, what would yield a major challenge for the future electricity.

The market evolution, associated with an efficient regulatory framework, will promote economic growth and play a key role in the EU's competitiveness strategy. Increasing competition will encourage efficiency and spur on technological progress and innovation. As a result, the internal market is expected to provide benefits to the European citizens such as a wider choice of services and downward pressure on electricity prices.

In spite of several pilot tests, for example in Portugal, the Inovcity Project [www.inovcity.pt], this upcoming reality is far from massive implementation due to high costs and the considerable amount of work involved. Since the information that a Smart Grid provides is important for EV charging and for energy market, the current work proposes and alternative simulation environment that based on past data, on information from a tracking device, and on weather information (see Chapter 3), is able to provide important simulation values about consumption.

Since this upcoming reality is not implemented yet, in the context of this work the simulation process provides simulation results of what we could have if a Smart Grid was fully implemented, and we could get consumption data from it. Details of this simulation process can be seen in Chapter 3.

1.1.2. Electricity New Challenges

The electricity industry faces new challengers, namely related to electricity renewable market, microgeration and the deregulated electricity market.

Energy Renewable Market is based on the production and selling of electricity produced by renewable energy sources (e.g., wind, solar, waves). In January 2007 the European Commission brought forward a set of medium-term targets to speed up the transition towards a low carbon economy, including a reduction of 20% of carbon emission by 2020, and an increase of the share of renewables in the final energy consumption to 20% by 2020. The electrical power sector will likely bear a disproportionate share of the burden given the limited scope for renewable deployment in other sectors, such that the 2020 target translates into a share of 30–40% of renewable in the electricity generation mix by 2020 [EWEA, 2008]. Among the different renewable energy sources, wind power development is expected to account for a large share of the increase in renewable electricity to meet the 2020 target. Wind power has experienced the fastest growth in renewable electricity source over the past years in Europe and accounted for about 4% of the total European electricity demand in 2007 [EWEA, 2008].

Microgeneration is the small-scale generation of electricity by individuals, small businesses and communities to meet their own needs, as alternatives or supplements to traditional centralized grid-connected power, and this is a new important growing market [www.delta-ee.com]. It is expected a fast growing in microgeneration, and by 2025 it is projected 20% of energy produced from these resources [www.delta-ee.com]. A significant synergy is expected between microgeneration and EV (see Section 3.3), with the possibility of microgeneration production excess to be stored locally by EV. A system and a business model are needed to control these transactions.

Deregulated Electricity Market is based on an open market, where we can have several suppliers of electricity in opposition to the monopoly. In contrast to the experience in transportation and telecommunications industries, electricity deregulation has experienced many difficulties, due to the complexity of the electricity market [ERSE, 2009]. At the same time of this liberalization process a new reality arrives with the EV introduction and with renewables and microgeneration integration. EU directive created a single integrated European electricity market in 2007. Main output from this fact in the research context is that EV can play a role of producer, if conveniently aggregated in communities, creating a 'large storage device' (see Chapter 3, for further analysis). Figure 1-5 illustrates EV usage driving profile and its implication of EV battery charging, and also a typical consumption curve for Low Voltage (LV) power in Portugal, where in night period (low home consumption), it can be used for EV charging process, or to sale energy back to the electrical grid when the demand is high (e.g., around 12 hours or 21hours).

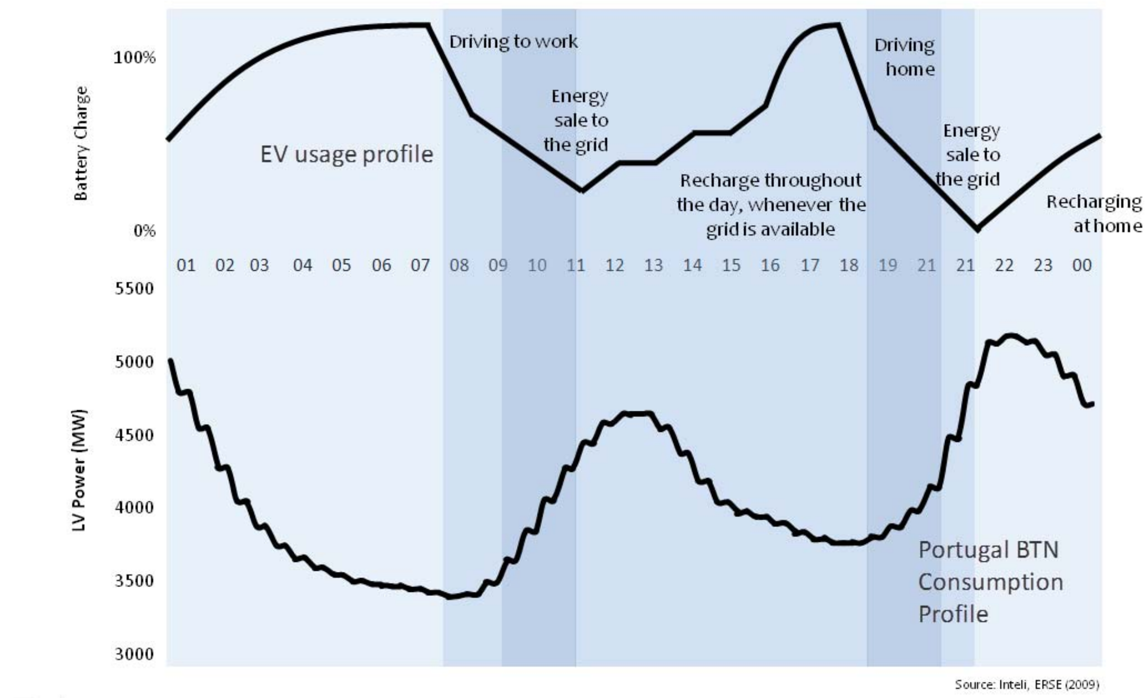

Figure 1-5: EV battery charge and Low Voltage (LV) typical consumption in a day, [ERSE, 2009]

Figure 1-6 shows current electricity market reality where distribution network remain regulated. For more information see the Section 2.3 of Chapter 2.

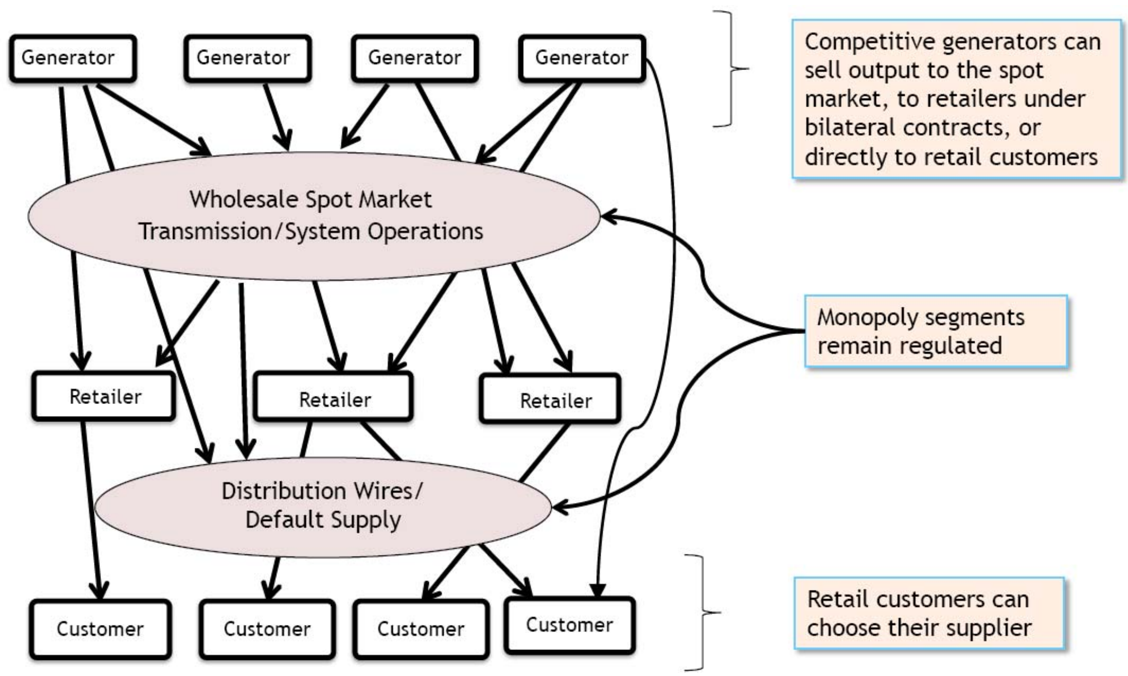

Figure 1-6: Current reality of electricity market, from [EPRI, 2010]

1.1.3. Smart Cities

The “Smart Cities” concept is a new paradigm that has been quite fashionable in the policy arena in recent years. Its main focus seems to be on the role of ICT infrastructure, although much research has also been carried out on the role of human capital/education, social and relational capital, and environmental interest, as important drivers of urban growth [Caragliu, 2009].

The European Union has devoted efforts to the developed of a strategy for an urban growth in a ‘smart’ sense for its metropolitan areas. The "Smart Cities Initiative" was born under the SET-Plan (Strategic Energy Technology Plan) of the European Commission, with the aim of encouraging cities and regions to adopt ambitious measures in order to progress for a 40 percent reduction in emissions of greenhouse gases, through the use and production of sustainable energy. One of the biggest challenges facing the world is the rapid increasing urbanization, with half the world's population living in cities. Since this scenario has a clear tendency to increase, the initiative has the main mission of a substantial reduction of CO_2, dealing with the upcoming reality of decentralized power generation in buildings, which change from energy consumers to energy producers. Thus it is important the intelligent management of energy systems and transportation system, where information and communication systems play an important role.

For this work the main input from Smart Cities initiatives is the support for the usage of information systems sustained by an ICT infrastructure, which supports the data integration among different players, and promotes a collective knowledge maintained by the usage of cooperative systems and social networks.

1.1.4. Electric Vehicles

Automobile plays an important role in transportation and new challenges appears with the introduction of the EV in 2010: the so-called “city EV”, that is EV with autonomy of less than 160 km [Leaf, 2010]. Drivers of such EV will have to cope with a new problem: the fear of being stranded in an EV due to inadequate battery capacity: the range anxiety problem [Schott, 2009; Nilsson 2011]. This problem gains more relevance during this startup phase due to the lack of charging stations. The success of EV in part is going to depend on how comfortable people are so that they can get where they want to go, without running out of charge, and without having to go through some process that will take them a long time and impact their ability to use the vehicle. So, taking out real time EV information, such as SOC (State of Charge), energy transactions, and other vehicle events; play an important role. This information, taking into account recent progress in mobile devices, geographic information systems and communication processes, can bring added value to drivers.

Other interesting problem on EV research is the potential of EV for the energy market, since it has storage capacity. This is the logic behind the concept of V2G (Vehicle-to-Grid), where EV provides electricity to the distribution grid, and G2V (Grid-to-Vehicle), where EV is charged with electricity from the grid. The potential of these concepts is that vehicles are parked, on average, 93-96% of their lifetime, and thus are available for alternative uses [Kempton, 2005]. While parked, vehicles represent an idle asset—in terms of both energy storage (in the fuel tank or battery) and energy conversion capacity—and can create negative value due to parking costs. V2G provides a means by which to exploit parked EV to generate electricity for the grid, creating additional value. That is, V2G enables EV to both act as Distributed Energy Resources (DERs) and provide mobility services, bringing the transportation and the electricity systems together.

Figure 1-7 schematically illustrates how V2G power generation works. It shows conventional electricity generation from primary energy sources (left hand side of the diagram), and the transmission and distribution systems leading to the retail power market and end-use consumers, i.e., houses, buildings, industries, commercial areas, parking lots, etc. The doubled-arrows represent potential two-way flows to and from EV. Electricity flows one-way from conventional electricity generators through the grid to electricity users, including EV charging their batteries. And electricity flows back to the grid from EV. Such a system must be controlled by the grid operator, who monitors the flows from and to the vehicles by some remote control system. There are virtually no limits to where and when EV power could be generated, providing that there is an outlet and the proper infrastructure and connection system. For example, the EV power could be generated during the night at home, when the vehicle is parked in the garage, or in parking lots at the office, during the working hours.

The V2G system concept adds functionality to the basic charging and metering capabilities of a power plug by allowing bidirectional routing of energy between the EV battery pack and the (smart) grid. This way, batteries can be considered part of the grid that in peak times may be available for power regulation. A V2G system has to anticipate and be aware of the user's charging needs and of the state of the electrical power grid, and thus would be a smart system providing both new functionality and new business opportunities at the interface between EV and energy supplier

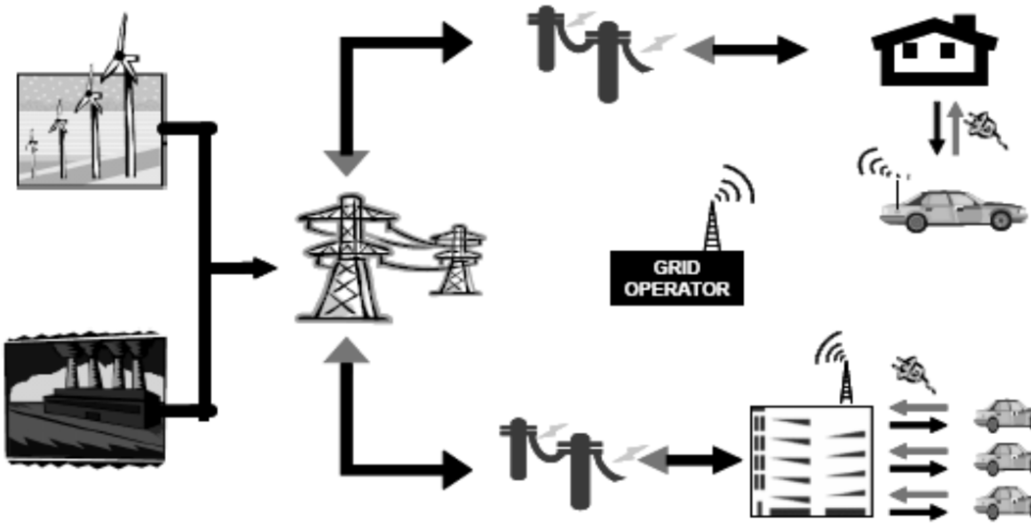

Figure 1-7: Illustrative diagram of the proposed V2G power generation system extracted from [Kempton, 2005]

Three main types of vehicle may be suitable for generating V2G power: Electric Vehicle (EV), Hybrid-Electric Vehicle (HEV) and Fuel Cell-Electric Vehicle (FCEV). Today's EV rely on large battery systems and are routinely connected to the electricity grid for recharging (with regenerative braking providing additional recharging), and thus may be well suited to providing power back to the grid during times when additional power is needed. On the other hand, today's HEV cannot be plugged into the grid to be recharged, even though they have similar (albeit smaller) electric propulsion and battery systems to EV, in addition to a more conventional Internal Combustion Engine (ICE). However, the next generation of HEV is expected to have larger batteries (up to 9 kWh, unlike today's 1-2 kWh storage capacity), and be able to be recharged by plugging into a standard household outlet [EPRI, 2001; Sanna, 2005]. The third type of vehicle examined here is the FCEV, which also relies entirely on electric motors for propulsion, but generates electricity onboard directly from liquid or gaseous fuel, typically, by feeding molecular hydrogen (H2) into a fuel cell. In other words, FCEV represent a potential source of V2G power that does not rely on battery storage, but rather the fuel stored in the onboard tank. Moreover, in the future it may be possible to connect FCEV to gaseous or liquid fuel (e.g., H2) distribution systems at many of the places where vehicles are parked (i.e., commercial or residential buildings). Such a fuel connection would allow electrical power production of essentially unlimited duration. However, FCEV currently face a number of commercial and technical barriers related to cost, distribution infrastructure requirements, on board storage of H2, and conversion losses, meaning that these vehicles are unlikely to be practical and cost-effective, at least in the shorter term [Little 2002]. However, over the longer term significant cost reductions and improvements in competitiveness are possible for FCEV.

1.2. Research Problems and Goals

Taking the main principles and guidelines of smart cities initiatives and the upcoming reality of energy markets and EV integration, this information gives us a complex scenario where this research intends to contribute with a model to data integration among EV data, charging data, electricity market participation and the cooperation with existing transportation infrastructures. This cooperation can be achieved if it is possible to provide information regarding routes, schedules and pricing of public transportation, information about availability of parking places, or even bike and car sharing systems.

Also the minimization of the driver range anxiety problem is an interesting research work with the follow necessities: (1) an accurate EV range prediction based on past driver behavior and external parameters, like road traffic and weather; (2) representation on a map of the distance possible to reach, associated with an uncertainty associated with driver behavior; and (3) guidance and reservation of charging slots on Public Charging Station (PCS).

Taking into account the current development and proliferation of mobile devices, associated with the increasing communication connectivity in mobile communication (higher speed rates and coverage), the proposed system should run in a mobile device.

1.2.1. Research Problems

From the referred areas overview the author identifies several problems related with the integration of EV and the cooperation with public transportation infrastructures. The main problems related with the EV integration are: guidance and reservation of charging slots in public charging stations; the smart charging needed to be performed at home charging devices to overcame electrical distribution power limitations; the support to drivers towards the range anxiety problem; the electricity market participation to increase drivers profits, and consequently increase the EV attractiveness; and even the support to the integration of local renewable resources (microgeneration) by storing the excess of energy production. Cooperation among transportation infrastructure can be achieved by public transportation data integration, access to car and bike sharing system, or even by carpooling. Real time traffic information together with all these transportation options could incentive drivers to use vehicles where public transportation is poor or do not meet their needs, using public transportation only when their requirements are fulfilled. Also this can be achieved, or at least partially, with all the information described in Figure 1-8, available in a mobile device.

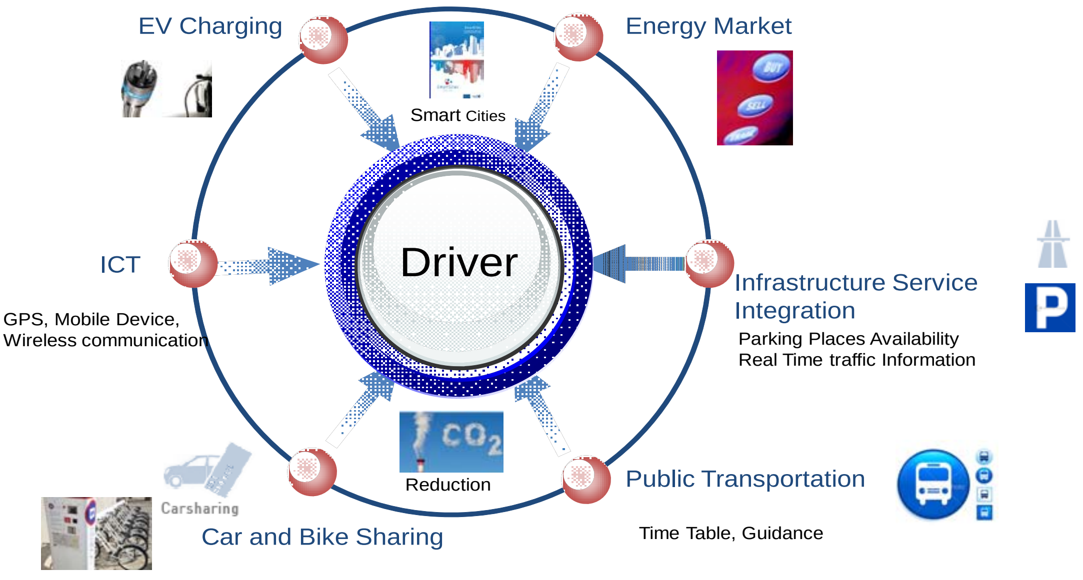

Figure 1-8: Purpose of current research work: mobile information system design, with focus in the driver's information needs adapted to the new reality of EV introduction and cooperation with transportation infrastructures

1.2.2. Research Goals

Considering the scope and the problems identified above, the research goal is the design of a system to give drivers relevant information in real time, taking into account emergent future realities, such as the EV integration, smart cities, cooperation among transportation infrastructures, services integration, and participation in the electrical energy market. The **main challenge addressed in this research is the definition and discussion of a model for that system and the development of a prototype** in order to address the following issues:

- The problem of EV charging at public places (route guidance based on current vehicle position and reservation of time at charging slots) and at home, with the transactions account, and considering smart charging to deal with possible electrical grid power limitation on electricity distribution due to simultaneous charging processes;
- Deal with the drivers range anxiety problem;
- Integrate EV in electricity market participation through the V2G and G2V modules and the creation of EV communities based on a collaborative approach. These communities can constitute market players, taking into account that several EVs constitute a large capacity storage device;
- Smart integration of local microgeneration resources, taking locally the excess of energy produced by microgeneration;
- Support driver's mobility in smart cities, providing integrated information related to transportation systems and other systems, such as carpooling, car and bike sharing systems.

The objective of this work is to define a model for an integrated information system, which can make possible to accomplish the following Research Goals (RG):

- RG-1: Mitigate the EV charging problem;
- RG-2: Minimize the driver range anxiety;
- RG-3: Create and manage EV communities for electricity market participation and microgeneration integration;

- RG-4: Integrate the EV in cooperative transport infrastructures, with different operators transportation data integration, and interaction with carpooling, car sharing and bike sharing systems;
- RG-5: Provide route guidance, taking into account traffic information, transportation available data, or even public charging station locations.

Due to the diversity of topics involved in this research work, this thesis is organized under four topics (see Figure 1-9), each one described in a separated Chapter, namely:

- **EV related functions** (see Chapter 3), where it is proposed a process to extract relevant information for charging process, to deal with the present distribution power limitations, without a Smart Grid infrastructure, and to help the driver to overcame the range anxiety problem by range prediction, representation features and guidance to the nearest public charging station;
- **Electricity market related functions** (see Chapter 4), where it is proposed the creation of EV communities for electricity market participation, with the integration of local renewable energy resources;
- **Sustainability Mobility functions** (see Chapter 5), where a diversity of data integration is proposed, and a diversity of environment friendly systems are suggested (carpooling, car sharing and bike sharing), towards possible advices for the best path, taking into account the travel time. In spite of the lack of real world testing scenarios, this integrated view with traffic information is a new approach that can help in a near future the reduction of vehicles in the city, without great penalty for drivers;
- **Mobi-System**, prototype created for user interaction with previous functions. This system is based on a web application called V2G Smart System (see Section 6.1), on a mobile application developed for android operating system designated by SiREV (see Section 6.2), and on an application called IRecommendit developed for windows mobile operating systems (see Section 6.3) and SITP application for public transportation interaction (see Section 6.5).

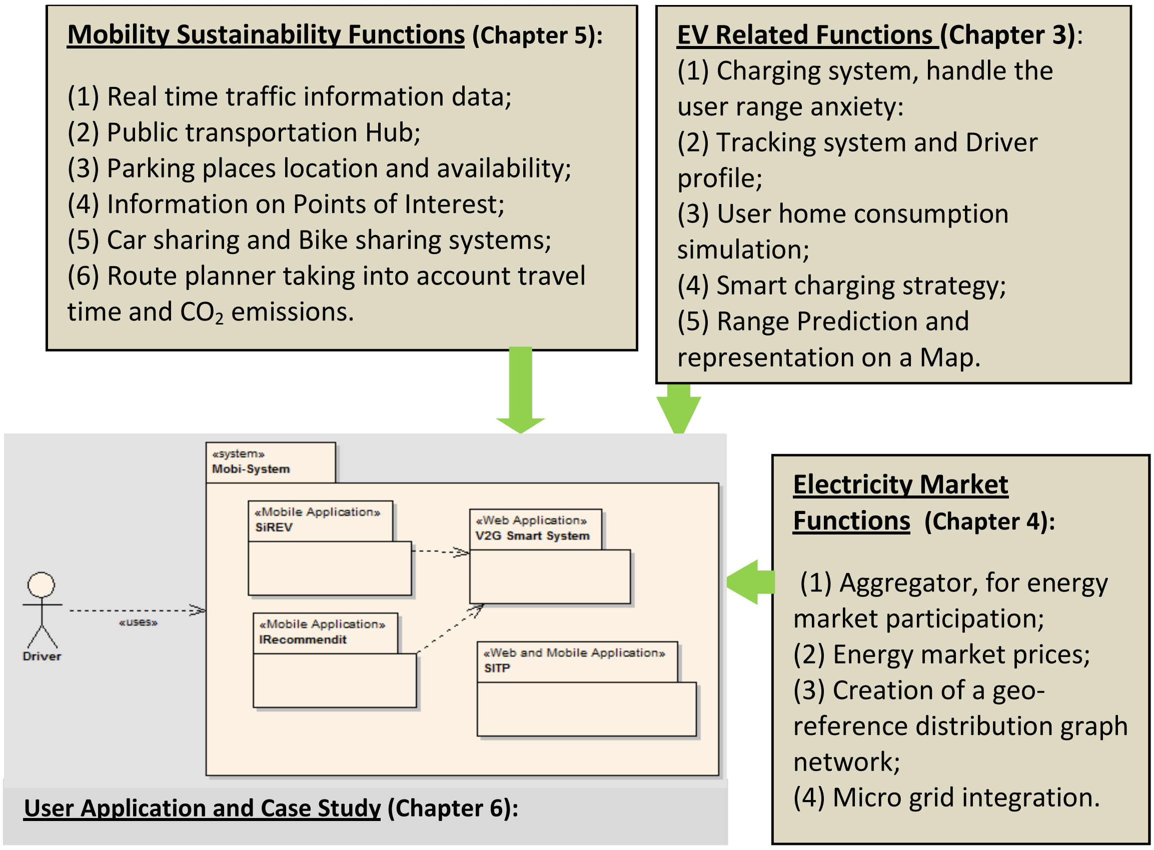

Figure 1-9: Mobi-System Chapter organization

1.3. Research Methodology

The research developed in this thesis addresses the questions enumerated in Section 1.2.2, following the Action Research Method [Lewin, 1946], considering the set of problems identified in Section 1.2.1.

The issues raised shall be approached from an engineering perspective, using available technology to build a prototype that allows the development and validation of models. The research makes use of the following techniques: state of the art analysis, identification of the relevant features in the research context, and a prototype construction, providing means for model development using a domain specific language.

To validate the research's resulting prototype a set of possible case-studies are be used, during a first phase reproducing reference models described in scientific literature, and on a second phase addressing "real-life" problems with scientific relevance on their own. The results of this research have been submitted to evaluation in peer reviewed international conferences and journals, seeking validation from the scientific community.

1.4. Main Contributions

The result of this research work has already produced the following technical Papers (P):

P1. João C. Ferreira; Trigo, Paulo, Porfírio Filipe. Collaborative Car Pooling System. Proceedings of International Conference on Sustainable Urban Transport and Environment, Paris, 24-26 June 2009.

P2. Vítor Monteiro, João C. Ferreira, Gabriel Pinto, Delfim Pedrosa, João L. Afonso, iV2G Charging Platform, IEEE-ITSC, 13th International IEEE Conference on Intelligent Transportation Systems, 19-22 September 2010, Madeira, Portugal. IEEE Press (ISBN: 978-1-4244-7658-9, ISSN: 2153-0009).

P3. João C. Ferreira, João L. Afonso, A Conceptual V2G Aggregation Platform. Proceedings of the 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition (EVS-25), 5-9 Nov. 2010, Shenzhen, China.

P4. João C. Ferreira, João L. Afonso, Towards a Collective Knowledge for a Smart Electric Vehicle Charging Strategy. Proceedings of the International Conference on Industrial and Intelligent Information (ICIII 2011) 1st to 3rd April 2011 Bali.

P5. João C. Ferreira, Pedro Pereira, Porfírio Filipe; João Afonso. Recommender System for Drivers of Electric Vehicles in proceedings of the IEEE 3rd International Conference on Electronics Computer Technology (ICECT 2011), 8-10 April 2011, Kanyakumari, India, pp. 244-248, IEEEXplore Digital Object Identifier: 10.1109/ICECTECH.2011.5941995, ISBN: 978-1-4244-8678-6.

P6. João C. Ferreira and João L. Afonso. Mobi-System: A Personal Travel Assistance for Electrical Vehicles in Smart Cities. Proceedings of the 20th IEEE International Symposium on Industrial Electronics (ISIES 2011), 27-30 June 2011, Gdansk University of Technology, Poland.

P7. João C. Ferreira, Alberto Silva and João L. Afonso. Agent based approaches for Smart charging strategy for Electric Vehicle. Proceedings of the 1st

International Electric Vehicle Technology Conference (EVTEC 11), 17-19 May 2011, in Yokohama, Japan.

P8. João C. Ferreira, Alberto Silva and João L. Afonso. EV-Cockpit - Mobile Personal Travel Assistance for Electric Vehicles. Advanced Microsystems for Automotive Applications 2011.Smart Systems for Electric, Safe and Networked Mobility. Series: VDI-Buch. Meyer, Gereon; Valldorf, Jürgen (Eds.) 1st Edition, 2011, (ISBN 978-3-642-21380-9).

P9. João C. Ferreira, Paulo Trigo, Alberto Silva, Helder Coelho, João L. Afonso. Simulation of Electrical Distributed Energy Resources for Electrical Vehicles Charging Process Strategy. Published by IEEE computer magazine dedicated to the Second Brazilian Workshop on Social Simulation (BWSS 2010), 24-25 Oct. 2010, São Bernardo do Campo, São Paulo, Brazil, pp. 82-89, IEEEXplore Digital Object Identifier: 10.1109/BWSS.2010.15, ISBN: 978-1-4577-0895-4.

P10. Vítor Monteiro, João C. Ferreira, João L. Afonso. Modelo de Agentes para Simulação da Gestão dos Carregamentos dos Veículos Eléctricos. Proceedings of the 6th Iberian Conference on Information Systems and Technologies (CISTI2011).

P11. João C. Ferreira, Alberto Silva, Vítor Monteiro, João L. Afonso. Smart Electric Vehicle Charging System. Proceedings of the IEEE Intelligent Vehicles Symposium (IV 2011), June 5-9, 2011, in Baden-Baden, Germany.

P12. João C. Ferreira, Vítor Monteiro, João L. Afonso. V2G Smart System: Sistema Inteligente de Gestão dos Carregamentos dos Veículos Eléctricos. Proceedings of the 6th Iberian Conference on Information Systems and Technologies (CISTI2011).

P13. João C. Ferreira, P. Filipe, Alberto Silva. Multi-Modal Transportation Advisor System. Proceedings of the First IEEE FISTS Forum on June 29 - July 1, 2011 in Vienna Austria.

P14. Joao C Ferreira, Vitor Monteiro, Alberto Silva and Joao Luiz Afonso. Collaborative Broker for Distributed Energy Resources. Proceedings of the

International Symposium on Computational Intelligence for Engineering Systems (ISCIES 2011), from 16 to 18 November 2011, Coimbra, Portugal.

P15. Joao C. Ferreira. Green Route Planner. Proceedings of the International Workshop on Nonlinear Maps and their applications (NOMA11), from 14 to 16 September, in Évora, Portugal.

P16. Joao C. Ferreira, Vitor Monteiro and João Afonso. Mobile Geographic Range Prediction for Electric Vehicles. Proceedings of the 1st Conference in Electronics, Telecommunications, and Computer Engineering, from 24th to the 25th November, 2011, at Instituto Superior de Engenharia de Lisboa – ISEL, Lisbon- Portugal.

P17. Joao C. Ferreira. MultiModal Best Path. Proceedings of the 1st Conference in Electronics, Telecommunications, and Computer Engineering, from 24th to the 25th November, 2011, at Instituto Superior de Engenharia de Lisboa – ISEL, Lisbon- Portugal.

The author developed the Supervision (S) of the following academic projects in the context of this research work:

S1. "Visualização de dados geográficos em dispositivos móveis", Paulo Sousa, MSc dissertation, ADEETC-ISEL, 2009.

S2. "Sistema de Recomendação para Condutores de Veículos Eléctricos", Pedro Romão Pereira, MSc dissertation, ADEETC-ISEL, 2010.

S3. "Determinação do melhor caminho em sistemas de transporte terrestre (BPath – Best Path)". Tiago Fernandes and Miguel Fontes, Final Year Project, ADEETC-ISEL, 2009.

S4. "Vehicle-2-Grid, Sistema de Carregamento Controlado à Distância". Xênia Beatriz Henning and Andreia Sofia Reis Mouta, Final Year Project, ADEETC-ISEL, 2010.

S5. "MyTracking: Sistema de Tracking de Movimentos de Condutores de Veículos em modo off-line". João António Gomes de Sousa and Pedro Nuno Pereira dos Santos, Final Year Project, ADEETC-ISEL, 2010.

S6. "V2G - Modelo de Simulação". Ana Rita Gonçalves Ramada, Final Year Project, ADEETC-ISEL, 2010.

S7. "V2G SMART SYSTEM: Sistema inteligente para gestão de carregamentos de veículos eléctricos". Cláudio Russo and Nuno Bento, Final Year Project, ADEETC-ISEL, 2100.

S8. "IRecommendIt: Sistema de recomendação para veículos eléctricos". Luís Filipe Valente Borges and Miguel Ângelo Valente Borges, Final Year Project, ADEETC-ISEL, 2010.

S9. "Forget about Traffic - Sistema cooperativo para gestão de incidência de tráfego". Fernando Vaz and Vítor Viana, Final Year Project, ADEETC-ISEL, 2011.

S10. "CarSharing". Alberto Xavier and Nuno Lourenço, Final Year Project, ADEETC-ISEL, 2011.

S11. "Green Route-Assistente 'verde' em viagens na cidade". Miguel Marques and Raul Jesus, Final Year Project, ADEETC-ISEL, 2011.

S12. "Assistente pessoal de viagem". Daniel Costa, MSc dissertation, ADEETC-ISEL, 2011.

1.5. Outline of the Thesis

This thesis is divided in 7 Chapters:

- Chapter 1 presents the introduction, motivation, scope, and main goals of this thesis.
- Chapter 2 describes the literature review related to the topics of mobility processes in smart cities, EV and electricity market. The following sections were created: (1) Sustainable transport system, to study the impact of Electric Vehicle (EV); (2) Smart energy network systems, to study the impact of V2G systems; (4) Characterization of Electric Vehicles and battery devices; (5) The emergent energy market; (6) Distribution network; and (7) Brief description of collaborative social networks and associated impact on current proposal.
- Chapter 3 presents the proposal towards the EV function modules and shared modules of tracking system, home consumption simulator and weather module.
- Chapter 4 presents the Electricity Market functions, taking into account EV market participation, and the integration of local renewable energy resources.

- Chapter 5 describes the sustainable mobility functions, with the proposal of carpooling, car sharing and bike sharing systems, and a system for public transportation data integration in the European space. A supporting decision system informs the user about the best path and public transportation, taking into account traffic information.
- Chapter 6 describes the driver's mobile application for portable devices, like PDA or mobile phones, and also a web application. Also some used cases of applications are showed.
- Chapter 7 summarizes the main conclusions of the work, and future work to be developed, as well as work impact, are also presented.

2. Literature Review

Due to the diversity of Electrical Vehicle (EV) topics, the present literature review focuses on: (1) Sustainable transport system, to study the impact of electrical vehicles; (2) Electric Vehicle; (3) The energy market with the study of electricity distribution network; (4) Electromobility, where is studied the EV charging process, characterization of batteries and a brief description of hard standardization process; (5) Computer Science Related Topics with a brief description of collaborative social networks ICT and associated impact on current proposal of smart energy network systems; and (6) The identification of main related European scenarios.

General R&D needs, relatively to V2G systems, to cover mainly three areas: the development of basic control algorithms and appropriate hardware, research in user acceptance, and the development of new business models at the interface of vehicle and grid, including leasing concepts for batteries and life cycle cost sharing between the EV owner and the utility. All these topics are considered being of high urgency, and thus have to be considered at the earliest possible instance.

According to the experts, foremost R&D needs related to Smart Systems are seen at both the subcomponents level and at the level of system integration. Regarding subcomponents for actuation, challenges are, e.g., semiconductor devices for switching with high power/temperature capabilities. Therefore, research will have to address innovative circuit technologies and the proper choice of materials like GaN (Gallium Nitride) and SiC (Silicon Carbide). At the level of sensors, devices that determine the state of charge, health, and function of accumulators, even of each single cell therein, will be required. Such systems may be based on local measurements of current, voltage and temperature. Regarding the diagnostic and predictive capabilities of Smart Systems, models have to be developed, e.g., for battery ageing, failure prediction, management of energy/power demand and availability, and both deterministic and intelligent algorithms have to be derived. Major system integration issues are related to thermal management of power circuits and motors, operability in harsh environments, and the circumstances of bidirectional energy flow. Advanced cooling measures, robust packaging and intelligent interfaces between the vehicle and the grid or between a choice of power sources (battery pack, supercapacitor bank, plug-in battery, ICE range extender and photovoltaic solar cells) and the motor will deserve particular attention. Overall R&D priorities include the reduction of cost, weight and volume, as well as the gain of safety, reliability, and electromagnetic compatibility. According to the experts, there is also need for secondary research in safety, user acceptance, privacy protection, business models, physiological compatibility and assessment criteria.

2.1. Sustainable Transport System

Sustainable transport system is a hot investigation topic with a diversity of publication that can be divided in the following E3 (Energy–Economy–Environment) scenarios: (1) suitable demographic; (2) economic; and (3) social driving forces.

Combination among these types of scenarios is an investigation topic and for example, among the 40 scenarios that were presented in the Special Report on Emissions Scenarios (SRES) from the Intergovernmental Panel on Climate Change [Nakic´enovic´, 2000], several describe future worlds in which the basic economic and social drivers are consistent with a number of the principles of sustainable development [Azar, 2003].

Earlier published works began to address what the scope of transportation sustainability meant: In 1997 DeCicco and Delucchi [DeCicco, 1997], the Transportation Research Board [TRB, 1993], [TBR, 1997], and Richardson [Richardson, 1999], and [Richardson, 2000] addressed passenger issues. Gordon [Gordon, 1995], ORourke and Lawrence [Rourke, 1995], Browne [Browne, 1997], Duleep [Duleep, 2005], Joseph [Joseph, 1997], Rodriguez et al. [Rodriguez, 1997], Scrase [Scrase, 1998], and Whitelegg [Whitelegg, 1997] addressed freight sustainability issues. More recent literature ranges from European freight models, [Beuthe, 2002], Friedl and Steininger [Friedl, 2002], Priemus, [Priemus, 2002], to reviews of international transport sustainability practices, [American Trade Initiatives, 2001] and [Deakin, 2002], an international conference on social change and sustainable transport [Beuthe, 2002], social and psychological driving forces behind changes in transport [Geenhuizen, 2002], and the impacts of mobility management projects in 13 European countries [Wilhelm, 2003].

Each transportation system is complex, and this complexity derives from the pluralism of its hardware (infrastructure and vehicles) and of the people and organizations involved.

The complexity is multiplied by the existence and roles of different modes, regulatory and legislative bodies, service providers, builders, financing systems, technologies, land-use patterns, and, most importantly, human behavior. The consequences of transportation use are both positive and negative and are addressed in considering the sustainability of the transportation system. Among these consequences are safety, traffic congestion, fuel consumption, vehicle emissions, and accessibility.

By modifying the Brundtland Commission's definition of sustainability for the planet [UNWCED, 1987], it is derived a definition of sustainable transportation as the ability to meet today's transportation needs without compromising the ability of future generations to meet their transportation needs [Black, 1996]. Irrespective of the specific definition of sustainable transportation, there is frequently reference to the ''triple bottom line'' of economic, environmental, and social equity sustainability [Loo, 2002] and [Schipper, 2003]. Even with this agreement on the triple bottom line, virtually every individual and group that addresses transportation system sustainability develops a different set of variables that they consider to be the indicators of sustainability. Based on a review of the literature, participation in committees, meetings, discussions, and task forces devoted to this topic, and also on empirical evidence, the present work choses as indicators of transportation sustainability these five consequences: safety, traffic congestion, fuel consumption, vehicle emissions, and accessibility. Clearly there is room for discussion and debate on these choices.

For example, Black et al. [Beuthe, 2002] use the term ''indicators'' to mean quantifiable measures of performance resulting from transportation policies. They note that indicators that can be grouped into three categories influencing six sub objectives for sustainable transportation. They derive these from diagrams of hierarchies of non-sustainable and sustainable transportation systems similar to those developed by Richardson [Richardson, 1999] and [Richardson, 2000].

2.1.1. Key Factors in Transportation

According to the literature [Nijkamp, 1998], Masser, 1992], [Masser, 1993] and [Nijkamp, 1999] there are five main factors that influence the development of transportation: spatial and land use planning, government policy, economic forces, technology and social and behavioral trends. Each of these factors evolves over time, and affects both the others and the transportation system. These factors influence mobile technology, infrastructure design, travel behavior, the level of motorization, and policy measures. Thus, these factors will determine whether the progress in transportation will be sustainable or not. The five individual factors discussed in the present literature review are outlined below:

- **Spatial and land use patterns**: The demand for travel and thus the transportation system are influenced by the size of the urban area, building density, level of specialization and the spread of activities within the urban area. Due to the long life span of buildings and infrastructure, the influence of spatial patterns on transportation is a long run one.
- **Economic forces**: Large-scale transportation projects are highly sensitive to economic changes because of the huge financial investment involved, the primary capital needed, the long time span of the project and the slow rate of returns.
- **Technology**: Technology can contribute to sustainable transportation by improving waste treatments and thus reducing pollution, as well as by offering substitutes to physical travel through communication. Technological development in transportation, however, is relatively slow, mainly due to reasons such as the scale and cost of the projects, the long periods of research and development, and the long life expectancy of infrastructure and mobile equipment.
- **Government policy**: Authorities are strongly involved in transportation development due to several reasons, including the need for long range planning to reserve rights-of-way for future development, the huge financial investment and the consideration of negative external effects. Thus, transportation development is sensitive to political priorities.
- **Social and behavioral trends**: Individual behavior is a combination of habits, practical and emotional considerations. Thus, social values and norms may greatly affect the transportation choice of individuals.

2.1.2. Planning for Sustainable Transportation Systems

Planning for a sustainable transportation system is a complicated task that involves a high degree of uncertainty due to several reasons: (1) the large number of alternative potential policy packages, (2) the way of implementation, and (3) the traveler's response to each of these policy packages. In addition, it depends upon how planners and policy makers define and interpret the concept of sustainable development. Transportation planning usually uses a cost-benefit approach or a multi-criteria analysis. In both cases, to evaluate the benefits and the cost of different scenarios, transportation planning usually applies statistical and behavioral models to analyze the performance of the transportation system under these scenarios. These tools, that have initially been developed to analyze the effects of new transportation infrastructure or public transport services, have been expanded to evaluate the environmental impact of transportation projects, as well as to analyze the sustainability of transportation alternatives. This approach, however, cannot be used as a systematic tool for developing a sustainable transportation system because of several reasons. First, it is not a planning tool; rather it is an evaluation tool, where the suggestion of alternatives is left to the planner. Second, with all the advances in this approach, it still lacks the capability to analyze the effects of many policies and is limited in the sustainable indicators it can predict [Shiftan, 2000]. Third, this approach is based on extracting existing behavior and trends, making it difficult to account for significant changes in behavior, values or unexpected events.

Finally, quantifying all the benefits and costs is a complicated task, and may therefore complicate the design of transport policies. A discussion of these issues is performed at [Lakshmanan, 2001].

Some authors have attempted to suggest approaches for sustainable development planning in the general (non-transportation) literature. Different approaches used for urban planning including multi-criteria analysis, contingent valuation, and risk assessment were studied by [Leitmann, 1999].

Other examples include [Kelly, 1998] who suggested a system approach identifying the key linkages among the sustainable indicators as a tool to help in better implementation of sustainable planning. Mathematical modelling tools for R&D investment decisions within a sustainable development climate are discussed at [Kelly, 1998]. A systematic thinking and the use of value trade-off is discussed in [Minns, 1994]. An integrated city planning framework combining an information system and a dynamic model is analysed in

[Rotmans, 2000]. A graph model for conflict resolution over groundwater in Ontario, Canada is proposed in [Levy, 1995].

2.1.3. Transport Scenario

Future transport demand is uncertain, but there is an expectation that transport activity will experience rapid growth over the 21st century as incomes in developing countries rise, with a concomitant increase in energy consumption. For example, some of the nearer-term projections suggest that global transport energy demand could increase to 120–135 EJ 1 by 2020 [EIA, 2002] and [EIA, 2004], with the lower estimation consistent with a consumption of 145 EJ by 2030 [EIA, 2004], compared to around 80 EJ in 2000.

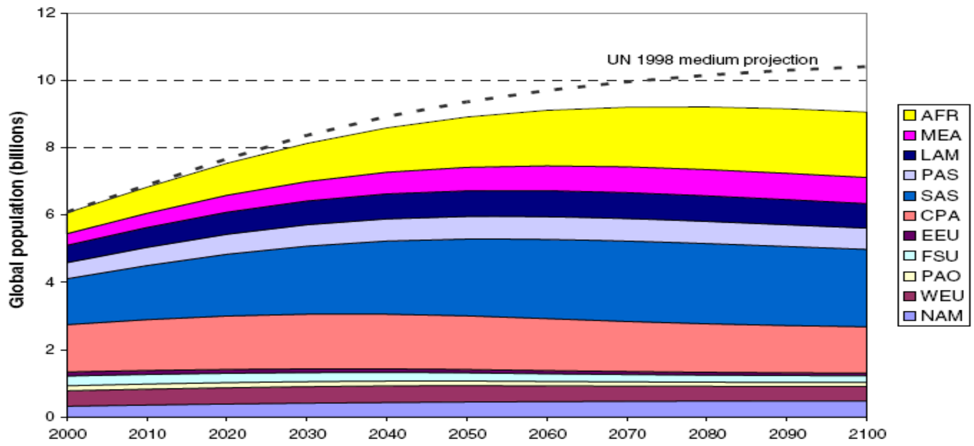

Figure 2-1: Global population scenario, UN 2004 medium projection. (Source: UN [UN, 2004])

Acronyms used in Figure 2-1, Figure 2-2 and Figure 2-3: NAM: North America, WEU: Western Europe and Turkey, PAO: Pacific OECD, FSU: Former Soviet Union, EEU: Eastern and Central Europe, CPA: Centrally Planned Asia, SAS: South Asia, PAS: Pacific and Other Asia, LAM: Latin America, MEA: Middle East and North Africa, AFR: Sub-Saharan Africa

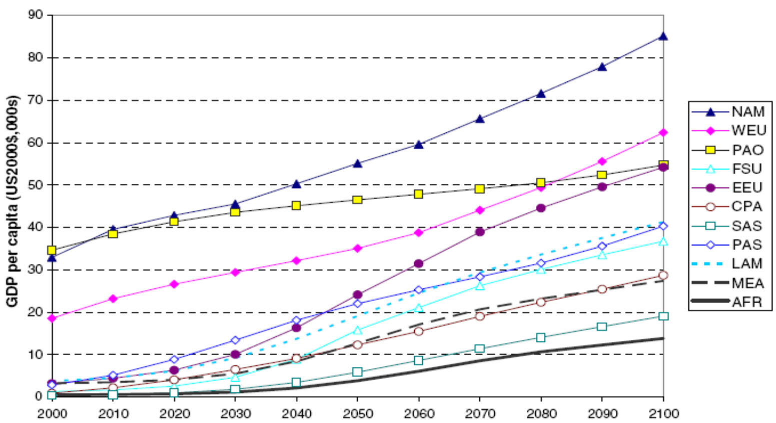

Figure 2-2: Economic growth scenario, based on SRES B2 (Source: derived from Miketa [L. Schrattenholzer, 2004], Riahi and Roehrl [L. Schrattenholzer, 2004]

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[1] 1 EJ (ExaJoule) = 10^{18} J

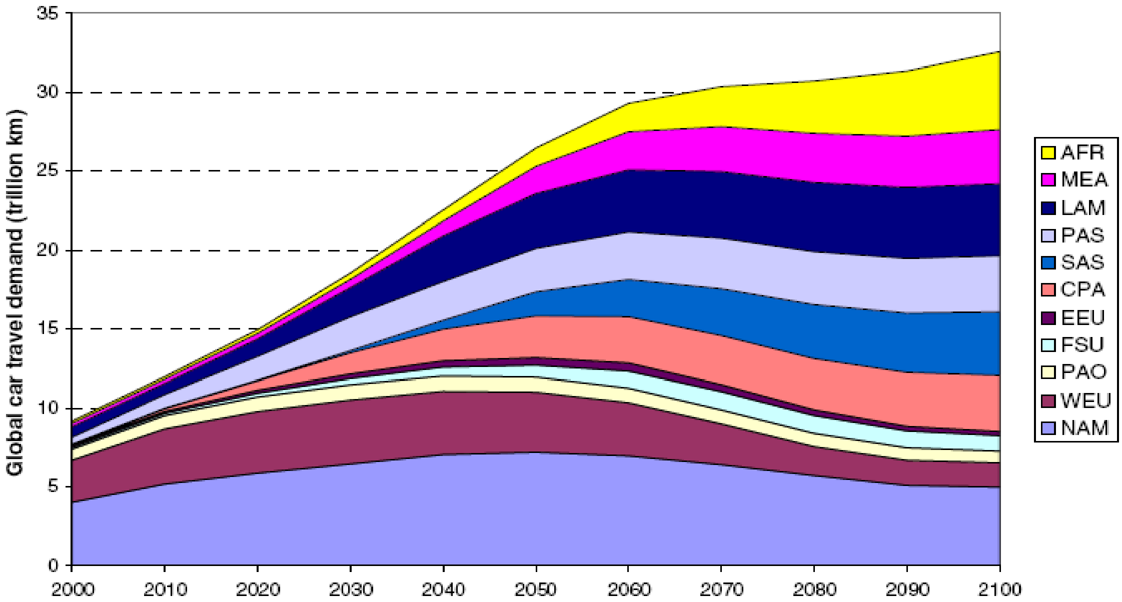

Figure 2-3: Automobile transport, calibration scenario [L. Schrattenholzer, 2004]

2.1.4. Sustainable Development Objectives

Another key driver assumed in the sustainable transport scenario is the sustainable development, divided on three key aspects: (1) Continuing economic growth, with a moderate reduction in income disparities between different world regions. This is represented by the economic growth trajectories presented in Figure 2-2. Although substantial differences in income persist under this growth scenario, there is a considerable improvement in distribution of income; (2) Access to energy supplies, which implies a need to manage effectively long-term threats to security of energy supply. This encompasses reducing exposure to the risk of supply disruptions by a combination of diversification, demand reduction, and maintaining domestic production capacity and resources. In developing this scenario, this is assumed to be implemented on a regional level and global level. Regionally, those regions most dependent on oil and gas from external sources are assumed to maintain an aggregate resources-to-consumption ratio of 20 years and maintain capacity to ramp up production rapidly in the first half of the 21st century, as described in more detail in Turton and Barreto [Turton, 2006]. Globally, it is assumed that the resources-to-production ratio (Rsc/P) for oil and gas is maintained above 30 years throughout the century as a hedge against unforeseen requirements or supply disruptions. Clearly, resource assumptions affect the stringency of measures aimed at achieving this goal. In this scenario, it is applied resource estimates from Rogner [Rogner, 1997] for oil and gas that include conventional reserves and resources, enhanced recovery, identified unconventional reserves and unconventional resource estimates (Categories I–VI using Rogner's notation)—for oil this is equivalent to roughly 5500 billion barrels, which is consistent with other recent estimates (for example, see Odell [Odell, 2004]); and (3) The need to mitigate climate change through greenhouse gas emissions abatement.

2.2. Electric Vehicle

2.2.1. Main Types of Vehicles

On Figure 2-4 are identified the main vehicle types related with energy power supply. The main classes are the: (1) ICE (Internal Combustion Engines) with high emission production; (2) Hybrid electric vehicles. These types of vehicles were first commenced in 1997 in Japan with the introduction of Toyota Prius [Toyota, 2007]. The main specification of this type of vehicle is the operation of the ICE on its efficient interval by means of a regenerative braking system; and (3) Latest generation of the vehicle the PHEV (Plug-in Hybrid Electric Vehicles) with additional capability to be charged from the grid; (4) Electrical Vehicle (EV); and (5) Fuel Cell Electric Vehicles.

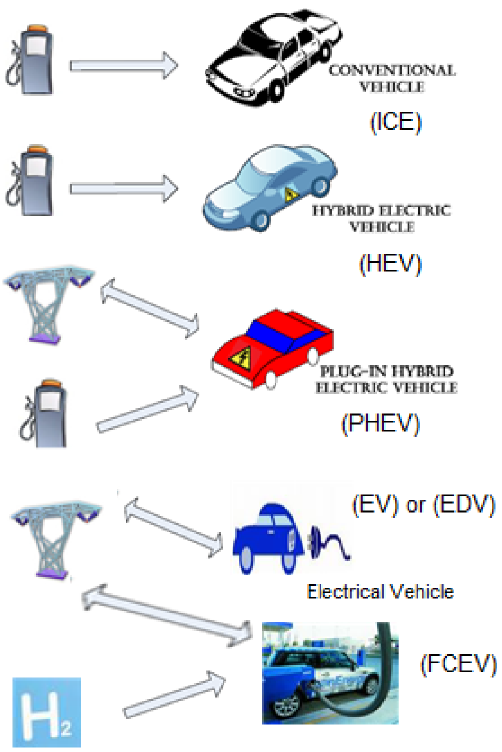

Figure 2-4: Main vehicle types

2.2.2. Why Electrical Vehicles?

A large percentage of the total emissions production is from light-duty cars, which are private and company cars. Reducing emission production is a big challenge for the world (both developed and developing countries). On the other hand, another major challenge in today's world is the high consumption of fossil fuels with increasing price and diminishing number of resources. Light-duty cars are one of the major agents of fossil fuel consumption. Therefore, reducing fuel consumption and emission production are the major incentives to make changes in the light-duty car sector. Tendencies are shown graphically in Figure 2-5.

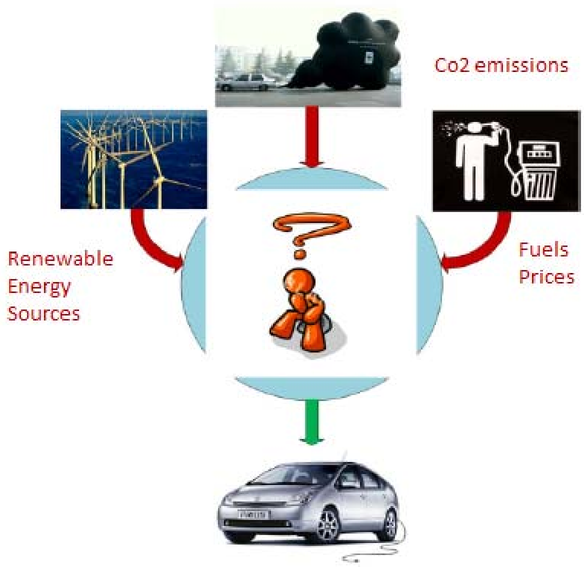

Figure 2-5: Tendencies for the introduction of EV

Global greenhouse gases emissions from different sectors are shown graphically in Figure 2-6. Transportation sector is the third factor of pollution after power stations and industries. The introduction of EV can be even more interesting when there are no emissions from power stations, in the case electricity is generated from clean resources. Conversion of the cars from the ones with fossil fuel consumption to the ones with electricity consumption is not just interesting for the car sector, but is also interesting from the grid point of view. The high intermittency of the electricity from renewable resources can be synchronized with the intermittency of consumption of electric cars, providing stability and avoiding load flow problems in the power systems. However, increase in electrical energy generation is needed in order to provide energy to charge the electric cars.

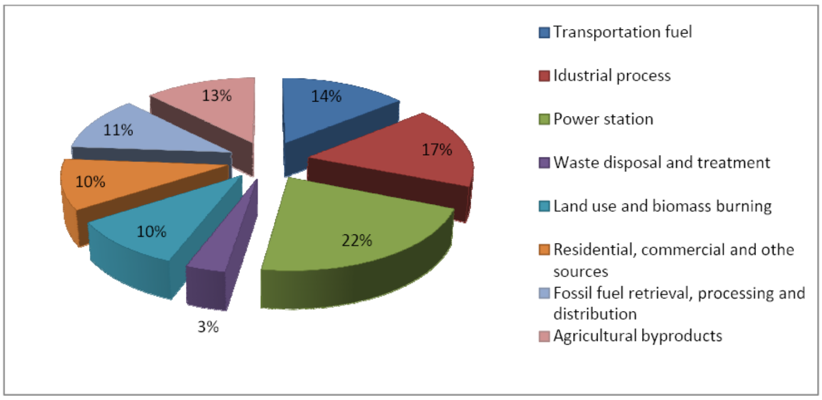

Figure 2-6: Global Green house gasses emissions [Rosmarino, 2009]

In Figure 2-7 it is compared the CO_2 emissions for different vehicle types, taking into account that electricity is produced based on 20% of renewable sources. *In the 1990s the European Automobile Manufacturers Association entered into a voluntary agreement with the European Commission to reduce CO_2 emissions per kilometer. The target was 140 g CO_2/km by 2008, down from an average of 187 g CO_2/km in 1995. By 2005, it was apparent that the target was not going to be reached (World Resources Institute, 2005). In response the European Commission has, after much push-back from European automakers, extended the time of compliance to 2012, but reduced the target to 130 g CO_2/km* [Barkenbus, 2010].

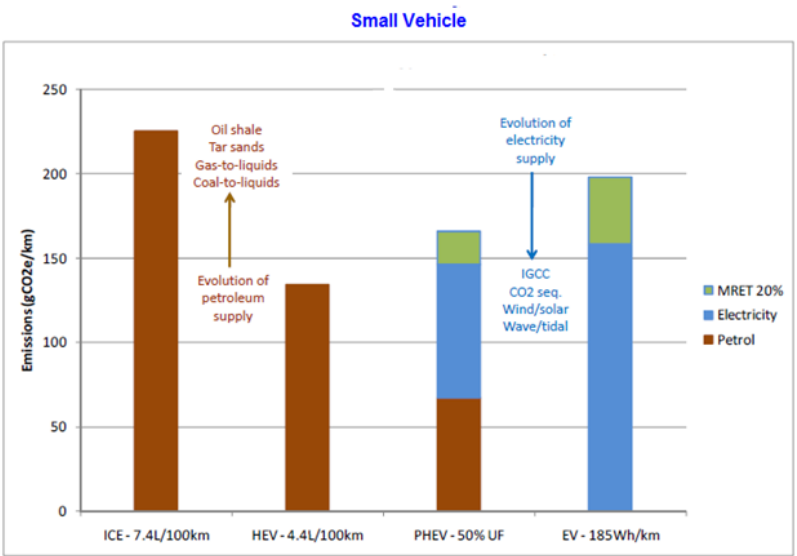

Figure 2-7: Greenhouse emissions[2]: Well-to-Wheel [3]GHG[4] emissions for different types of vehicles. MRET 20% is the mandatory renewable energy target. Increase renewable power will reduce CO_2 emissions associated with energy production. A complete report produced by the Researchers at Argonne National Laboratory [Argone, 2009]

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[2] Greenhouse gases are gases in an atmosphere that absorb and emit radiation within the thermal infrared range.

2.2.3. Conventional Vehicles

Conventional vehicles are the primary type of vehicles, and with their efficiency around 30 percent, it means that 70 percent of the energy consumed by them is being wasted in the process of energy conversion in an ICE (Internal Combustion Engine). Figure 2-8 shows the major losses in a typical ICE.

As can be seen from the Figure 2-8, the energy that is actually being used by an ICE is approximately 13 percent of the total input energy. There are several existing technologies to improve the efficiency, such as, variable valve timing and lift, turbo charging, direct fuel injection, and cylinder deactivation. But, by introduction of hybrid vehicles, these losses have been decreased significantly.

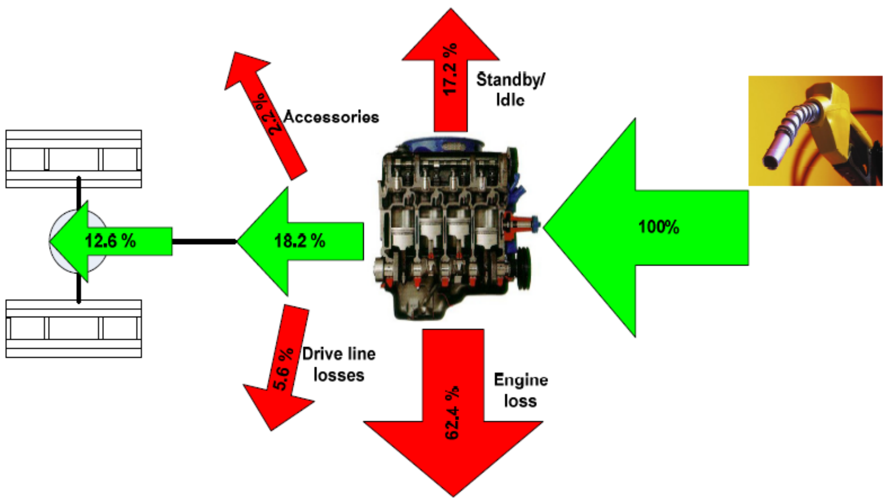

Figure 2-8: Energy losses in a typical ICE (Internal Combustion Engine)

2.2.4. Hybrid Electric Vehicles

Saving braking energy in battery through a regenerative braking system, the ICE can be adjusted to work on its efficient velocity and torque. This can be done by extracting additional required energy from the battery when is needed a higher torque or velocity than the ICE can produce efficiently. In contrast, the excess of energy produced by the ICE, while a lower torque or velocity is needed, can be saved in the battery. This will lead to a more efficient operation of the ICE, and consequently to less emissions production.

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[3] Well-to-wheel is the specific Life Cycle Assessment of the efficiency of fuels used for road transportation. The analysis is often broken down into stages such as "well-to-station" and "station-to-wheel, or "well-to-tank" and "tank-to-wheel".

[4] greenhouse gas

The ICE and the electric machine can be connected to each other in different configurations. The basic configurations are series and parallel hybrid, as shown in Figure 2-9.

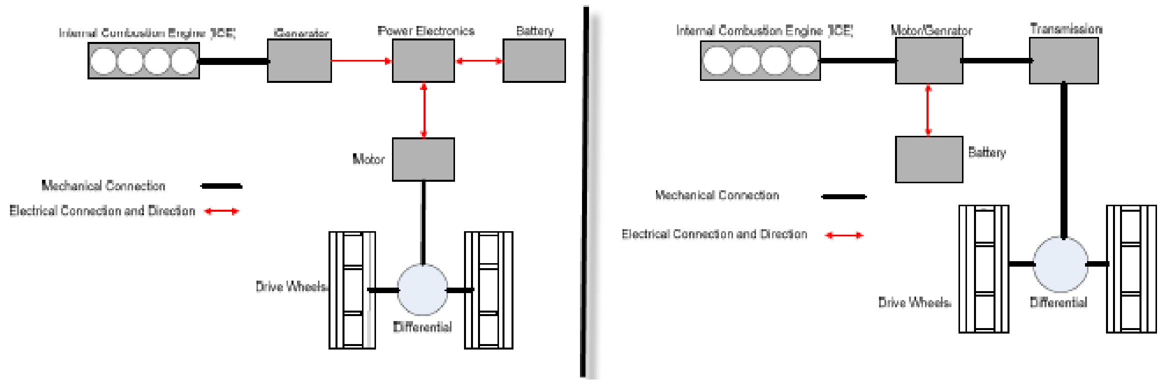


Figure 2-9: Series and parallel hybrid configurations (Left: Series - Right: Parallel) [Weiwei, 2009]

As a matter of fact, series and parallel configurations refer to the orientation of the two power sources in the propulsion system [Xiong, 2009]. The presented configurations in Figure 2-9 are actually the basic ones, in which more advanced configurations with the combination of the series and parallel designs are used for different types of recent vehicles. For example, in Toyota Prius, by using a planetary gear, a configuration has been implemented which has both advantages of parallel and series hybrid.

2.2.5. Plug-in Hybrid Electric Vehicles

The new generations of vehicles that start to appear in the market are Plug-in Hybrid Electric Vehicles (PHEV). A PHEV has basically the same structure of a HEV, but the grid charging capability is an additional feature, which consequently result in the necessity of higher battery capacity.

Grid connection capability in PHEV will make it possible to coordinate energy resources for domestic consumption and also will lead to lower emission production from private cars in the business and residential areas.

Larger battery capacity is always a challenge from weight, cost and viability perspectives. Battery industry has grown fast during the last years and the price and weight of the batteries has dropped off significantly, while their efficiency and capacity have improved a lot.

2.2.6. Different Types of Vehicles

In Figure 2-10 is showed a comparison with main vehicle types. The difference between Micro and Mild Hybrid vehicles is that the second type uses a smaller ICE (Internal Combustion Engine) and a larger electric motor. A Full Hybrid allows to run only on batteries, without help of the ICE, although it usually can be done only for a few kilometers. On the other hand, a PHEV (Plug-in Hybrid Electric Vehicle) is a full hybrid vehicle with larger battery size and capability of grid charging. Recently a new generation of PHEV vehicles has come to existence, in which, although an ICE is implemented in these types of vehicles, the energy usage preference is the electricity from the batteries.

Even if it is not the case, the transition from conventional and hybrid vehicles (that use fuel as energy source) to PHEV (that use electricity as energy source) will make it possible to manage the emission production from numerous car exhausts to fewer power plants chimneys.

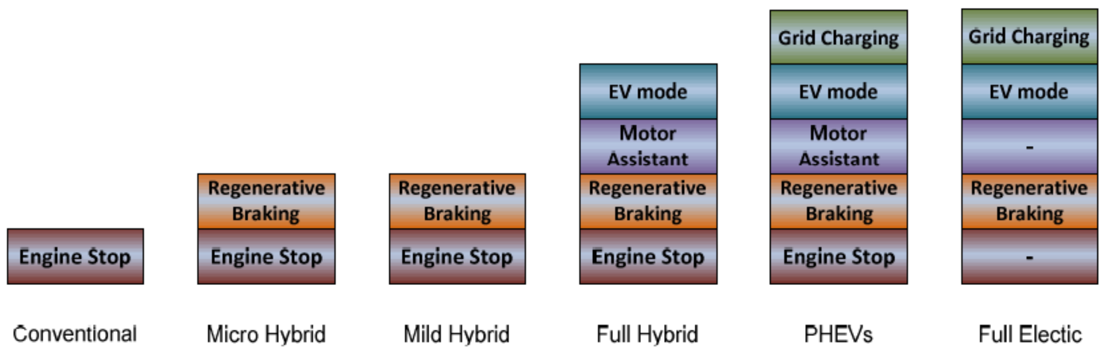


Figure 2-10: Comparison between different vehicle types [Holger Jené, 2006]

2.2.7. Available EV and PHEV in the Market

The automobile companies, especially those companies that are active in HEV market, are vigorously increasing their investment on full electric or plug-in hybrid electric vehicles. For example, both Toyota (with Prius hybrid car) and GM, in NAIAS 2009 (North American International Auto Show), have announced for soon the market release of PHEVs. Other companies, like Think in Norway, have specifically focused on Electric Vehicles. In Table 2-1 are presented some available PHEV with their characteristics.

Toyota is the company which introduced the first HEV in 1997. By having a lot of experience in HEV industry, the expectations for the introduction of PHEV are higher than with the other companies. But Toyota is waiting for progresses in the battery industry in order to introduce its PHEV model. However, unofficially the battery energy storage capability for the Prius PHEV is estimated to be 10 kWh, with a new generation of lithium-ion batteries.

General Motors and Chevrolet have close cooperation for the development of a new series PHEV called Volt. This vehicle, with 16 kWh lithium-ion batteries, has an electric range around 60 km. The price of the Volt is expected to be around US$ 40,000. The price is subject to decrease with USA government approved subsidies to around US$ 32,500.

Tesla Motors has delivered more than 250 full electric cars until March 2009. These cars have the capability to be charged in 3.5 hours with a 70 A home charging station (3-phase). A 377 V AC induction air-cooled electric motor with variable frequency drive has been implemented in this car to cover all required power to run at maximum speed of 200 km/h.

The Norwegian company, Think, has manufactured the modern urban car TH!NK city since July 2008. A rack of sodium or lithium batteries with storage energy capacity near to 30 kWh has made it possible to travel up to 180 km in one charge, with a top speed of 100 km/h.

Recharge is the name of the Plug-in Hybrid concept car which has been introduced by Volvo. The car is more fuel efficient and produces fewer emissions in comparison with other hybrid electric models. Recharge Concept has used series hybrid technology where there is no mechanical connection between the engine and the wheels. Moreover, four electric motors, one at each wheel, provide independent traction power for the vehicle. Acceleration from 0-100 km/h takes 9 seconds and top speed is 160 km/h.

iMiev is an Electric Vehicle produced by the Japanese company Mitsubishi. A highly efficient permanent magnet synchronous motor has been implemented in this vehicle, which has led to a quiet car with a high efficiency. The car can be charged in half an hour with fast charging stations (3-phase 200 V, 50 kW). In slow charging it takes 14 hours (100 V, 15 A) or 7 hours (200 V, 15 A).

Table 2-1 shows the most relevant characteristics of different PHEVs and EVs discussed in the preceding paragraphs.

Table 2-1: Different pure EV and PHEV (data from different company's websites)

Vehicle Type	Battery Capacity (kWh)	Electric Range (km)	Full Charging Time (hour)	Battery Type
 Toyota Prius	10	48	8	*Lithium-ion*
 Nissan Leaf	24	160	8	*Lithium-ion*
 Chevrolet Volt	16	64	10	*Lithium-ion*
 Mitsubishi iMiev	16	160	7 - 14	*Lithium-ion*
 Volvo C30	24	150	8	*Lithium-ion*

BYD Auto is a Chinese company which basically produces 65% of the world's nickel cadmium batteries and 30% of the world's lithium-ion mobile phone batteries, and that has also focused on PHEV and EV manufacturing. The F3DM model, which is a dual mode car, is mostly called as the first mass produced plug-in hybrid, and has entered the market in December 2008. The gasoline engine of this vehicle is a 2.4 litre engine, and its battery can be recharged by normal household power outlet.

2.3. Electricity Market

The electricity industry throughout the world, which has long been dominated by vertically integrated utilities, is undergoing enormous changes. The electricity industry is evolving into a distributed and competitive industry in which market forces drive the price of electricity and reduce the net cost through increased competition.

A new concept appears: the electricity market. The electricity market is where the competitive trading of electricity occurs. The electricity market is a centralized mechanism that facilitates electrical energy trading between buyers and sellers. The electricity market's prices are reliable prices indicators, not only for market participants but for other financial markets and consumers of electricity as well. The main stakeholders', illustrated on Figure 2-11, are:

- **ISO (Independent System Operator)**. The ISO is the leading entity in an electricity market and its functions determine market rules. A competitive electricity market would necessitate an independent operational control of the grid. The control of the grid cannot be guaranteed without establishing the ISO. The ISO administers transmission tariffs, maintains the system security, coordinates maintenance scheduling, and has a role in coordinating long-term planning. The ISO should function independent of any market participants, such as transmission owners, generators, distribution companies, and end-users, and should provide non-discriminatory open access to all transmission system users.
- **GENCOs (GENerating COmpanies)**. A GENCO operates and maintains existing generating plants. GENCOs are formed once the generation of electric power is segregated from the existing utilities. A GENCO may own generating plants or interact on behalf of plant owners with the short-term market (power exchange, power pool, or spot market). GENCOs have the opportunity to sell electricity to entities with whom they have negotiated sales contracts. GENCOs may also opt to sell electricity to the PX from which large customers such as DISCOs and Aggregators may purchase electricity to meet their needs. In addition to real power, GENCOs may trade reactive power and operating reserves. GENCOs are not affiliated with the ISO or TRANSCOs. A GENCO may offer electric power at several locations that will ultimately be delivered through TRANSCOs and DISCOs to customers.
- **TRANSCOs (TRANSmition COmpanies)**. The transmission system is the most crucial element in electricity markets. The secure and efficient operation of the transmission system is the key to the efficiency in these markets. A TRANSCO

transmits electricity using a high-voltage, bulk transport system, from GENCOs to DISCOs, for delivery to customers. It is composed of an integrated network that is shared by all participants and radial connections that join generating units and large customers to the network. The use of TRANSCO assets will be under the control of the regional ISO, although the ownership continues to be held by original owners in the vertically integrated structure. TRANSCOs are regulated to provide non-discriminatory connections and comparable service for cost recovery.

- **DISCOs (DIStribution COmpanies)**. A DISCO distributes the electricity, through its facilities, to customers in a certain geographical region. A DISCO is a regulated (by state regulatory agencies) electric utility that constructs and maintains distribution wires connecting the transmission grid to end-use customers. A DISCO is responsible for building and operating its electric system to maintain a certain degree of reliability and availability. DISCOs have the responsibility of responding to distribution network outages and power quality concerns. DISCOs are also responsible for maintenance and voltage support as well as ancillary services.
- **RETAILCOs (RETAIL COmpanies)**. A RETAILCO is a newly created entity in this competitive industry. It obtains legal approval to sell retail electricity. A RETAILCO takes title to the available electric power and re-sells it in the retail customer market. A retailer buys electric power and other services necessary to provide electricity to its customers and may combine electricity products and services in various packages for sale. A retailer may deal indirectly with end-use customers through Aggregators.
- **Aggregators**. An Aggregator is an entity or a firm that combines customers into a buying group. The group buys large blocks of electricity and other services at cheaper prices. The Aggregator may act as an agent (broker) between customers and retailers. When an Aggregator purchases electricity and re-sells it to customers, it acts as a retailer and should initially qualify as a retailer.
- **Brokers**. A broker of electrical energy services is an entity or firm that acts as a middleman in a marketplace in which those services are priced, purchased, and traded. A broker does not take title on available transactions, and does not generate, purchase, or sell electrical energy but facilitates transactions between

buyers and sellers. If a broker is interested in acquiring a title on electrical energy transactions, then it is classified as a generator or a marketer. A broker may act as an agent between a GENCO, or as an Aggregator of generating companies and marketers.

- **Marketers.** A marketer is an entity or a firm that buys and re-sells electricity but does not own generating facilities. A marketer takes title, and is approved by Federal Energy Regulatory Commission (FERC), to market electrical energy services. A marketer performs as a wholesaler and acquires transmission services. A marketer may handle both marketing and retailing functions.
- **Customers**. A customer is the end-user of electricity with certain facilities connected to the distribution system, in the case of small customers, and connected to transmission system, in the case of bulk customers. In a vertically integrated structure, a user obtains electrical energy services from a utility that has legal rights to provide those services in the service territory where the customer is located. In a restructured system, customers are no longer obligated to purchase any services from their local utility company. Customers would have direct access to generators or contracts with other providers of electricity, and choose packages of services (e.g., the level of reliability) with the best overall value that meets customers' needs. For instance, customers may choose providers that would render the option of shifting customer loads to off-peak hours with lower rates.

Figure 2-11: Main Electricity Market Stakeholders

Electricity is grouped in several different markets with correspondingly different control regimes. In the next Sections are referred some of these markets.

2.3.1. Ancillary Services (AS) Market.

The Federal Energy Regulatory Commission <http://www.ferc.gov/> defined ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."

FERC identified six ancillary services: (1) reactive power and voltage control; (2) loss compensation; (3) scheduling and dispatch; (4) load following; (5) system protection; and (6) energy imbalance.

Ancillary services are needed for the power system to operate reliably. In the regulated industry, ancillary services are bundled with energy. In the restructured industry, ancillary services are mandated to be unbundled from energy. Ancillary services are procured through the market competitively. In general, ancillary services bids submitted by market participants consist of two parts: a capacity bid and an energy bid. Usually, ancillary services bids are cleared in terms of capacity bids. The energy bid represents the participants' willingness to be paid if the energy is actually delivered.

Different ancillary services in the market could be cleared sequentially or simultaneously. In the sequential approach, a market is cleared for the highest quality services first, then the next highest, and so on. For example, suppose that four types of ancillary services are traded, including regulation, spinning reserve, non-spinning reserve, and replacement reserve, which are from the highest quality to the lowest quality. The market would be cleared first for regulation, then spinning, non-spinning, and replacement reserves. In each round, market participants would be allowed to rebid their unfulfilled resources in the previous rounds.

For example, if a participant's regulation bid is not accepted in the regulation clearing round, the participant could bid it again as spinning reserve. The participant could modify the bid in a new round before resubmitting it.

2.3.2. Transmission Market

In a restructured power system, the transmission network is where competition occurs among suppliers in meeting the demands of large users and distribution companies. The commodity traded in the transmission market is a transmission right. This may be the right to transfer power, the right to inject power into the network, or the right to extract power from the network. The holder of a transmission right can either physically exercise the right by transferring power or be compensated financially for transferring the right for using the transmission network to others. The importance of the transmission right is mostly observed when congestion occurs in the transmission market. In holding certain transmission rights, participants can hedge congestion charges through congestion credits.

2.3.3. Forward Market

In most electricity markets, a day-ahead forward market is for scheduling resources at each hour of the following day. An hour ahead forward market is a market for deviations from the day-ahead schedule. Both energy and ancillary services can be traded in forward markets.

2.3.4. Real-Time Market

To ensure the reliability of power systems, the production and consumption of electric power must be balanced in real-time. However, real-time values of load, generation, and transmission system can differ from forward market schedules. Therefore, the real-time market is established to meet the balancing requirement.

2.3.5. Future Market

This work is oriented for a near future electricity market, in which the storage of energy produced from renewable energy sources in microgeneration has to be considered, as well as the impact of the utilization of Electric Vehicles (EVs). This future electricity market can be approximated as combinations of the existing markets, and taking into account this goal we discuss four of them — baseload power, peak power, spinning reserves, and regulation — which differ in control method, response time, duration of the power dispatch, contract terms, and price. The work will focus particularly on spinning reserves and regulation, which must deliver power within minutes or seconds of a request.

Baseload power is provided just in time and the energy is mainly produced through large nuclear or coal-fired plants that have low costs per kWh. Baseload power is typically sold via long term contracts for steady production at a relatively low per kW price. V2G (Vehicle-to-Grid) has been studied across multiple markets [Kempton, 1997], [Kempton, 2000], [Hawkins, 2001] and [Tomic, 2003], showing that EV cannot provide baseload power at a competitive price. This is because baseload power hits the weaknesses of EV — limited energy storage, short device lifetimes, and high energy costs per kWh — while not exploiting their strengths — quick response time, low standby costs, and low capital cost per kW.

Peak Power Market. Peak power is generated or purchased at times of day when high levels of power consumption are expected — for example, on hot summer afternoons, coal nights in winter. Peak power is typically generated by power plants that can be switched on for shorter periods, such as gas turbines. Since peak power is typically needed only a few hundred hours per year, it is economically sensible to draw it from generators that are low in capital cost, even if each kWh generated is more expensive. Earlier studies have shown that V2G peak power may be economic under some circumstances [Kempton, 1997], [Kempton, 2000], [Kempton, 2001] and [Nagata, 2005]. The required duration of peaking units can be 3 to 5 hours, which for V2G is possible but difficult due to on-board storage limitations. Vehicles could overcome this energy-storage limit if power was drawn sequentially from a series of vehicles (see in the next Chapter the topic aggregation or community), or if there were home refueling (for example, with natural gas). These options analyzed elsewhere [Kempton, 2001], but are not covered here.

Spinning Reserves. Spinning reserves refers to additional generating capacity that can provide power quickly, say within 10 minutes, upon request from the grid operator. Generators providing spinning reserves run at low or partial speed and thus are already synchronized to the grid. Spinning reserves are the fastest response, and thus most valuable, type of operating reserves; operating reserves are "extra generation available to serve load in case there is an unplanned event such as loss of generation" [Kirby, 1999] Spinning reserves are paid for by the amount of time they are available and ready. For example, a 1 MW generator kept "spinning" and ready during a 24 hours period would be sold as 1 MW-day, even though no energy was actually produced. If the spinning reserve is called, the generator is paid an additional amount for the energy that is actually delivered (e.g., based on the market-clearing price of electricity at that time). The capacity of power available for 1 hour has the unit MW-h (meaning 1 MW of capacity is available for 1 hour) and should not be confused with MWh, an energy unit that means 1 MW is flowing for 1 hour. These contract arrangements are favorable for EV, since they are paid as “spinning” for many hours, just for being plugged in, while they incur relatively short periods of generating power. Contracts for spinning reserves limit the number and duration of calls, with 20 calls per year and 1 hour per call typical maxima [B. Kirby, 2003]. As spinning reserves dispatch time lengthens, from the typical call of 10 minutes to the longest contract requirement, 2 hours, fuelled vehicles gain advantage over battery vehicles because they generally have more energy storage capacity and/or can be refueled quickly for driving if occasionally depleted by V2G. Spinning reserves, along with regulation (discussed next), are forms of electric power referred to as “ancillary services” (discussed in the previous Section). Ancillary services account for 5–10% of electricity cost, with 80% of that cost going to regulation [Brooks, 2001].

Regulation. Regulation also referred to as automatic generation control (AGC) or frequency control is used to fine-tune the frequency and voltage of the grid by matching generation to load demand. Regulation must be under direct real-time control of the grid operator, with the generating unit capable of receiving signals from the grid operator’s computer and responding within a minute or less by increasing or decreasing the output of the generator. Depending on the electricity market and grid operator, regulation may overlap or be supplemented by slower adjustments, including “balancing service” (intra-hour and hourly) and/or “load following.” Here, it is analyzed only regulation, but V2G may be appropriate for some of these other services.

Some markets split regulation into two elements: one for the ability to increase power generation from a baseline level, and the other to decrease from a baseline. These are commonly referred to as “regulation up” and “regulation down”, respectively. For example, if load exceeds generation, voltage and frequency drop, indicating that “regulation up” is needed. A generator can contract to provide either regulation up, or regulation down, or both over the same contract period, since the two will never be requested at the same time.

Markets vary in allowed combinations of up and down. Regulation is controlled automatically, by a direct connection from the grid operator (thus the synonym "automatic generation control"). Compared to spinning reserves, it is called far more often (say, 400 times per day), requires faster response (less than a minute), and is required to continue running for shorter durations (typically a few minutes at a time).

The actual energy dispatched for regulation is some fraction of the total power available and contracted for. We shall show that this ratio is important to the economics of V2G, so it is defined the "dispatch to contract" ratio as:

$$R_{d-c} = E_{disp} / (P_{contr} \cdot t_{contr}) \qquad \text{[Equation 1]}$$

where R_{d-c} is the dispatch to contract ratio (dimensionless), E_{disp} is the total energy dispatched over the contract period (in MWh), Pcontr is the contracted power capacity (in MW), and t_{contr} is the duration of the contract (in hours). R_{d-c} is calculated separately for regulation up or down.

We have found that this R_{d-c} ratio is not tracked or recorded in most grid operators [Kempton, 2001]. Kempton studies, using data from CAISO of frequency regulation needed during the course of 1 day (unpublished data from Alec Brooks), and modeling the response of one EV, obtained R_{d-c} equal to 0.08. So, a conservative (a higher value of Rd–c increases the cost of V2G) value of 0.10 will be used for R_{d-c}. In Figure 2-12 is illustrated the regulation service on the electrical energy market and on Table 2-2 the values involved in the same US markets.

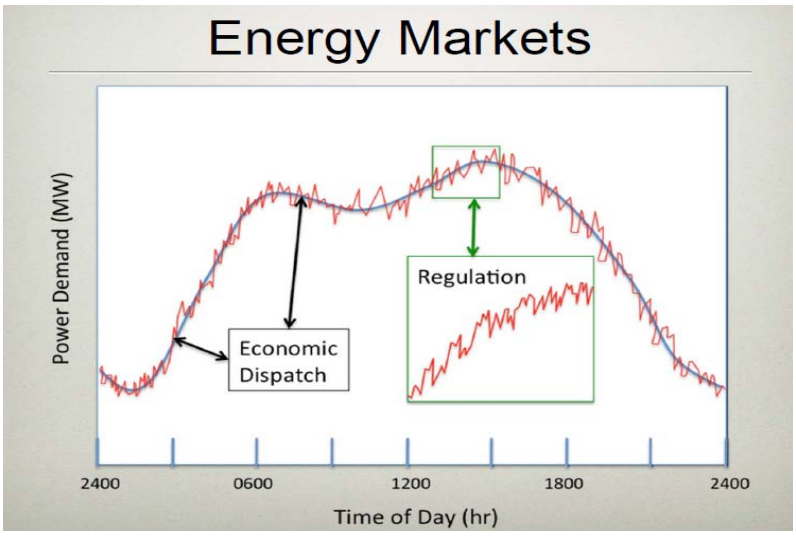


Figure 2-12: Electrical Energy Market functions [Kempton, 2001]

Table 2-2: Values of Regulation, values from US market [Kempton, 2001]

	Average Annual Market Clearing Price ($/MW-h)		
	2004	2005	2006
PJM	$42.75	$49.73	$32.69
RTO-NE	$28.92	$30.22	$24.02
NY ISO	$22.59	$39.21	$51.26
ERCOT	$22.66	$38.07	n.a
CA ISO	$29.00	n.a.	$36.04

2.3.6. Smart Energy Network Systems

Future electricity markets and networks must provide all consumers with a highly reliable, flexible, accessible and cost-effective power supply, fully exploiting the use of both large centralized generators and smaller distributed power sources across Europe. End users will become significantly more interactive with both markets and grids: electricity will be generated by centralized and dispersed sources; and grid systems will become more inter-operable at an European level to enhance security and cost-effectiveness. This new concept of electricity networks is described as the 'Smart Grids' vision. It will enable a highly effective response to the rising challenges and opportunities, bringing benefits to all network users and wider stakeholders. So, Distributed Energy Resources (DERs) have become the focus of considerable research and investigation, as well as commercial interest in the EU, USA and around the world. There is a substantial volume of research on the subject of DERs and their potential to provide various benefits to individual customers, to the utilities, and to society. In this scenario energy prices will change based on market law of demand versus production available.

In this scenario Electric Vehicles (EV) can play an important role, which will be discussed in the next Sections. This role is associated with the Vehicle-to-Grid (V2G) concept.

2.3.7. Identification of the Role of Electrical Vehicles in Electricity Markets

The V2G concept links two critically important technological systems – the electrical power system and the petroleum-based transportation system – in ways that may address significant problems in both. By consuming and supplying back (during peak power consumption intervals) electrical energy to the power grid, electric vehicles could displace the use of petroleum and mitigate pollution and security issues related to oil extraction, importation, and combustion. Of course, it only could be possible with the increase in production of electrical energy from renewable energy sources, where microgeneration could play an important role. This scenario could also improve the economics and technical performance of the electric utility industry and generate revenue to owners of PHEV or EV. Of course, a host of technical and social impediments exists that forestalls the immediate realization of these potential benefits.

Electric Vehicles (EV) must possess three elements to operate in V2G configuration: (1) a power connection to the electricity grid; (2) a control and/or communication device that allows the grid operators access to the energy stored in the EV batteries; and (3) precision metering on board the vehicle to track energy flows [Kempton, 2005].

This intelligent, two-way communication between the electricity grid and the vehicle enables utilities to manage electricity resources better, and it empowers vehicle owners to earn money by selling electrical energy back to the grid and participate in the electricity market.

V2G system can improve future smart energy systems, because electric vehicle can store energy production excess (renewable sources are intermittent) and can supply energy when production is low. A preliminary analysis of market potential for V2G power generation extends substantially on research work by Kempton et al. [Kempton, 2005], [Kempton, 2001]. Other studies explore the potential of V2G from the perspective of consumers, accounting mainly for capital and energy costs. It is important to reiterate that this analysis excludes the costs of purchasing and running the vehicles. As referred by Kempton et al. [Kempton, 2001], these costs are assumed to be allocated to mobility services and are not accounted in their analysis. Moreover, this analysis presents simple accounting costs, which differ from economic opportunity costs corresponding to the value of the best alternative. The methodology of Kempton et al. [Kempton, 2001] develops equations to calculate the capacity for providing power to the grid from the three types of EV mentioned in earlier Sections. These equations are applied to estimate costs and revenues for three power markets: regulation services, spinning reserves and peak power.

After characterizing the electricity markets to which EV can potentially provide electrical energy, the V2G power capacity and energy dispatched for each electricity market can be estimated. Providers of regulation services and spinning reserves are assumed to be paid for both the power capacity they make available (contracted capacity) and for the total amount of energy dispatched. These contract arrangements are favorable for EV and V2G power generation, since owners are paid for having their vehicles plugged in, while generating power for only relatively short periods. Typical times of dispatch vary depending on the power market. In the case of peak power, it is assumed that EV owners are only paid for the energy they provide and not for contracting capacity.

2.3.8. Distribution Network

The term grid is used for an electricity network which may support all or some of three distinct operations: electricity generation, electric power transmission and electricity distribution. It may be used to refer to an entire continents' electrical network, a regional transmission network or may be used to describe a local utility's transmission or distribution grid. Electricity might be provided by a simple distribution grid linking a central generator to homes, though the traditional paradigm for moving electricity around in developed countries is much more complex (Figure 2-13). Generating plants are usually located near a source of energy and away from heavily populated areas. Power generation can range from 200 MW in hydroelectric plants up until 1.500 MW for some nuclear power facilities. The generated electricity is stepped up to a higher voltage suited to connect the plant to the transmission network. The transmission network operates usually with voltages higher than 110 kV and with an upper limit that depends on national and continental constraints, but usually below 800 kV (Figure 2-14 left). Most European grids operate at a maximum voltage of 400 kV. This bulk power transport network can cross national boundaries until it reaches its wholesale customer (usually the company that owns the local distribution network.) Upon arrival at the substation, the voltage will be stepped down from the transmission level voltage to the distribution level voltage, which is lower than 110 kV. As it exits the substation it enters the distribution wiring. Finally, upon arrival at the service location, the voltage is stepped down again from the distribution voltage to the required service voltages. The topology of a distribution grid can vary widely, depending on the constraints of budget, requirements for system reliability, and the load and generation characteristics. Due to cost constraints, though, it usually uses a more radial than meshed structure (Figure 2-14, right). This is usually a tree-shaped grid where power from a large supply substation radiates out into progressively lower voltage lines until the destination homes and businesses buildings are reached. Though any power grid requires some level of redundancy in order to be reliable and secure, the expensive cost of more meshed topologies restricts their application. As a consequence, distribution grids tend to be more meshed when the type of consumers demand an improved quality of supply. A meshed electrical grid secures electrical energy supply in case of a line failure, since the power can be simply re-routed while the damaged line is repaired.

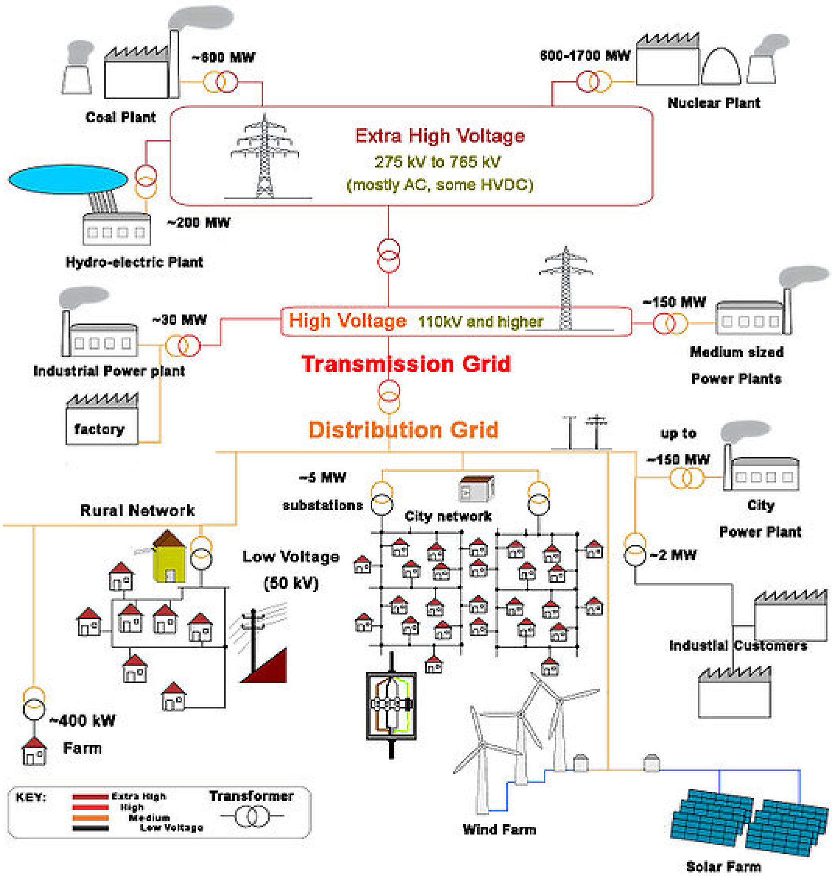


Figure 2-13: Electrical network general layout. The transmission grid is usually defined for voltages higher than 110 kV. (image source: http://en.wikipedia.org/wiki/File:Electricity_Grid_Schematic_English.svg)

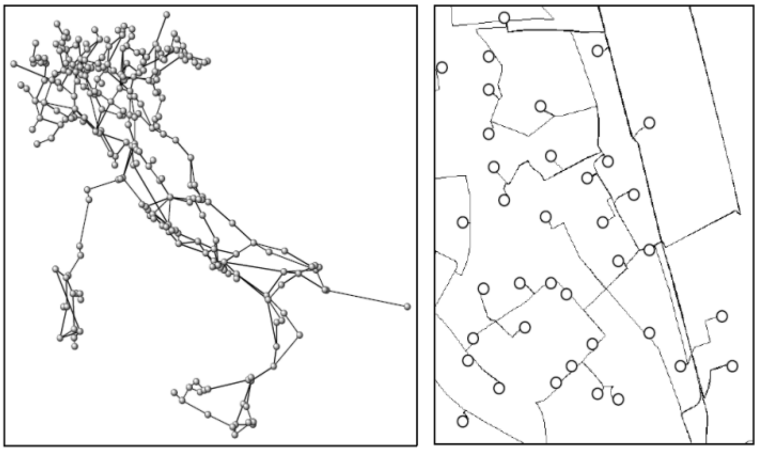


Figure 2-14: **The particular objectives followed in transmission and distribution grids force different structural patterns and layouts. Left: 220 kV – 400 kV transmission power grid, where each node is a substation or transformer. Right: local distribution grid topology (< 60 kV) where each node is a distribution feeder (also transformer) that sets the final voltage at domestic or industrial level [Casals, 2009]**

The new trends in deregulation, markets, generation and demand equilibrium, and reliability pose the structure of the transportation grid at a stack. More power is needed and it has to be transported to far away distances. The traditional centralized model along with its distinctions is breaking down with the introduction of new technologies and renewable energy. In Section 3.1.7 a new approach is proposed based on a geo-reference graph topology to represent and visualize this network.

2.4. Electromobility

Electromobility refers to the use of electric vehicles for various transport needs and is a new growing area, where it is given a small overview on: the Storage Technology (e.g., the Batteries) (Section 2.4.1), the EV Charging Process (Section 2.4.2), EV Utilization Characteristics (Section 2.4.3), Standardization Process (Section 2.4.4).

2.4.1. Storage Technology

The Battery Energy Storage System (BESS) comprises the batteries, the Control, the Power Conditioning System (C-PCS), and the rest of plant. The rest of the plant is designed to provide good protection for the batteries and for the C-PCS. The battery and C-PCS technologies are the major BESS components, and each of these technologies is rapidly developing. So the present state of the art of each of them has been discussed separately.

Batteries

The batteries are made of stacked cells where the chemical energy is converted to electrical energy and vice versa. The battery voltages as well as the current levels are obtained by electrically connecting the cells in series and parallel. Some important features are: their energy and power capacities, efficiency, life span (stated in terms of number of cycles), operating temperature, depth of discharge (batteries are generally not discharged completely and depth of discharge refers to the extent to which they are discharged), self-discharge (some batteries cannot retain their electrical capacity when stored in a shelf for a long time and the self-discharge represents the rate of discharge), and energy density.

Currently, significant development is going on in batteries technology. Different types of batteries are being developed, of which some are available commercially, while some are still in the experimental stage. The batteries used in power systems applications so far are deep cycle batteries [Linden, 1995] (similar to the ones used in EV) with energy capacity ranging from 17 MWh to 40 MWh, and having efficiencies of about 70–80%. Of the various battery technologies [Linden, 1995], some types seem to be more suitable (have already been used) for power systems applications, and these have been discussed briefly below, Table 2-3:

Table 2-3: Different battery types and their functions

Type (name)	Description
Lead Acid	Each cell of a lead-acid battery comprises a positive electrode of lead dioxide and a negative electrode of sponge lead, separated by amicro-porous material and immersed in an aqueous sulfuric acid electrolyte (contained in a plastic case).
Flooded type	In the flooded type battery an aqueous sulfuric acid solution is used. During discharge, the lead dioxide on the positive electrode is reduced to lead oxide, which reacts with sulfuric acid to form lead sulfate; and the sponge lead on the negative electrode is oxidized to lead ions, that reacts with sulfuric acid to form lead sulfate. In this manner electricity is generated and during charging this reaction is reversed.
Valve Regulated Lead Acid (VRLA)	The VRLA uses the same basic electrochemical technology as flooded lead-acid batteries, except that these batteries are closed with a pressure regulating valve, so that they are sealed. In addition, the acid electrolyte is immobilized.
Sodium Sulfur (NaS)	A NaS battery consists of molten sulfur at the positive electrode and molten sodium at the negative electrode separated by a solid beta alumina ceramic electrolyte. The electrolyte allows only the positive sodium ions

Type (name)	Description
	to go through it and combine with the sulfur to form sodium polysulfide. During discharge, positive sodium ions flow through the electrolyte and electrons flow in the external circuit of the battery producing about 2 V. The battery is kept at about 300 ºC to allow this process.
Lithium Ion (Li-ion)	The cathode in these batteries is a lithiated metal oxide and the anode is made of graphitic carbon with a layer structure. The electrolyte is made up of lithium salts dissolved in organic carbonates. When the battery is being charged, the lithium atoms in the cathode become ions and migrate through the electrolyte toward the carbon anode where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge.
Metal Air	The anodes in these batteries are commonly available metals with high energy density like aluminum or zinc that release electrons when oxidized. The electrolytes are often a good hydroxide (OH–) ion conductor such as potassium hydroxide (KOH). The electrolyte may be in liquid form or a solid polymer membrane saturated with KOH.
Flow Batteries	This type of battery consists of two electrolyte reservoirs from which the electrolytes are circulated (by pumps) through an electrochemical cell comprising a cathode, an anode and a membrane separator. The chemical energy is converted to electricity in the electrochemical cell, when the two electrolytes flow through. Both the electrolytes are stored separately in large storage tanks outside the electrochemical cell. The size of the tanks and the amount of electrolytes determines the energy density of these batteries. However, the power density in flow-batteries depends on the rates of the electrode reactions occurring at the anode and cathode. Flow batteries are often called redox flow batteries, based on the redox (reduction–oxidation) reaction between the two electrolytes in the system.

From all these batteries, the lead-acid battery is the oldest and most mature technology, which has been used for majority power system applications. The Li-ion, NaS and NiCd batteries seem to represent the leading technologies in high-power-density battery applications. Of these, Li-ion possesses the greatest potential for future development and optimization. In addition to small size and low weight the Li-ion batteries offer the highest energy density and storage efficiency close to 100%, which makes them ideally suited for portable devices. Li-ion technology disadvantages are its high cost (due to manufacturing complexity arising from the special circuitry to protect the battery) and the detrimental effect that deep discharging has on its lifetime.

Battery Life Cycle

Battery life cycle represents still a negative point because the charging cycles decreases the State of Charge (SOC) capacity (see Section 2.4.3), and this behavior is worse in fast charging scenarios.

As showed in Figure 2-15, in Li-ion batteries SOC capacity decreases to half after more or less 10 years, assuming two charging cycles every day (about 7,300 cycles in 10 years). The most expensive component in an EV is the battery pack. Let's take the example of the upcoming Nissan Leaf: Mark Perry, Nissan's chief product planner for North America, told The Wall Street Journal that the actual (December 2010) cost is a little less than \$750 per kilowatt hour, bringing the total to just below US \$18,000 (about € 14,000). In Portugal Nissan Leaf is around € 30,000 (initial market value), so the battery pack is more less half of the EV price. This fact makes still EV market penetration difficult, because of the high initial investment, even considering government incentives (no acquisition taxes), and in spite of the low utilization costs in €/km of the Electric Vehicles, that are about four times smaller than the costs with conventional vehicles.

In Figure 2-16 are showed battery prices based on technologies (NiMH, Li-ion), application (HEV – Hybrid EV) and price evolution to 2015. Previsions for 2015 show a decrease of more or less 25% in relation to 2007 prices, that gives a decrease of about 14% from present prices (assuming linear behavior), which is too much. In the author opinion the most important factors for EV market penetration are battery price, battery energy storage capacity and charging infrastructure availability.

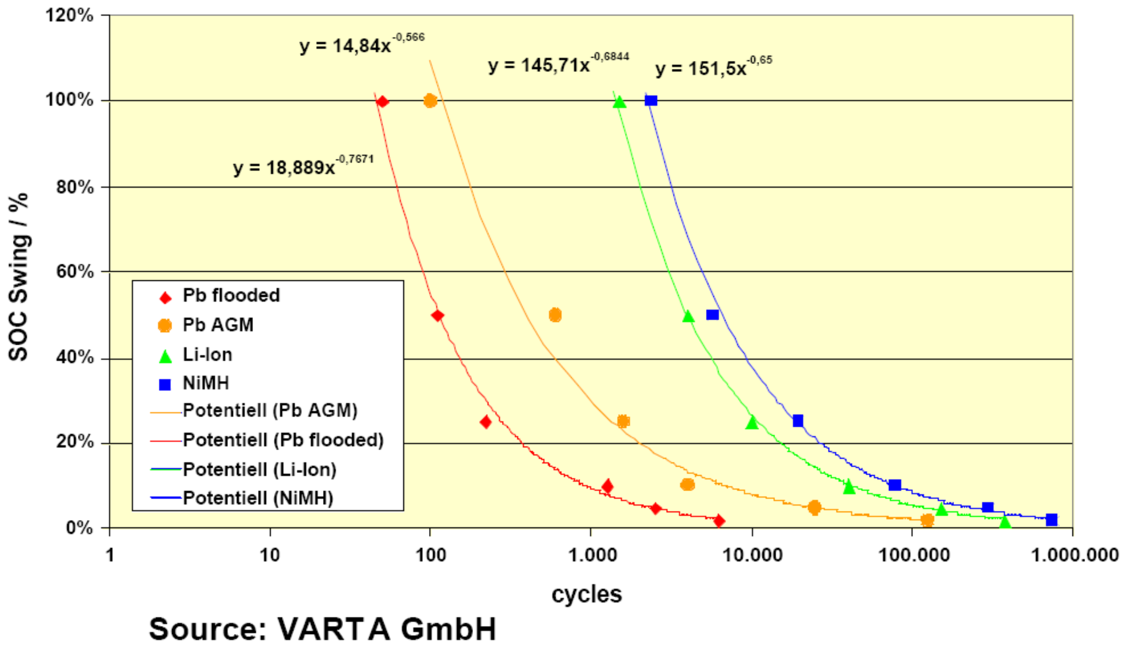


Figure 2-15: SOC capacity versus charging cycles

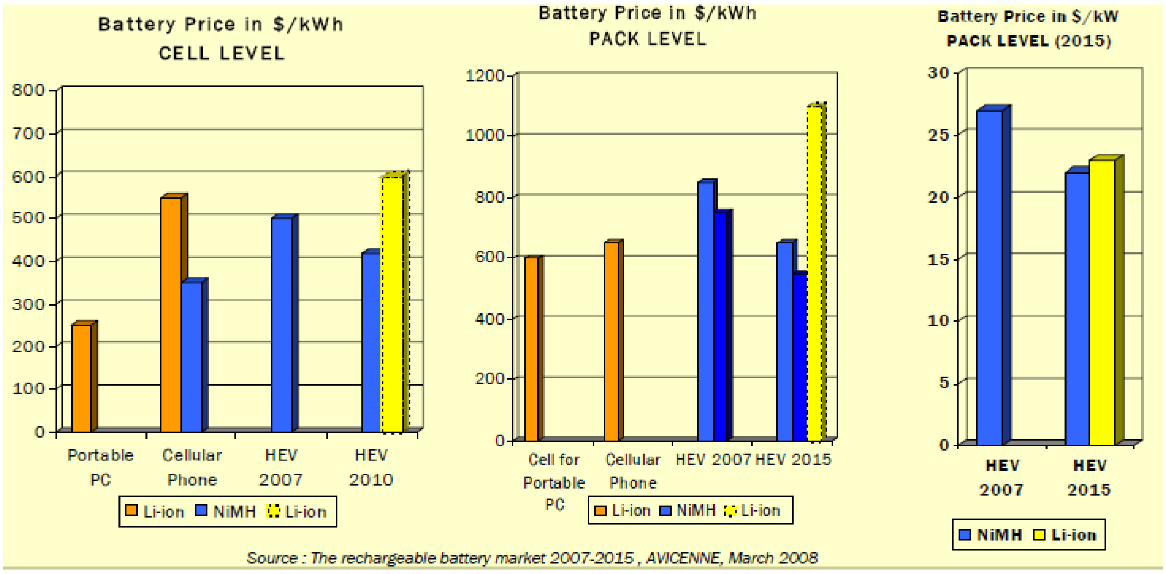


Figure 2-16: Battery prices per amount of energy stored for different technologies and applications, at cell and pack level

2.4.2. EV Charging Process

EV Charging Process is associated with the G2V process, where energy is taken from the grid to the EV battery in a process that takes much more time than a conventional vehicle fill up. For this process it is needed the charging stations (at public places) or charging devices (at users' home) with ICT approach to manage and control the electricity flow (transactions, electrical network distribution limitations, renewable integration) and interoperability problems (see Section 2.4.4). We divide this Section on: (1) Charging Methods; (2) charging infrastructures; and (3) Information System for EV Charging Process.

Charging Methods

The charging mode describes the method by which the electric vehicle is charged. There are five main methods of charging EV batteries (see Figure 2-17): (1) constant voltage; (2) constant current; (3) taper current (where the charging is performed from a crude unregulated constant voltage source, and the current diminishes as the cell voltage builds up); (4) pulsed charge (where pulsed chargers feed the charge current to the battery in pulses - the charging rate, based on the average current, can be precisely controlled by varying the width of the pulses, typically of about one second); (5) a combination of the previous methods of charging the batteries.

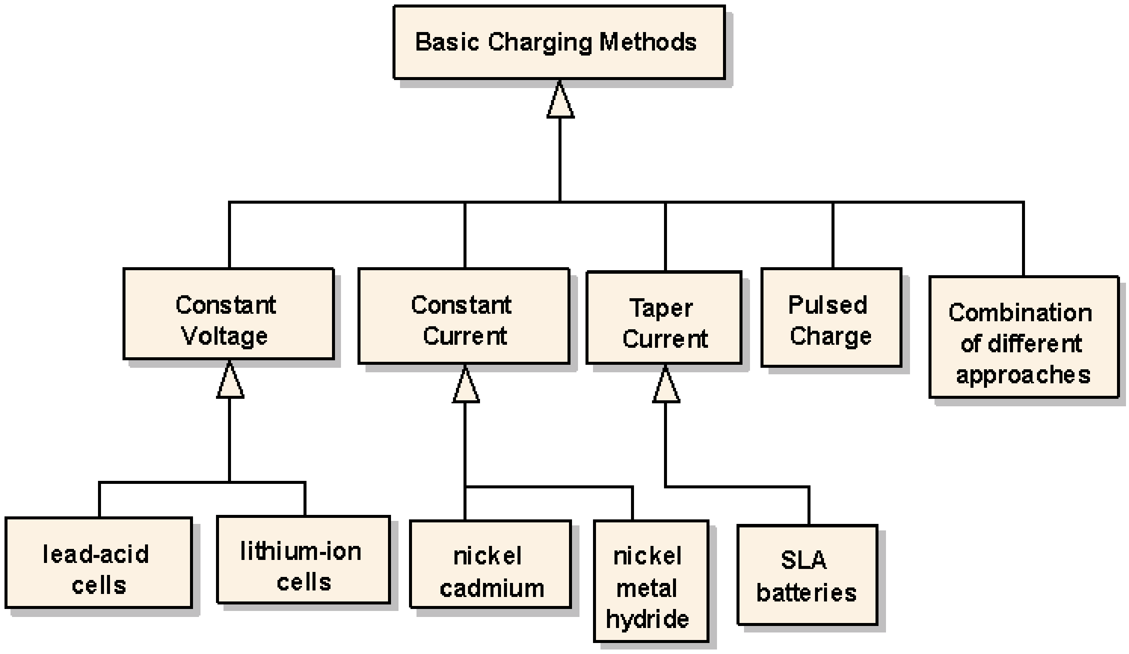


Figure 2-17: Main methods of charging EV batteries

Most EV charging systems use a constant voltage for the initial portion of the charging process, followed by a constant current for the finish. Most of the battery capacity is restored during the constant voltage portion of the charging cycle. Temperature should be controlled (in all the charging methods), and thus it is preferable to have a temperature compensated charger (the coefficient of the temperature compensation should be about +/– 18 mV/battery/°C variation, from 25°C). The charging voltage must be reduced for ambient temperatures in excess of 25°C and increased for temperatures lower than 25°C.

Three possible methods can be implemented to recharge the battery. In a charge infrastructure review, [Morrow, 2008] describes three charging "levels" defined by the US Electric Power Research Institute (EPRI):

- The level 1 method uses the US standard 120 VAC, 15 A or 20 A branch circuit, used in the residential and commercial buildings. It delivers a 1.44 kW maximum power. This method would require for the user to install a new dedicated circuit to avoid overload.
- The level 2 method is based on a 240 VAC, single phase, branch circuit with up to 40A. Under 15A, the maximum charging power would be 3.3 kW. This method could be implemented for both residential and public charging.

- The level 3 is the method suitable for fast charging through public facilities, based on 480 VAC, three-phase circuit, and enabling 60 kW to150 kW charging power. This option implies a number of specific safety precautions.

Level 2 method would be enough to ensure a "rich" charging infrastructure. Table 2-4 summarizes the technical features, infrastructure requirement:

Table 2-4: Technical features of each charging level defined by EPRI

	Level 1	**Level 2**	**Level 3**
Voltage/Current	US: 120 VAC / 15 A; EU: 220 VAC	US: 240 VAC / 40 A; EU: 240 VAC	480 VAC
Charging power	1.44 kW in US, higher value in EU	3.3 kW (15 A)	60-150 kW
Charging time for a 10 kWh battery	~5-8 hours, even faster in EU	~1-2 hours	< 10 minutes
Vehicle equipment requirement	Higher battery capacity Required. On-board charger.	High battery capacity Required. On-board charger.	Low battery capacity required
Infrastructure requirement	Cable from electricity outlet to the vehicle. New dedicated circuit.	Stationary charger. Cable from electricity outlet to the vehicle. New dedicated circuit.	Stationary charger Three-phase

Charging Infrastructure

The creation of a charging infrastructure is essential for EV market introduction. The electrical energy sector, with the help of government initiatives, car manufactures and private companies are the main stakeholders of this complex process. An encouraging framework, with clear targets for market penetration and standards for battery chargers and billing systems, are required to build-up an infrastructure and several pilot tests have been performed, most of them with governments funding's. Table 2-5: Pilot tests performed with EV charging processes, show some of these initiatives, and Figure 2-18 illustrates current public charging station implementations and forecasts for the most active countries on this business.

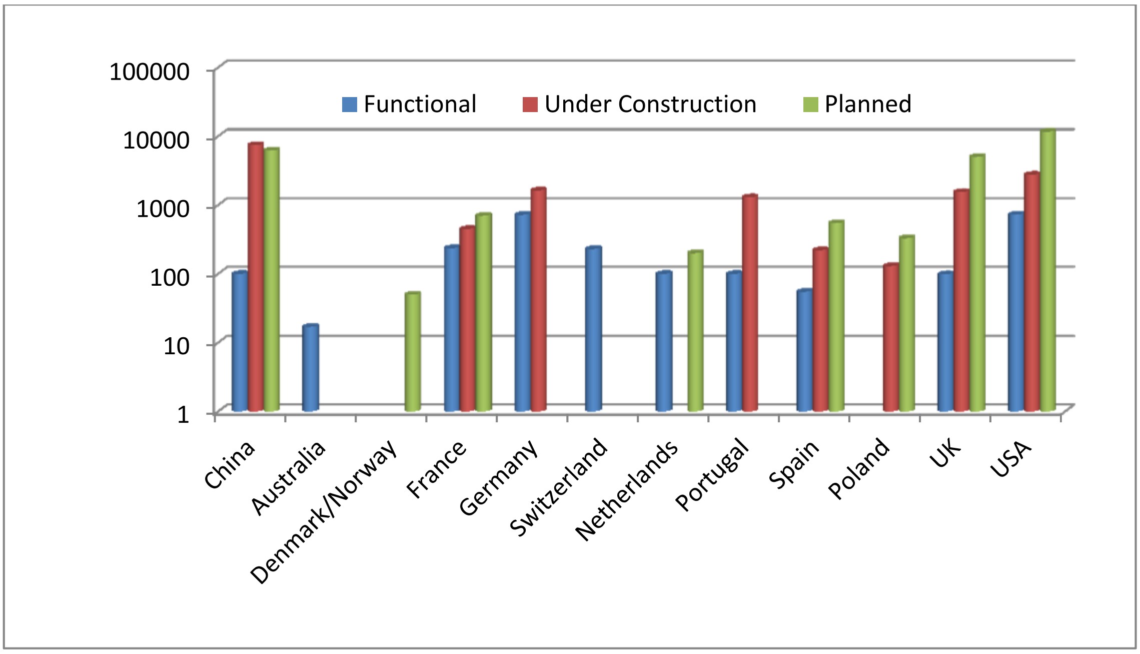


Figure 2-18: Number of Public EV Charging Stations by countries

Table 2-5: Pilot tests performed with EV charging processes (June 2011 Status)

City/Country	Description
London / UK	"Electric Vehicle Delivery Plan for London" – Mayor of London – May 2009 – building of infrastructure, EV procurement, incentives & marketing.
Singapore, Singapore	"Electric Vehicle Test Bed program" – CEO, Energy Market Authority – May 2009.
Los Angeles / USA	"Southern California Regional Plug-In Electric Vehicle (PEV) Plan" – Mayor of Los Angeles – Dec 2009 - Investment in charging infrastructure, streamlining permitting, fleet acquisition.
San Francisco / USA	9-step plan to make Bay Area "EV Capital of US" – Mayors of San Francisco, San Jose & Oakland – Feb 2009.
Portland / USA	Mayor of Sam Adams - announcement with Nissan for electric vehicle pilot Project.
Paris / France	Mayor of Delanoe announces "Autolib"15, a 4,000 EV rental program – Oct 2009.

An appropriate infrastructure provides the availability and necessary density of recharging possibilities. In a first phase, recharging places should be installed in parallel at strategic locations – including homes, workplaces and truck or bus depots – as well as on main roads: (1) identification of the early adopter hotspots and build capacity there; (2) public recharging stations (parking garage, shopping mall, Park & Ride, dedicated); (3)

parking spots along streets; (4) home/depot recharging; and (5) workplace recharging. Standardization and business models play an important role on this starting process.

There are also several federal government initiatives or projects funded by federal governments across the world. In Portugal, Renault and Nissan have signed a contract with MOBIE.Tech in 2008. The MOBI.E [http://www.mobie.pt/] network has installed 100 charging stations and it is deploying 1,300 charging stations as well as 50 fast-charging stations in 25 cities up to June 2011, [http://www.mobie.pt/]. The MOBI.E stations work with magnetic stripe card and bills are sent to the cell phones of the users. In Singapore, a US $ 99.8 Million stimulus grant was awarded. In the USA, the government of Arizona launched the ECOtality program, for an EV test pilot across 5 USA states, involving the deployment of up to 4,700 Nissan LEAF EV and 11,210 charging stations. In September 2009, China & the USA announced the launch of the US-China EV Initiative under which both countries would work together on standards development, demonstrations, a technical roadmap, as well as public awareness and engagement. Governments are not alone in showing increasingly high levels of activity in what regard to EV. Almost all large OEMs have by now announced EV prototypes, models, or even concrete dates for launching EV models in the market. Nissan launched its LEAF electric car in 2010, and Renault Fluence is in the reservation phase. GM, Ford, Volkswagen and BMW have not only shown prototypes of full EV, but also have announced concrete launch dates. Even Porsche, a sports car manufacturer, has recently shown its first EV prototype. The automotive supplier industry is also jumping on the bandwagon. First, tier suppliers, like Valeo and Bosch, are announcing EV products, and are joining forces with battery manufacturers, or are publishing white papers that take a bullish position on EV adaptation. Even consulting companies seem to believe that EV is a defining topic for the future of the car industry – both McKinsey and the Boston Consulting Group have recently released extensive studies on the EV market [http://online.wsj.com/public/resources/documents/mckinsey_electric_vehicle_ 0113.pdf] and [http://www.bcg.com/documents/file36615.pdf].

Infrastructure providers companies start to emerge proving charging stations, products and works related to EVs. Examples are:

- In the USA: Coulomb Technologies, Better Place, EV-Charge America;

- In Europe: Park & Charge, Circontrol, POD Point, Efacec, Magnum Cap, Cabelt.

A uniform worldwide charging infrastructure is necessary (interoperability), where should be possible to charge electric vehicles everywhere, at any times. User interests must have priority over the interests of individual companies.

Information System for EV Charging Process

EV charging process (remote interactions, power limitations of home consumer or electrical distribution network), integration of renewable energy resources, and electricity market, raise a complex environment where mobile information systems can play an important role. In author opinion this is a rich scenario similar to the Internet. This information system can play an important role by automatically managing the charging process, maximizing the use of renewable energy, such as wind energy, which is generally strongest at night when demand is low, which can enable customers to schedule charging based on price signals, allowing EV owners to reduce their cost of charging, and also permitting them to specify the use of renewable energy only for charging the EVs, what can incentive future EV sales. Through these systems, customers will be able to monitor and manage charging online, from within the vehicle's information system, and through mobile devices. Initial information systems will focus on collecting data and presenting it to consumers, but once charging infrastructures are growing, and communication standards between EV and external systems are defined, a diversity of applications could be created to help EV drivers. The understanding of the benefits of Information Systems for EV across all aspects of grid operations, including load management, use of renewable energy, and avoidance of capital investment in generation and transmission equipment, are not well known today, yet. Greater knowledge of the lifetime value of EV IT (Information Technology) systems, including the financial benefits from reducing carbon emissions, would make it easier for utilities to justify the investments. Also, a study [Pikeresearch, 2010] shows that this market has a huge growing potential. EU opens a tender call (May 2011) for the study of "The impact of ICT R & D in the large-scale deployment of the electric vehicle SMART 2011/0065". A preparatory study to EU is open (May 2011) [Tender, 2011] for future definition of new FP7 calls on this new topic.

The implementation of information systems for EV will be slowed down by the lack of standards for sharing information between utilities and external systems. The automotive, home networking, Smart Grid, and utility industries are collaborating with organizations, such as the National Institute of Standards and Technology (NIST), in developing standards to establish first-time interoperability with grid equipment, and many of these standards will not be completed until 2012, or later. The participation of utilities, automakers, and dozens of other stakeholders in the development of the standards will extend the ratification process.

The lack of standards today will encourage many companies to hold off on investment until interoperable products are released. Some of these systems will share information over the Smart Grid's emerging Advanced Metering Infrastructure (AMI) platform, but that infrastructure is not yet available in many service territories. Utilities that are deploying AMI and other Smart Grid technologies are likely to incorporate information systems for EV IT into their overall Smart Grid rollout schedule.

2.4.3. EV Utilization Characteristics

This Section describes the characteristics of the EV batteries and the utilization of the EV. The two fundamental characteristics of EV, which have interest to this work, are that they are vehicles and that their batteries can both generate and store electricity. As vehicles, they are used for transportation purposes at certain times and may be parked at other times.

We take advantage of the fact that, as various studies indicate, commuter vehicles remain parked on average 22 h a day, and that the driven distances do not exceed 80 km on average, which allows harnessing the EV batteries for effective deployment when connected to the electrical grid (returning part of the stored energy back to the grid when it is desired by the electrical system). We use the State of Charge (SoC) of each EV battery pack to determine its capability to provide services on supplying energy to the grid. We also provide the motivation for the need to aggregate EVs together to create a controllable load or generation/storage device of significant size on the power system scale.

As vehicles, EVs are not always stationary and therefore may be dispersed over a region at any point in time. In a moving state, EV may be used for commuting purposes or, possibly for longer trips – if the battery capacity is large or if the EV is a PHEV (Plug-in Hybrid Electric Vehicle). Our focus in this study is on the use of EV for daily commuting purposes.

Based on a review of the literature, participation in committees, meetings, discussions, and task forces devoted to this topic, and also on empirical evidence, the present work choses as indicators of transportation sustainability these five consequences: safety, traffic congestion, fuel consumption, vehicle emissions, and accessibility. Clearly there is room for discussion and debate on these choices.

SOC (State of Charge)

A critically important parameter is the State of Charge (SOC) of the batteries. SOC is defined as the ratio of the energy stored in a battery to the capacity of the battery. It varies from 0, when the battery is fully discharged, to 1, when the battery is fully charged, and provides a measure of how much energy is stored in the battery. It is often expressed in percentages, as a variation from 0 to 100%. The SOC typically decreases when energy is withdrawn from the battery and increases when energy is absorbed by the battery. Thus, for a day during which the EV owner goes to work in the morning, parks the EV, goes back home in the late afternoon, and then plugs-in the EV for charging during the night, the SOC will evolve along a pattern illustrated in Figure 2-19.

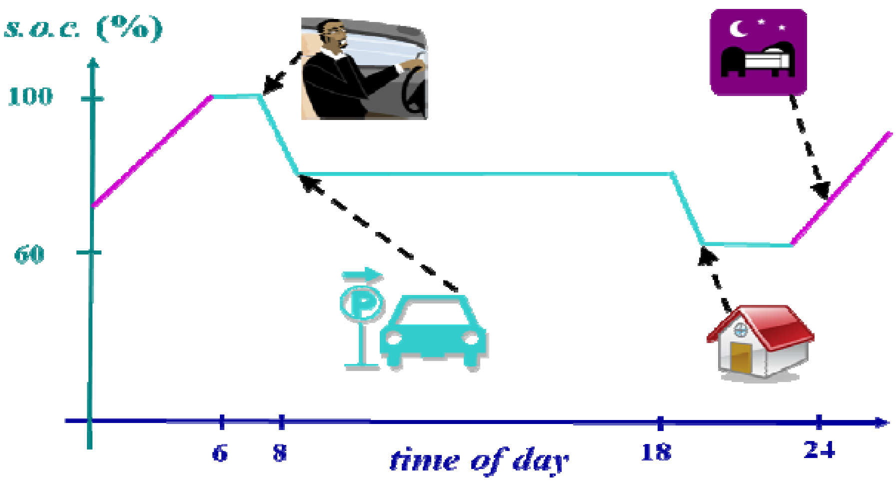


Figure 2-19: Evolution of the SOC of an EV battery pack for a typical day [Guille, 2009]

Batteries release energy more easily when their SOC is high or, more precisely, above a tolerance level. We stipulate 60% to be the tolerance level in this work. When the SOC is lower than 60%, a more appropriate utilization of this battery is for energy absorption (recharging of the batteries). Also, overall battery performance for either absorption or release is much higher in a band around this tolerance level [Yamane, 2002]. The width of this band is not well understood and so it is still a topic of research. If the battery releases energy, then the EV acts as a supply-side resource. If it absorbs energy, the EV acts as a demand-side resource. We can view the battery to represent supply and demand side resources as a function of the SOC. Figure 2-20 summarizes this information.

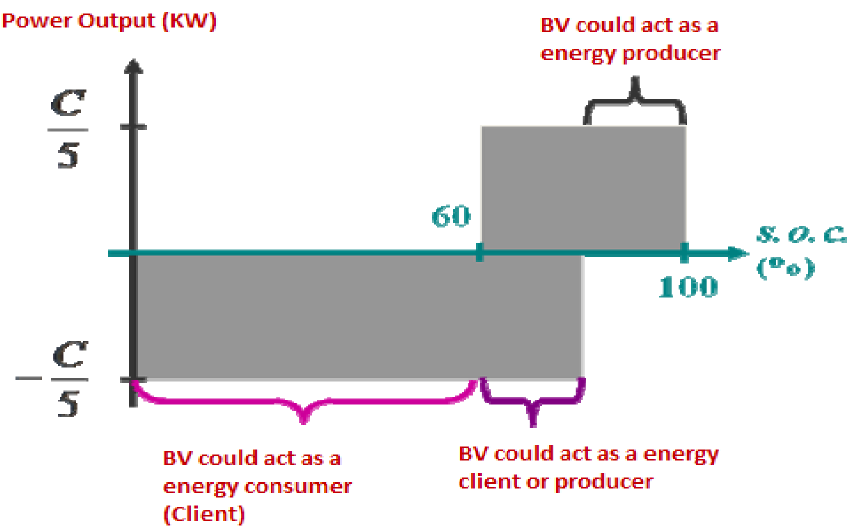


Figure 2-20: The SOC determines the functioning of the battery [Guille, 2009]

Frequent switching of the SOC may cause a decrease in battery storage capability, which is defined as battery degradation. We use the value of the SOC as the determinant decision to optimize the performance and also to decrease the battery degradation. For example, the charger of a EV battery can be programmed to stop drawing current when the SOC level reaches 85 or 90%. If such appropriate rules are used, the battery life can be quite longer. Some firms – A123Systems for example – claim that the manufacturing of batteries with 10-year lifetimes is currently feasible.

Battery degradation is also a function of the depth of the discharge and of the frequency of the fluctuations of the stored energy. In a study presenting the results of a V2G test for frequency regulation, the investigators noticed that, at the end of a one week test, the capacity of the tested battery had increased [Broks, 2002]. Their explanation is based on the fact that very small amounts of energy were concerned and that the frequency of the variations (fluctuations of the stored energy) was high.

In theory, once plugged in to the electrical grid, EV batteries may be used as distributed energy resources. However, the maximum capacity of energy storage of a typical EV battery pack is rather small. Such a small energy source cannot make any impact on the grid scale on its own. Thus, an EV appears simply as “noise” in the power system at the grid level. For the EVs to be a useful energy resource, a degree of aggregation is required to bring about a size that can impact the grid.

Range anxiety Problem

Range anxiety is a term mostly associated with EV in the context of their limited range and underdeveloped infrastructure of charging opportunities [Wellings, 2011]. In general terms, range anxiety can be explained as the fear of a possible negative future event. It is believed that range anxiety was first reported in the press in 1997. Range anxiety is, in many ways, an intuitive term which are most often defined as perceptions or the experience of drivers regarding the fear of not reaching your destination when you are in an EV. Some definitions refer to the problem of recharging the EV, that is, the phenomenon may not only relate to the occurrence of the particular situation but also to the available actions needing to be performed when in a situation in which the destination can no longer be reached. A summary of most used definitions is presented in table 2-6:

Table 2-6: Definitions of range anxiety

Reference	Definition
[Tate, 2008]	their [road users] continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle
[Agassi, 2009]	“range anxiety,” the driver’s fear of reaching the end of the charge and not being able to goanywhere for hours
[Brady, 2010]	”range anxiety, which describes the apprehension arising from the relatively high likelihood that the vehicle will run out of power before reaching a destination, and is described as being similar to the anxiety experienced when driving a combustion engine vehicle which is low on fuel with the nearest fuel station a significant or unknown distance away
[Wynn, 2009]	People are concerned that electric vehicles cannot travel far enough on a single charge, and they may have difficulties recharging. Additionally, they are concerned about the time required for a charge, and the potential

	inaccessibility of charge stations
[Philip, 2010]	Range anxiety is the fear of being stranded in an EV due to inadequate battery capacity / performance … As explained previously, range anxiety is the psychological phenomenon where people are afraid of running out of charge on a highway and want the assurance that in this case a charging station is close by. It is important to note that range anxiety is not describing the actual charging process for such a case – but people being afraid from such a hypothetical case and therefore demanding a certain kind of charging infrastructure, even though they might not actually use it.
[Wellings, 2011]	fear of running out of charge

2.4.4. Standardization Process

Standardization in the field of electromobility is characterized by several features distinguishing it from previous standardization processes (involves several different areas). Here, the challenge lies in coordinating and integrating diverse activities in different sectors in order to effectively meet demands. Electromobility is a breakthrough innovation that requires a new, cross-sectoral systems thinking. Up to now, standards in the electrical engineering/energy technology and automotive technology domains have been viewed as separate entities. So far there has been little attempt to view them in an integrated manner, although this would be an important approach, particularly because these domains are merging, resulting in new points of contact and interfaces.

This Standardization Roadmap reflects the general agreement among all actors in the electromobility sector – including automobile manufacturers, the electrical industry, energy suppliers/grid operators, technical associations and public authorities - that a strategic approach to standardization of electromobility is needed.

Standards and specifications are developed at various levels (national, European, international) in a number of different organizations (because EV involves several areas: automobile, electrical and telecommunication). To provide a better understanding, an overview of the various standards organizations and their interrelation is given below. ISO and IEC, which constitute the main standardization landscape for this Roadmap, and their counterparts at European and national level, are described in more detail. Figure 2-21 shows the relationship between the various standards organizations, together with their regulatory bodies. Also different approaches are taken in different regions: North America, Europe, Asia and others.

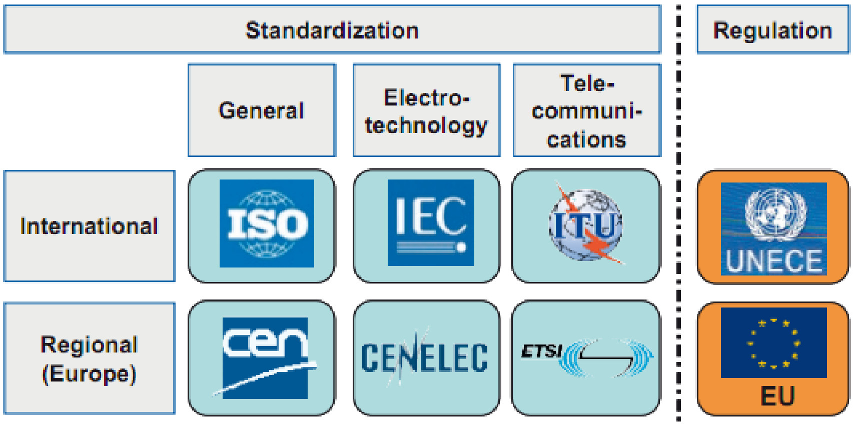


Figure 2-21: Main components of the standardization landscape and their interrelationships together with their regulatory body

In terms of full consensus-based standardization ISO, IEC and ITU-T are the authoritative standards organizations. The corresponding standards organizations at European are CEN, CENELEC and ETSI.

Society American Engineers (SAE) is an organization that develops documents (standards) which are not based on full consensus, and is represented mainly on the American continent.

Standardization is a central factor for disseminating electromobility, in addition to road vehicle engineering, energy supply, and the associated information and communication technologies. The automotive engineering, electrical engineering/energy technology and information and communication technology (ICT) domains which up to now have largely been considered separately need to converge if electromobility is to be a success. The Standardization Roadmap for electromobility presented here is part of this strategy and embraces immediate standardization needs at one end of the scale and long-term standardization activities at the other, as well as the need for research. System components, domains and subsectors relating to electromobility standardization are shown in Figure 2-22.

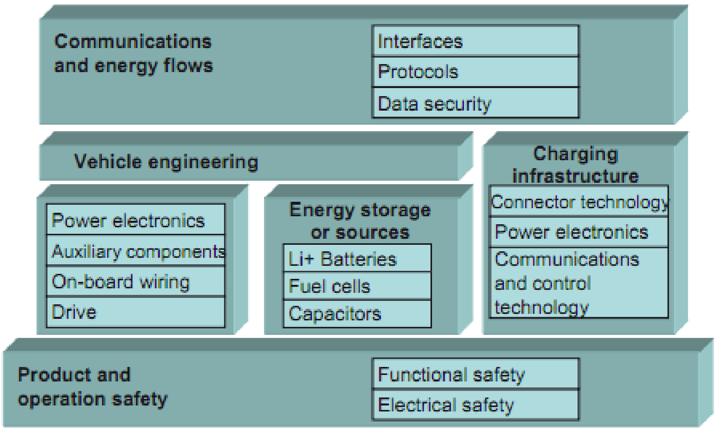


Figure 2-22: System components and domains relevant for standardization [Elektromobilität, 2010]

Broadly speaking, the various stakeholders can be assigned either to the "vehicle" or the "charging infrastructure" domain, as shown in Figure 2-23. In this figure the battery is depicted as a separate component, since it can be assumed that this branch of industry will play a particularly significant role, and services dealing specifically with batteries will emerge.

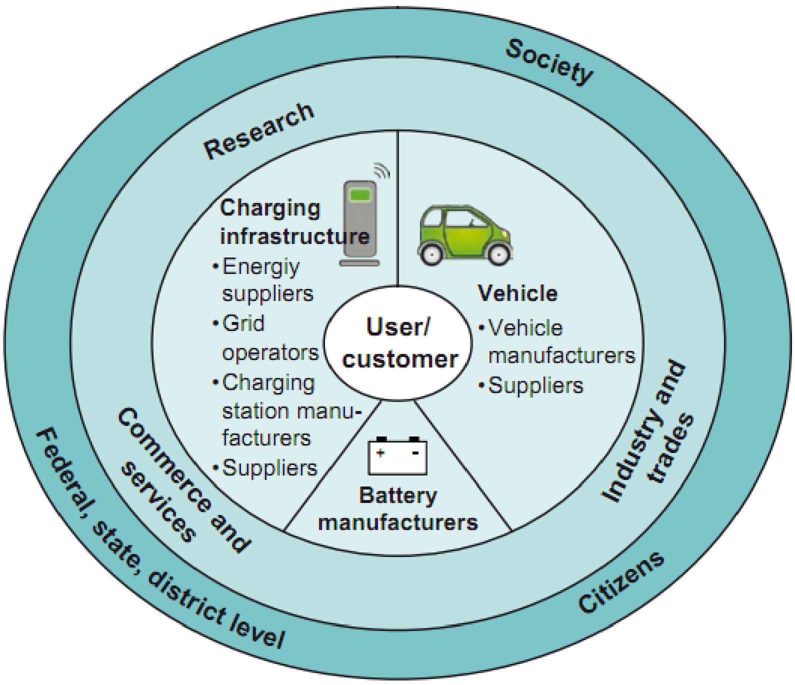


Figure 2-23: Electromobility Stakeholders

Electric vehicles and the Smart Grid electromobility offers the unique opportunity of combining the advantages of environmentally-friendly mobility with an efficient, optimized utilization of electricity supply grid resources and sustainably generated electric energy. This gives rise to a number of special requirements, particularly on the technology used and on standardization of the interface between electric vehicles and the grid. The development of standards is a fundamental success factor for the numerous application cases for the battery charging process. The various application cases are described below:

- Charging – Charging location: (1) Private (e.g. garage), semi-private (e.g. company yard), public or semi-public; (2) Parking lot or charging station; (3) home, with a normal single-phase (a.c.); and (4) While travelling (fast charging).
- Charging – Charging functions: (1) a.c. charging with currents up to 16 A (normal charging); (2) fast charging, a.c./d.c.; (3) Conductive (cable-bound) or inductive (wireless); (4) With or without communications path for individual billing or for negotiating electricity rates; (4) With or without load management (Home, SG); and (5) Grid interaction.
- Vehicle functions while connected to stationary grid: (1) Charging process monitoring; (2) Temperature control of battery and/or the vehicle interior while vehicle is stationary.
- Billing: (1) Without separate billing (billing as part of the "normal" electricity bill); (2) With a separate cumulative bill (separate meter); (3) With a separate detailed bill (comparable to a "fuel card"); and (4) With direct payment (cash, electronic).

Furthermore, from the viewpoint of energy suppliers and grid operators, the system must be linked to the smart grid. As a result, other load scenarios and grid integration will evolve in addition to the conventional "charging" scenario. Other scenarios are imaginable, as the examples in Figure 2-24 show. The Figure 2-24 shows from left to right, an increasingly close integration of the electric vehicle into the Smart Grid and ways of providing the respective grid services. In terms of systems theory, each of these variants represents a control loop for optimizing consumption (loads) and/or the feedback of energy into the grid. With the "price management" method, the current electricity price and/or the remuneration for energy fed back into the grid is the "control parameter" for consumption and feedback, whereas the "load management" and "grid integration" methods make explicit control possible.

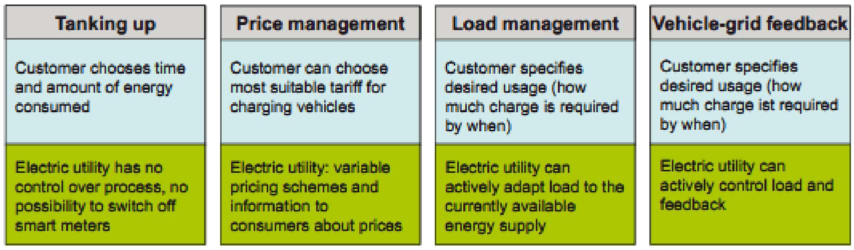


Figure 2-24: Various scenarios for integrating EV charging into the SG [Elektromobilität, 2010]

Charging stations can be installed in private, semi-private, public and semi-public areas. Depending on the location and the range of functions to be provided, several different functional units will be required. Figure 2-25 shows a block diagram of a charging station.

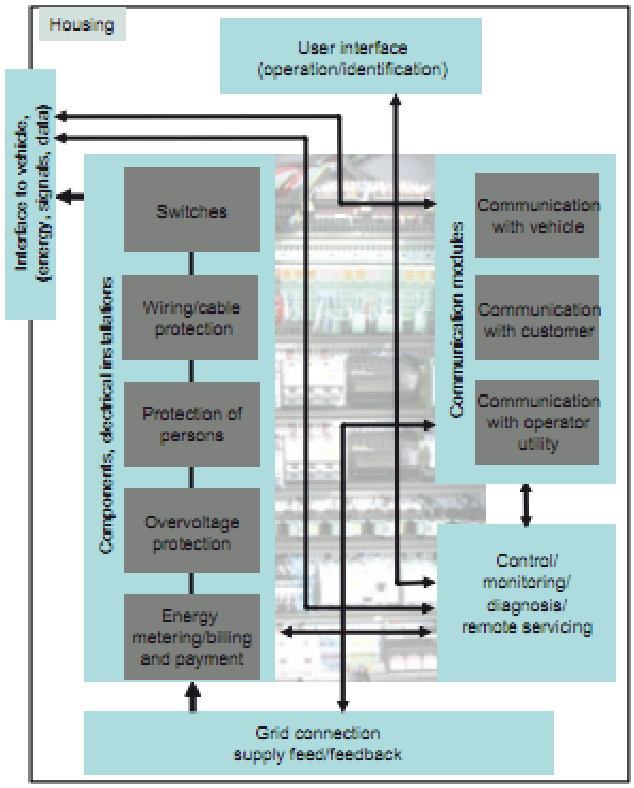


Figure 2-25: Block diagram of a public station for conductive charging of electric vehicles [Elektromobilität, 2010]

Depending on its location and the charging modes, a charging station must support different combinations of functions and meet various requirements. The following aspects need to be taken into consideration: (1) Energy flows; (2) Control/safety; (3) Communications ; (4) Accessibility; and (5) Value-added services.

2.5. Computer Science Related Topics

2.5.1. Mobile Devices

Worldwide the mobile phone sales to end users was 314.7 million units in the first quarter of 2010, a 17 per cent increase to the same period in 2009, according to Gartner, Inc. Smarpthone sales to end users reached 54.3 million units, an increase of 48.7% compared to the first quarter of 2009 [Gartner, 2010]. Most of these devices are equipped with GPS systems and have data communication capacities. So these devices have a big potential in mobility process, because they can give access to the users to important information in real time during users' journey. Also, if they will interact with EV charging devices, using communication potential, they can co-relate information, storing transactions in a central repository, and enquiry this database to obtain useful information.

2.5.2. Social Networks

Since its creation, the Internet has spawned many information, sharing networks, the most well-known of which is the World Wide Web. Recently, a new class of information networks called "online social networks" has exploded in popularity and now rivals the traditional Web in terms of usage. Social networking sites, such as MySpace (over 246 million users), Facebook (over 500 million users), Orkut (over 67 million users), and LinkedIn (over 9 million "professionals") are examples of wildly popular networks used to find and organize contacts. Other social networks, such as Flickr, YouTube, and Google Video, are used to share multimedia content, and others, such as LiveJournal and BlogSpot are used to share blogs.

Unlike the traditional Web, which is largely organized by contents, online social networks embody users as first-class entities. Users join a network, publish their own contents, and create links to other users in the network, called "friends". This basic user-to-user link structure facilitates online interaction by providing a mechanism for organizing both real-world and virtual contacts, for finding other users with similar interests, and for locating content and knowledge that has been contributed or endorsed by "friends".

Communities are interesting for a variety of reasons. For example, users in a community tend to interact frequently, often share interests, and trust each other to some extent. Therefore, communities are useful, for instance, for guiding information dissemination and acquisition, in recommending or introducing people who would likely benefit from direct interaction, and in expressing access control policies.

In this Section the main objective is to give a small description of this new reality, showing its huge potential.

2.6. Related European Projects

2.6.1. Public Transport Information Integration

Public transport information integration is one specific area, for which there is still lack of EU level data integration among different public transportation organisms. The European Commission has sponsored a series of recent projects which have succeeded in moving forward the state of the art in the provision of multimodal traveler information. Each project was built on the foundations of the projects before them, which include:

- ITISS (INTERREG IIIB) - developed the provision of real time information to travelers on the move through mobile devices (2003-7);
- SIMBA 2 (FP7) - sought to increase road transport research cooperation between Europe and the emerging markets of Brazil, China, India, Russia and South Africa by establishing a network of stakeholders in the field of Intelligent Transport Systems (ITS);
- eMOTION (FP6) - was a study to investigate, specify and assess multi-modal, on-trip Traffic and Travel Information Services for European travellers (2006-8);
- WISETRIP (FP7-SST) - developed a platform for the provision of public transport multi modal travel information between EU and Chinese partners (2008-10);
- OPTI-TRANS (FP7) - developed a mobile platform for travellers to plan their journeys using public and private transport (2009-10);
- IN-TIME (ICT-PSP) - focuses on the delivery of multimodal Real Time Traffic and Travel Information services to European travellers (2009-11);
- START (INTERREG IVB) - developed a trans-European information portal to enable cities/regions to provide multi-lingual information to travellers, perform simple route planning from region to region, access detailed planning tools and Public Transportation operator's data (2006-2011).

Additionally the EU ITS Directive 2010 requires member states to deliver a number of systems according to the ITS Action Plan. These systems include provision of Multi Modal Traveler Information Systems by 2015.

2.6.2. EV Energy Consumption and Management

ICT and smart systems will facilitate the EV integration with the sustainable mobility initiatives under the motto "Smart Cities", where the integration of information regarding the public transportation services will play an important role.

The application of ICT R&D in the large-scale deployment of the EV is a new challenging topic with a huge growing potential, and this study impact is an important task to prioritize and evaluate the diversity of options. The integration with renewable energy resources (Europe is leading this subject) could play an important role in this process and could be a key for Europe to recover some delay from Asia and North America in the EV areas.

The European Commission has sponsored a series of recent projects that contribute for the application of ICT in EV:

- EcoGem aims providing efficient ICT-based solutions to assist EV driver to increase range autonomy and energy efficiency through learning over time to predict (and thus avoid) congested and energy consuming routes, based on experience that they gather. This learning process will render each EcoGem EV capable of autonomously classifying routes according to their degree of energy efficiency, enabling energy-driven route planning optimization and extending considerably EV efficiency and range of operation.
- OpEneR addresses the problem of range anxiety with a proposal range increase based on efficient energy management. A particular focus will be given to an optimal cooperation between the electric drivetrain and the regenerative braking system, supported by data from radar, video, satellite navigation, car-to-infrastructure and car-to-car systems.
- ELVIRE addresses the problem of range anxiety based on a collaborative platform between driver and charging infra-structure. Great emphasis is placed on the openness of the electricity service platform, granting access to multiple players and maintaining the customer's choice.

- P-MOB project aims to break the link between the growth in transportation capacity and increased facilities, congestions and pollution. The project proposes a novel concept of fully-electric personal mobility, addressing the needs of urban mobility whilst also encompassing characteristics suitable for extra urban mobility; reduced system complexity (a common car can have more than 50 processors, actuators and sensors), with a focus on the key essentials, and advanced systems integration, including: thin film solar cells.
- Several projects on charging and infrastructure interaction: PowerUp, SMARTV2G.

2.7. Conclusions

In this Chapter it was researched and analyzed the state of the art of related topics. Due to the diversity of subjects involved, electrical energy, markets, transportation and computer science, a brief approach was applied. Main topics were covered, such as, EV types, batteries, charging process, standardization, EV usage, electricity market participation (identification of potential interesting topics), and electrical distribution networks. Since communication and telematics issues are not part of this work, no state of the art study was performed on these topics.

3. MOBI-SYSTEM: EV RELATED FUNCTIONS

This Chapter, as said before, is dedicated to the central Mobi-System functions, related with the EV charging process. The main EV function modules are illustrated in Figure 3-1, and each of them is described in this Chapter Sections.

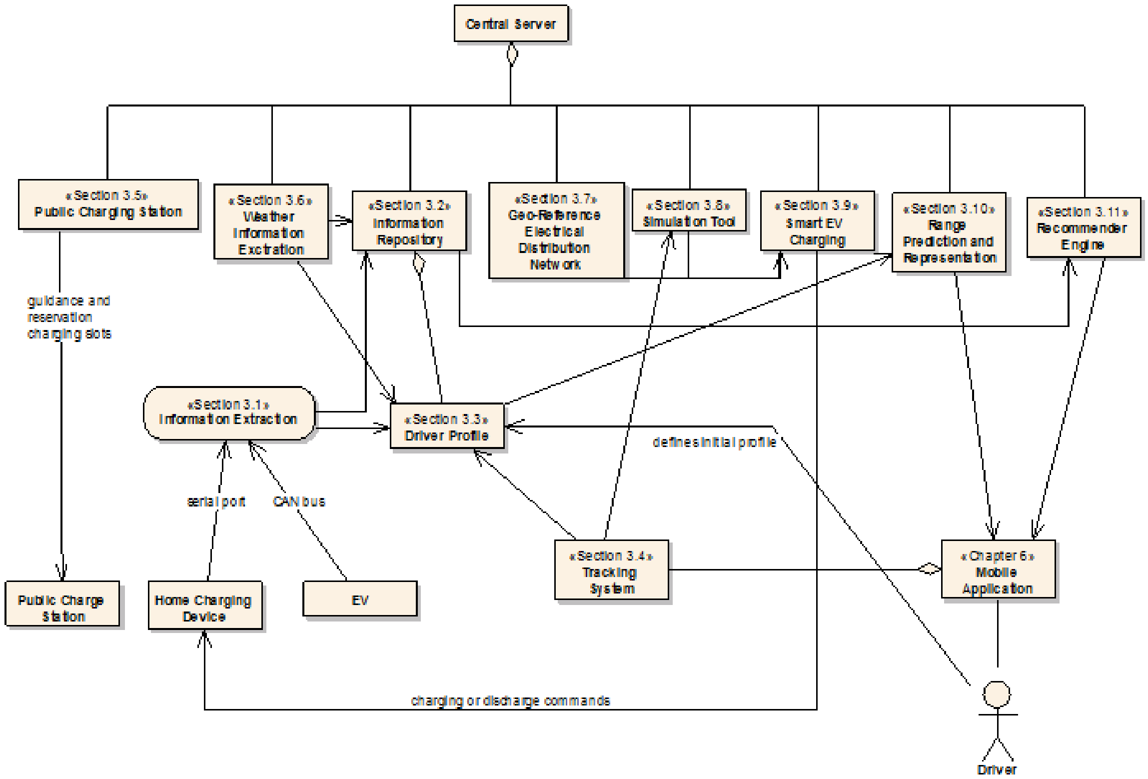


Figure 3-1: EV functions main modules

3.1. Information Extraction from EV and Charging Device

This module is based on two equipment, with wired and wireless communications interfaces, allowing access information for two different scenarios/systems: EV and Home Charger Device. Providing relevant data from EV and charging spots to the platform, these devices integrate Charger Systems and EVs with the Mobi-System, enabling intelligent and opportunistic EV charging management, and providing useful information for each driver according to her/his needs. Main information extraction is the charging log file performed by charging devices, the information from EV and the commands to the charging device (Figure 3-2):

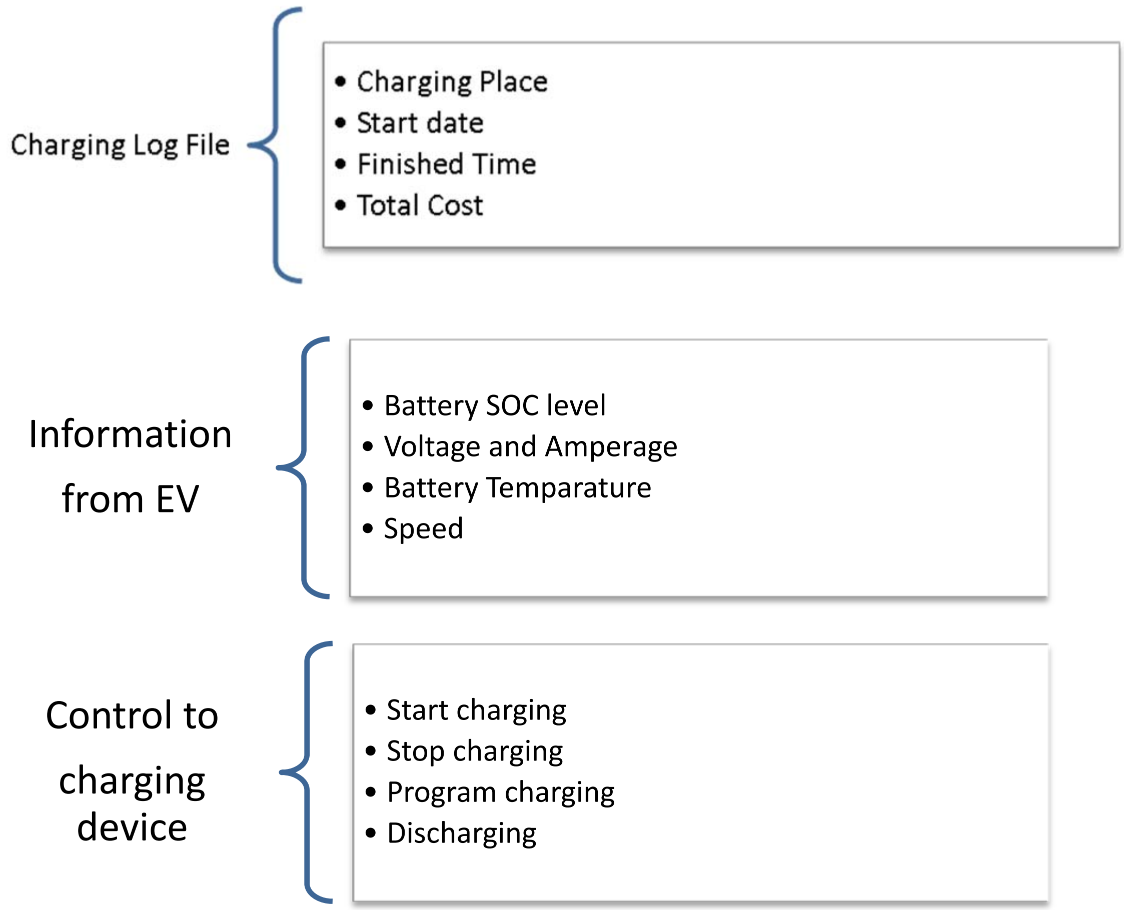


Figure 3-2: Main information to extract and commands to perform on charging device

Analyses of transactions data can be useful information for future charging or discharging processes, taking into account a smart charging strategy to combine distribution network limitation and low prices. All this information is stored on the information repository on the central server.

If Internet communication is available, the driver can check remotely the home charging process, and interact with it if he wants to.

3.1.1. Development of the OBU (On Board Unit)

This task consists in the development of an OBU (On Board Unit) working prototype, including hardware and software, to be installed on-board in the EV, providing telematics both locally (in the EV) and remotely (to the Mobi-System). The device is based on a microcontroller that integrates CAN, Bluetooth, GSM/GPRS (Global System for Mobile communications / General Packet Radio Service) and GPS (Global Positioning System). The implementation of CAN protocol allow requesting and receiving data from the car. With the available OBU wireless communications interfaces, it is possible to report both locally and remotely the data being received from the EV through Bluetooth and/or GSM/GPRS technologies, respectively. Moreover, Bluetooth allows the OBU integration with mobile equipment, such as a mobile/smart phones. Additionally, and by having knowledge of the EV current coordinates (GPS receiver), the OBU is able to make the best decisions through the platform. GPRS allows the development and implementation of the OBU update over the air, increasing the easiness with which software updates are made. This work was performed by an ISEL (*Instituto Superior de Engenharia de Lisboa* – Lisbon Superior Institute of Engineering) partner company (Dailywork), in an ISEL electric car project (Veeco - Veículo Eléctrico Ecológico – Ecological Electric Vehicle). Due to confidentiality agreements signed in Veeco project, it is not possible to provide more detailed information. Also, this task was not easy to be performed due to missing information provided by the electric motor manufacturer company. This work was part of a student final year project in ISEL, where Figure 3-3 shows the main results achieved: the extraction and visualization in real time of Veeco information.

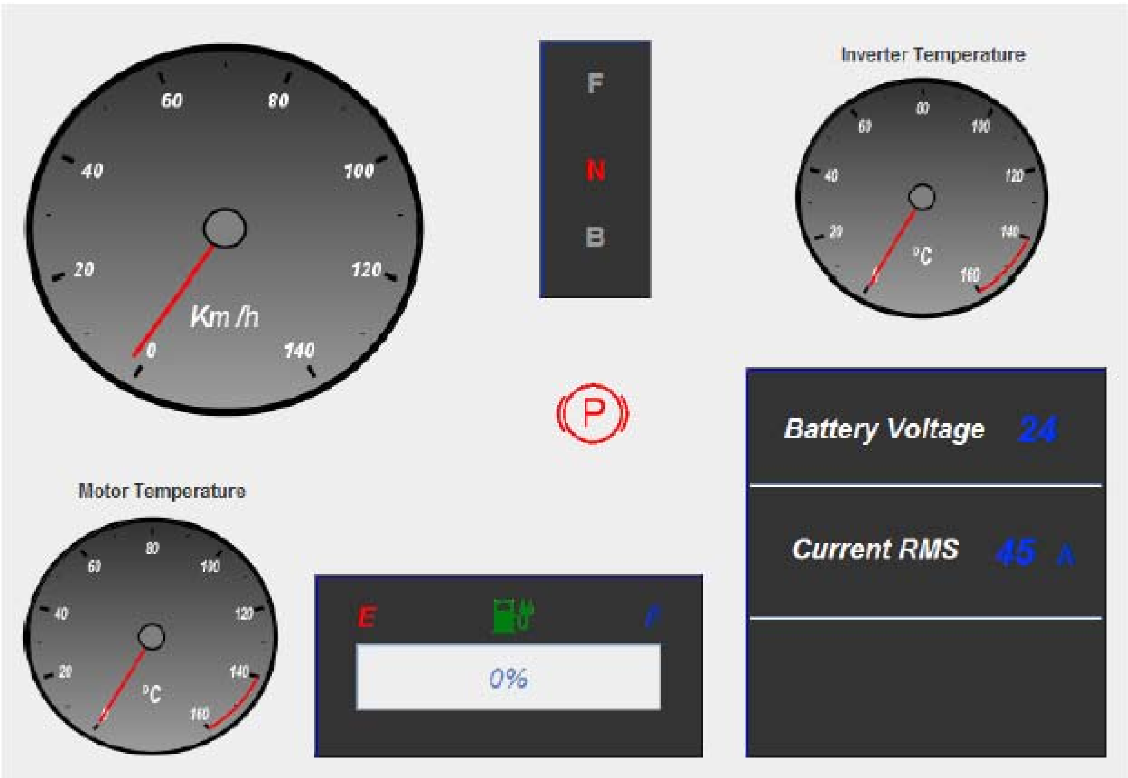


Figure 3-3: Visualization of Veeco extracted information in an external laptop [Geada, 2011]

3.1.2. Development of the RSU (Road Side Unit) Located on Charger System

Currently, a charger system is an equipment which only has in consideration the EV batteries charge level. This task aims to develop a RSU (Road Side Unit) which interacts with the different blocks that constitute the charger system to provide more information to the EV driver and to the Mobi-System. It can provide the SOC (State of Charge), the charge remaining time, the efficiency of charging, as well as other data.

In this task, it is developed the RSU, a prototype including hardware and software to be attached to the charger system, providing telematics, both locally and remotely. The RSU device integrates Bluetooth, GSM/GPRS and charger information. The available RSU wireless communications interfaces allow to report locally and remotely the charger system information data. As for the OBU, Bluetooth allows the integration of RSU with mobile equipment, such as a mobile/smart phone, and GPRS allows the development and implementation of the RSU update over the air, increasing the easiness of software updates.

3.2. Information Repository

The Central Information Repository stores EV related information, namely: (1) EV drivers profile; (2) electricity transactions of EV; (3) electricity prices; (4) weather information; (5) driving parameters; and (6) other EV related information. For detail information see corresponding Sections.

This Central Information Repository is based on XML files and a Mysql database implementation. Since our goal was the creation of a prototype, not a commercial application, this subject was not tuned for best system performance, but only for testing purposes.

3.3. Driver Profile

Initial driver profile is manually created by the driver, with the following information (Table 3-1):

Table 3-1: User Profile of an EV

Propriety	Description
User login information	User name and password
Drivers information	Driver Name, birth date, sex
Home Address	GPS position of home address
Work Address	GPS position of Drivers work
Car Information	Model, Year, Battery type and power
Energy market behaviour	Minimum SOC level, price to sell and to buy
Trip information	Work days or weekend + holidays, start time, finish time, distance (km)

Driver is allowed to perform the following operations (Figure 3-4):

Figure 3-4: User Profile Operations

This profile, later receives information about driver trip (time, duration and km travelled) from the tracking system. Also, home simulation module creates an electricity load profile (see Section 3.8) that is associated with this profile. A resume of EV parameters (speed, SOC level, travelled distance) is also stored and associated with this profile for later range prediction (see Section 3.10).

3.4. Public Charging Station

Public Charging Station (PCS) main module goal is the driver guidance towards nearest PCS, and the enable of on line advanced booking of charging spots. Due to missing standards communication formats, the system developed in Mobi-System uses KML3F5 file or compressed KMZ, to receive data from charging stations. In this file format EV position is defined, but in this work it is necessary additional information (see Figure 3-5):

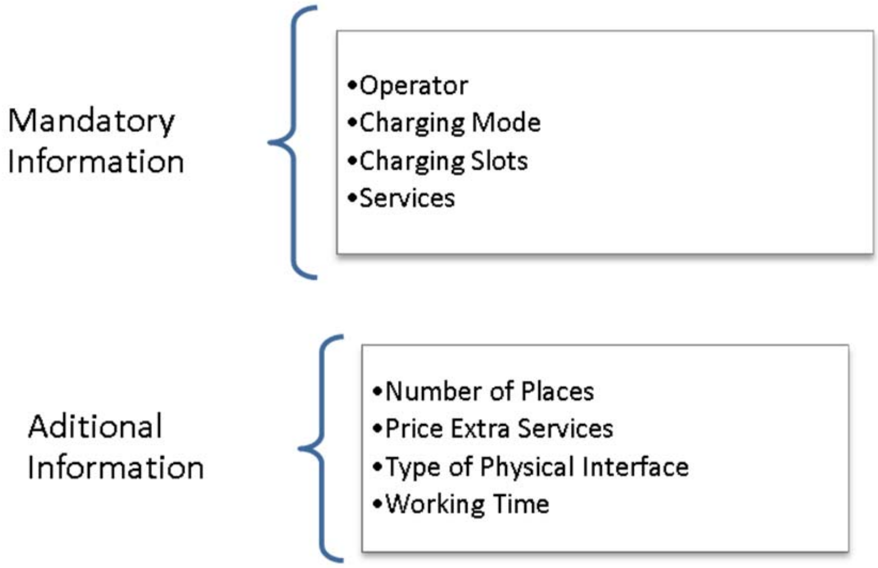


Figure 3-5: Fields of KML file for information exchange with charging station

The system developed for Mobi-System receives GPS coordinates of EV position and finds the nearest charging stations, showing the distances to them and giving guidance to the driver using Google Maps API (see used case in Chapter 6).

The booking slot process is complex, because batteries charging process takes more time than a usual gasoline deposit fill up, and a pre-reservation system should help on this process. So our proposal is a system for management of reserves (*Sistema para Gestão de Reservas* - SGR), that allows driver's mobile devices to communicate and performs reservations. To communicate with the SGR should be used a technology that allows synchronous communication. The Mobi-System is prepared to communicate with the SGR with a WebService. The SGR responds to mobile device communication response with a reservation confirmation, or with a warning indicating the unavailability of slots. One of the issues that arise when proposing an SGR is the possibility of drivers failed to

[5] **Keyhole Markup Language** (**KML**) is an XML schema for expressing geographic annotation and visualization within Internet-based two-dimensional maps and three-dimensional Earth browsers. KML was developed for use with Google Earth.

attend on time (or even didn't show) to a reserve performed. The SGR must implement mechanisms to minimize the impact of slots are being reserved, and then run out by failure of the driver. One possible solution is to implement a scoring system, which penalizes drivers with one point in their record when they fail to reserve a charging slot. When the driver reaches three points, equivalent to three failures, the driver has to go to an operator and try to reactivate his/her access to the SGR.

Figure 3-6: Image of a Public charging infrastructure (source from www.ekomiko.pl). Available charging spots could be a problem since fast charging takes time (more less 10 to 30 minutes (it depends applied power and desirable SOC level))

The diagram in Figure 3-7 illustrates how the SGR can be implemented with a system of penalty points. The information is centralized in the SGR, communicating with all operators, which also allows the exchange of information on penalty points, making the system more efficient. The SGR is prepared to follow a business model which is implemented with a slot reversion, failures penalties and a waiting of reservations of 5 minutes (administrator configurable time). The same approach and software module is used for parking places reservation. There are several issues related with PCS (Public Charging Station), which are not covered in this work: infrastructure creation, standardization, electrical energy network distribution (high power). In a PCS service, it is not used the previous module of smart charging, because should exist power limitation on charging process.

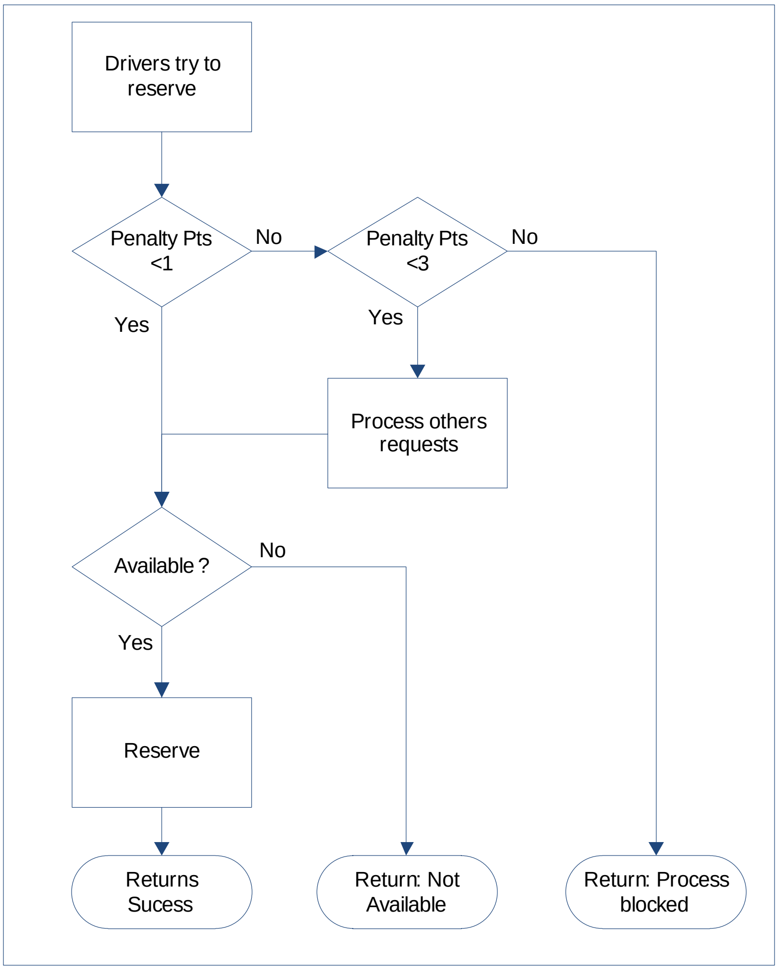


Figure 3-7: SGR penalty points to avoid user reservation failures

3.5. Tracking System in 'Offline' Mode Drive

User profile plays and important role in the V2G or G2V process. Also to study drivers' habits and profile update it has developed a tracking application to run in an offline mode (to avoid communication costs) in a mobile device with GPS device. Our project was performed in a final year project at ISEL, described at [Sousa, 2010], and its high level vision is showed in Figure 3-8.

This tracking application mainly stores time, GPS coordinates and user identification. From the GPS coordinates it is easy to calculate travel distances. Using Google Maps API it is represented the driver route and it is obtained the travel distance.

From the travelled distance and EV efficiency it is estimated the remaining energy stored in the batteries of each EV (SOC – State of Charge level), as well as the community SOC level (sum of all individual community SOC levels). The studied population (from the city of Lisbon area), with 50 cases, contains a mixture of university students and their parents, and takes into account the first EV introduced in Portugal, the Nissan Leaf, with a battery pack of 24 kWh and autonomy of 160 km (obtained with a careful driving). Some results presented come from this module.

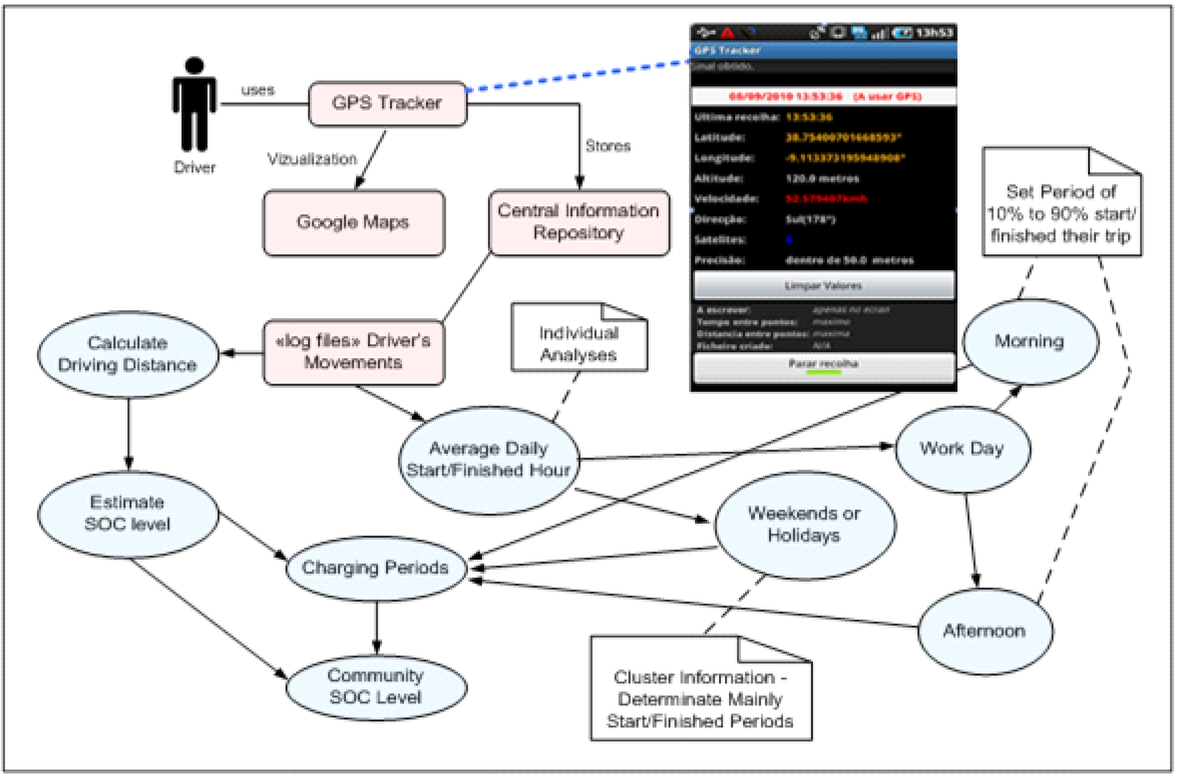


Figure 3-8: Main module of driver's tracking system in a mobile device with GPS, and information created from drivers movements database

Figure 3-9: Menu de Opções da Aplicação GPS Tracker

The application of GPS Tracker allows to see the GPS data on its position, direction, and speed. This information is placed on the screen of the mobile device using the method DisplayLocationInfo () in class GPS

Figure 3-10: Menu Principal da Aplicação GPS Tracker

The system allows seeing statistics on the route taken, including: (1) travel duration time; (2) total distance traveled; (3) average speed; and (4) others that can be obtained by data manipulation (e.g., trip cost, price). The system can also provide all the above parameters for all the paths of the user, thus obtaining the total average values.

The presentation of statistical results for one route or for all the paths of the user is done via GPS ReportView running a personal computer system user. The purpose of this application is to allow viewing of all the statistical data corresponding to journeys made by the system user and owner of an EV, so that it is possible to graphically view each journey made. This application provides a list of all journeys performed by the driver with statistics related with all journeys (average speed, distance, time).

3.6. Weather Module

In the residential and commercial sectors, heating and cooling account for more than 40% of end-use energy demand [FERC, 2004]. As a result, energy consumption in those sectors can vary significantly from year to year, depending on yearly average temperatures (http://www.energy.eu/). Several studies prove a relation between electricity consumption and temperature, especially for higher temperatures (most peak power consumption were reached on very hot days) [FERC, 2004]. Cooling is related with air conditioners (electricity powered) and heating with central heating (gas powered), so peak electricity consumption occurs in hot summer days [FERC, 2004]. As indicated in Figure 3-11, there is a high correlation between the simple average daily temperature from the four sites selected and daily electricity demand in the CalISO region, which comprises most of the state of California, in the USA [Crowley, 2005]. This relation has been observed by several authors [Crowley, 2005], [Franco, 2007], and there is more or less 1% of electricity demand increase by 2ºC of temperature rising. This Weather Module application was developed and is running, making possible to estimate this relation. A Web crawler (Web Content Extractor) was configured to take information from the main Portuguese weather site [www.meteo.pt]. From the Web pages extracted with pre-defined forms it is taken information related with temperature, wind (direction and speed), rain and solar conditions (e.g., sunny, cloudy, etc). This crawler runs in a pre-defined periodicity and the information is stored on a database. In a near future the present work intends to add more information from different web sites and merge this information on the proposed database. When a failure occurs the previously available values are stored in the DataBase (DB). Temperature data is related with electricity consumption, and the other parameters are associated with renewable energy production: wind to Eolic, temperature and solar radiation to Photovoltaic, and rain to Hydropower production.

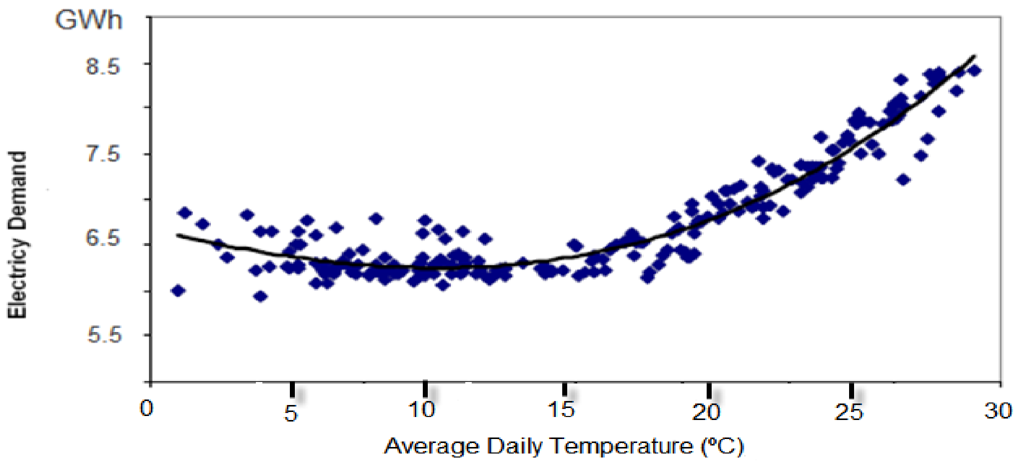


Figure 3-11: Electricity demand in the CalISO area as function of average daily temperatures: 2004 [Crowley, 2003]

The weather data is geo-referenced (several locations were considered) and is stored in an information repository correlated with:

- Temperature with average consumption. We apply K-Means algorithm to identify main groups. The first groups are: (1) bellow 0ºC; (2) from 0ºC to 8ºC; (3) from 8ºC to 18ºC; (4) from 18ºC to 26ºC; (5) from 26ºC to 31ºC; (6) from 31ºC to 35ºC; and (7) above 35ºC. From this centroids data (average consumption) it is calculated the percentage of consumption change due to group change.

- Wind speed and direction with Eolic production.
- Temperature and weather conditions with Solar Photovoltaic production.
- Rain in month's periods with Hydropower production capacity. We propose in a near future to try to identify which is the best time period to collect rain data.

Later in Section 4.3, it is explored this approach to estimate microgeneration production based on past data stored in a central repository. This weather information is used on range prediction process (see Section 3.10).

3.7. Geo-Reference Graph for the Electrical Distribution Network

One important approach introduced is the Geo-Reference Graph for the electrical distribution network. This allows computational data manipulation, such as distance calculation, identification of power limitation (Section 3.9) and identification of user communities (Section 4.2).

The area with the distribution of the electrical network is manually transformed in a graph (see Figure 3-12 and Figure 3-13), where it is added geographic information and power limitations between the nodes. This is a slow process where it is expected in a near future to introduce some automation. Assumptions on consumer's behavior are considered: (1) consumers define their house and family (number of house divisions, number of persons); (2) they define the number and type of electrical appliances from a pre-defined list; and (3) they define also their usual routine (arrival time, departure time). Tracking system data can tune arrival and departure times. Every consumer has its own behavior and changes or unexpected behavior are randomly generated at the beginning of the experiment, using an array of integers. Each consumer is represented by an agent who knows contractual power limitation and also the limitations of the distribution network.

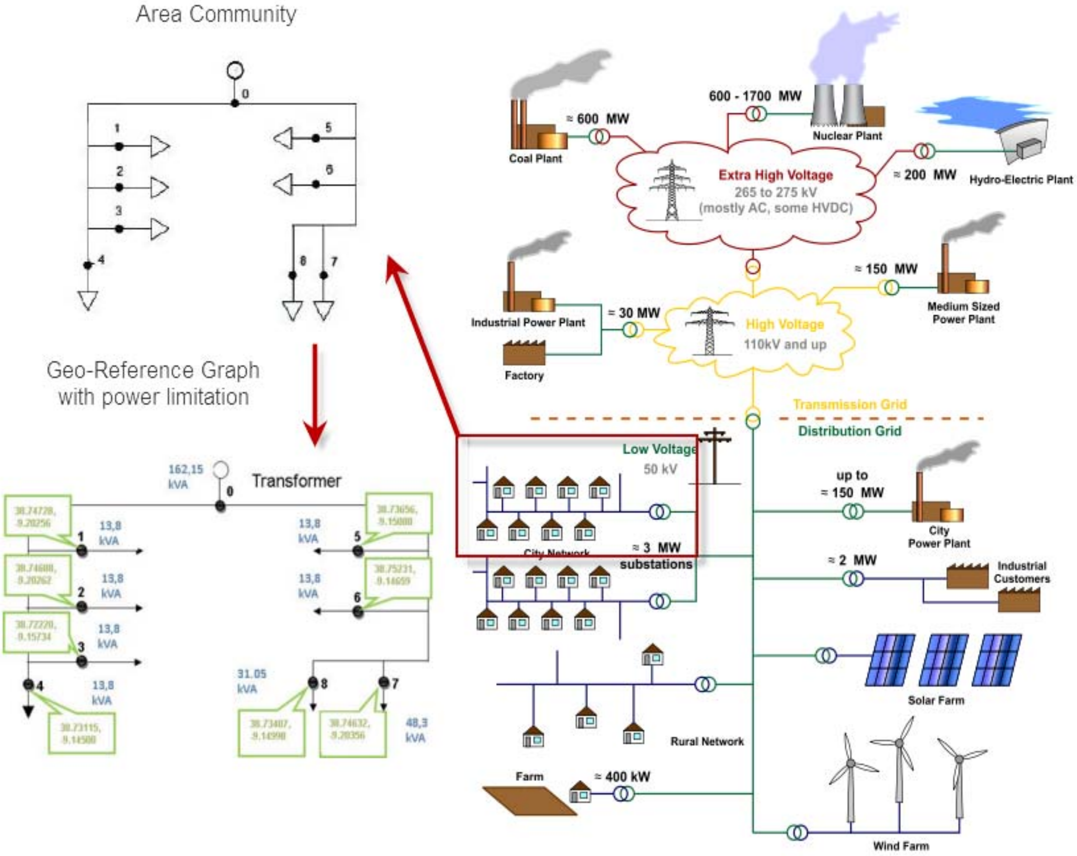


Figure 3-12: Electrical distribution network, transformed in a graph

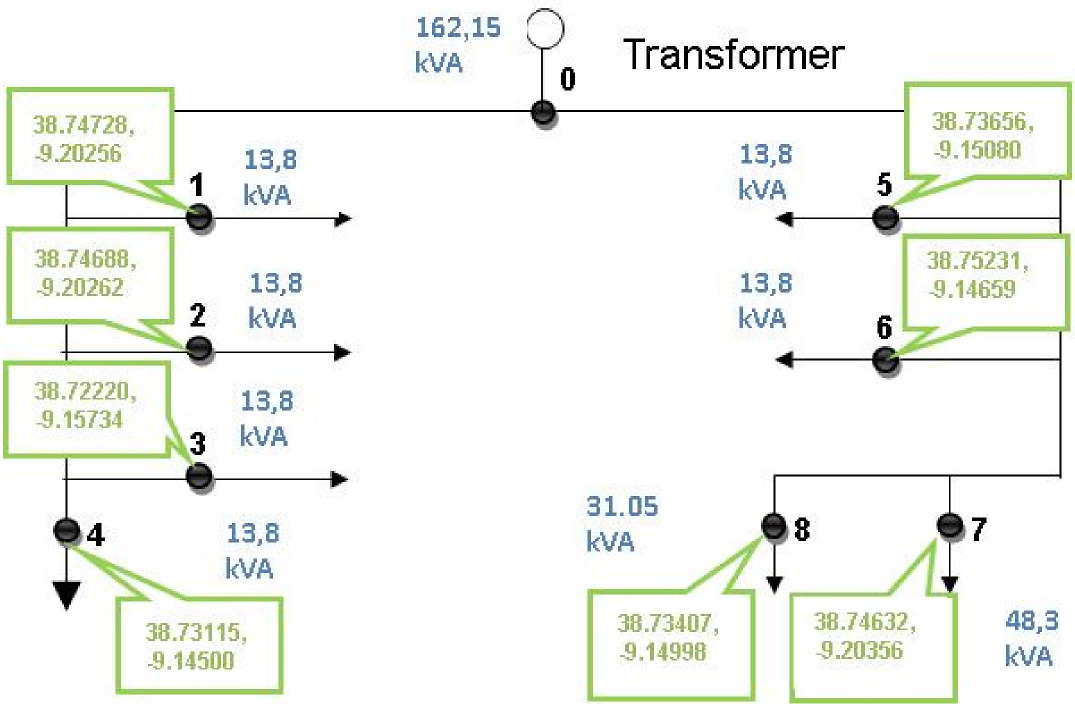


Figure 3-13: Geo-reference electrical distribution network with power limitations

Table 3-2: Information about distribution network, used for our case study

Node	Description	Type	Elevators (kVA)	Common Services (kVA)	Simultaneous Coefficient (kVA)	Power Available (kVA)
1	House 1	1x T4	0	0	1	13.8
2	House 2	1x T4	0	0	1	13.8
3	House 3	1x T4	0	0	1	13.8
4	House 4	1x T4	0	0	1	13.8
5	House 5	1x T4	0	0	1	13.8
6	House 6	1x T4	0	0	1	13.8
7	Building 1 3 Floors	6x T2	20.7	6.9	0.75 (6 installations)	48.3 (6 x 4.6 x 0.75) +6.9+20.7
8	Building 2 2 Floors	1xT4 1xT3	0	6.9	1	31.05 13.8+10.35+6.9

3.8. Home Consumption Simulation

An agent based simulation attempts to simulate an abstract model of a particular system. Computer simulations have become an useful part of mathematical modeling of many natural systems in Physics, Chemistry and Biology, and of human systems in Economics, Psychology, Social Sciences, and Engineering. Simulations can be used to explore and gain new insights into new technology, and to estimate the performance of systems too complex for analytical solutions. This approach already has been applied for electricity market [Figueiredo, 2010], [Zhao, 2007] [Pitt, 1999], creating a simulation environment for market prices determination based on consumers demand, and for production capacity of producers. Our main idea is to simulate consumers consumption taking also into account unexpected user behavior, using past experience (consumption log files), and then representing the information in an electrical distribution network graph.

There are several tools that can be used for this purpose, from which NetLogo tool has been chosen. NetLogo is a free agent-based simulation environment that uses a modified version of the Logo programming language, providing a graphical environment to create programs that control graphic "turtles" that reside in a world of "patches," which is monitored by an "observer". NetLogo also includes an innovative feature, called HubNet, which allows groups of people to interactively engage in simulation runs alongside of computational agents.

On the simulation tool (Netlog) it is followed a bottom-up approach where it is estimated consumption based on consumer profile and historical consumption data. Weather information (temperature) is used as a percentage increase factor on usual consumption. Each consumer is represented by an agent that is based on historical data, profile and temperature information, based on a random function for energy consumption, which is estimated at every 15 minutes (this time interval is configurable). Each agent has a utility function, but the agent is not optimizing it because this process is too expensive under many aspects: in terms of information retrieval cost, in terms of information processing costs from a computational point of view, and in terms of cognitive effort in searching alternatives. We decide to model each consumer as a node on a distribution network graph. Simulation takes into account house power limitation contract and electrical energy distribution limitations. Our simulation platform is: (1) Dynamic, updating each entity (agent) at each occurring event; (2) Stochastic, based on conditional probabilities; and (3) Discrete, with the changes in the state of the system occurring instantaneously at random points in time as a result of the occurrence of discrete events. Main output information is the visualization of electrical distribution network on a graph with the indication of power limits. Red color means above power capacity, which indicates that EV charging should be processed in an intelligent interactive process; green color means that it is possible to charge EV batteries on full power. It is estimated the consumption and this information is used for a smart EV charging, without measuring devices and real time information. The main application screen of the consumption simulation is illustrated in Figure 3-15.

Relatively to electricity market functions, it is aggregated energy production and consumption data, and based on this simulation, estimate prices and then determinate the best charging or discharging periods.

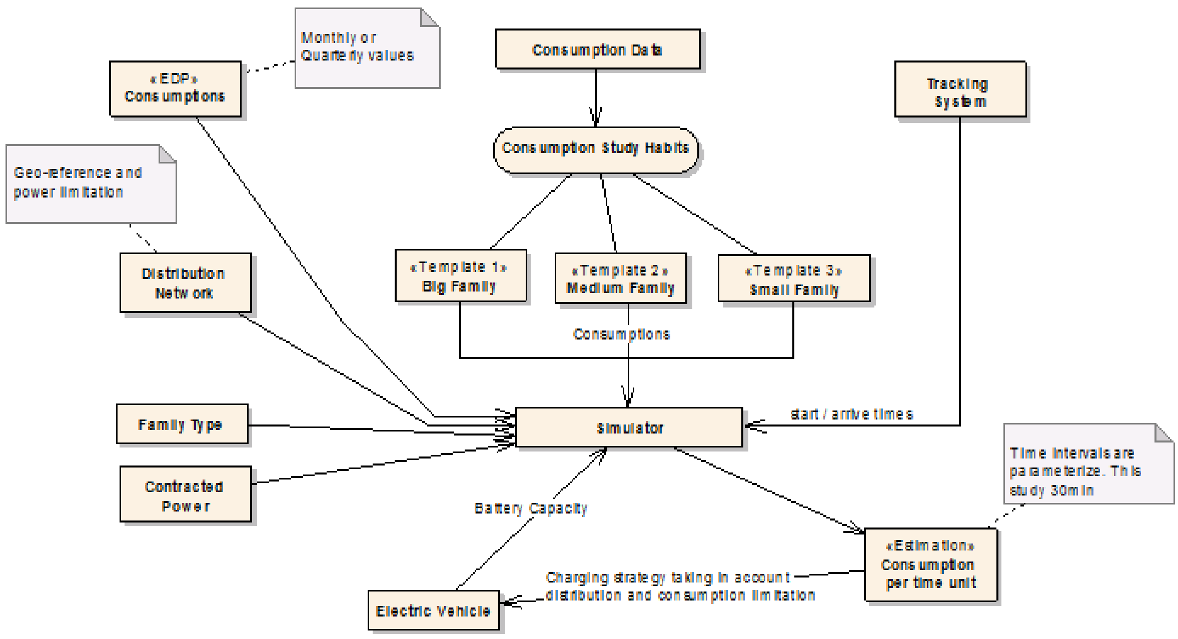


Figure 3-14: Simulation approach methodology

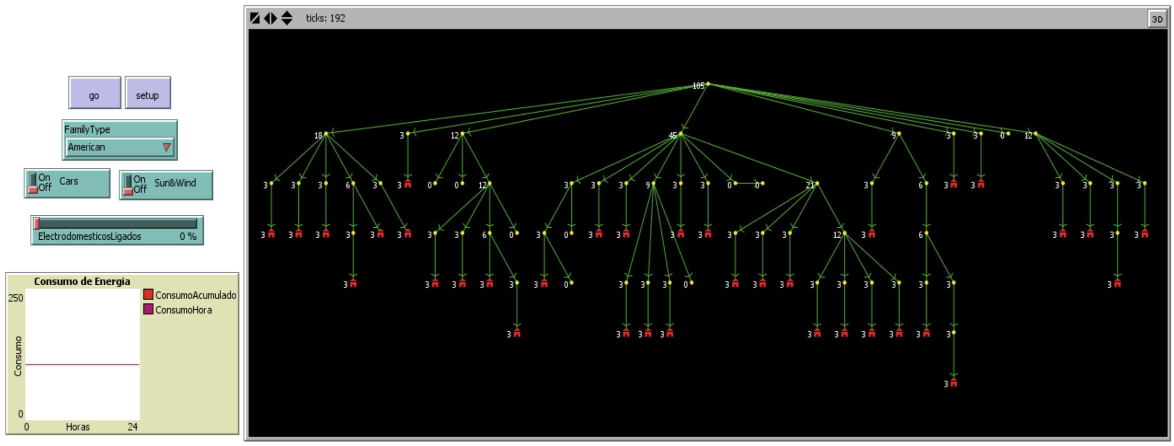


Figure 3-15: Simulation application on *Netlog*

Model for Collecting Consumption Data

Consumption patterns are studied based on two factors: (1) what equipment are used by consumers; (2) power used by these equipment; and (3) time interval in which they are used.

In order to know how much power each device consumes, it is used data available from ERSE (*Entidade Reguladora dos Serviços Energéticos* - Energy Services Regulatory Entity, from Portugal), and obtained the following tables of average values of maximum power per appliance:

Table 3-3: Power consumption of conventional home equipment. Data taken from [ESRE, 2010]

Home Appliances	Power (kWh)
Washing Machine	2.00
Tumble Dryer	3.50
Dishwasher	2.00
Oven	2.40
Cooktop	6.20
Microwave	0.90
Broiler	1.80
Exhaust	0.14
Toaster	1.00
Aspirator	1.60
Iron	1.60
Fridge	0.15
Freezer	0.25
Hairdryer	1.50
Fryer	1.90

Leisure	Power (kWh)
TV (convencional)	0.09
TV (plasma)	0.30
Stereo sound	0.06
DVD	0.24
Computer	0.30
Lighting	
Incandescent Lights	0.06
Halogen Lights	0.04
Fluorescent Lights	0.04
LFC (Economics lights)	0.01
Home Temperature	
Air Conditioning	1.80
Oil Radiator	2.00
Heater	2.00
Water Heater	1.50
Heat accumulator	2.50
W.C. Heater	1.20

Since there are no devices installed in the homes of consumers that allow collecting the power consumption information instantaneously, the data collection was done manually. Were chosen representative consumers (around 50 families in Lisbon area were asked to report supposed daily use of equipment in their homes). Details of this survey can be found at [www.deetc.isel.ipl.pt/matemtatica/jf/inq_cons.pdf]. Table 3-4 presents a table with a list of possible equipment used at homes, and it was asked to the representative consumers to fill this table with the equipment used and with the hours of utilization.

Table 3-4: Questionnaire table to users about home energy consumption

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Home Appliances																								
Washing Machine																								
Tumble Dryer																								
Dishwasher																								
Oven																					1			
Cooktop																								
Microwave																				1				
Broiler																								
Exhaust																								
Toaster								1																
Aspirator																								
Iron																							1	1
Fridge	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Freezer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hairdryer								1																
Fryer																								
Leisure																								
TV (convencional)	1	1																			1	1	1	1
TV (plasma)																								
Stereo sound								1																
DVD																								
Computer	1																					1		
Lighting																								
Incandescent Lights																								
Halogen Lights																								
Fluorescent Lights								1																
LFC (Economics lights)	3	1	1					1													4	4	3	3
Home Temperature																								
Air Conditioning																								
Oil Radiator																								
Heater																								
Water Heater																								
Heat accumulator																								
W.C. Heater																								

The study of consumer habits of each family is based on an analysis of the tables above. The set of connected devices and related values of power per hour will provide the total consumption of electrical energy per hour per family. We combine the study of these three sets in order to get the following templates: (1) Template 1: Large Family; (2) Template 2: Medium Family; and (3) Template 3: Small Family.

From tracking system it is taken information about the time drivers arrive / leave home and the travelled distance taken. These values are stored and a mean value and a standard deviation are used to feed simulation environment on Netlog. Agents represent drivers and average time is used to start actions. A stochastic environment is created by random functions (changing start times) that can change mean values to maximum deviations, taking into account a probabilistic function. Also weather information is used to increase or decrease overall energy consumption. This simulation process uses electrical distribution network information taken from the geo-reference graph.

3.9. Smart Charging Strategy

The strategy of the smart charging system is defined in order to achieve the goals identified in Figure 3-16, taking into consideration integrated home consumption, electrical distribution network limitations and availability of power for charging. This system is based on a central information repository that can store and manage historical data on electricity consumption and production. From this central repository it is possible the development of tools to extract knowledge from past electricity exchange log files, electricity market prices, renewable energy availability, home energy consumption (if EV is connected at home) and electrical distribution network constraints. Also, the weather information can be used for the forecast of energy production from renewable energy sources, and the EV users arrival and departure times from home (obtained from a tracking device) can be used for consumption timing optimization (e.g., users can change their behavior, and thus historical data needs to be fitted). This central repository will be later, in a Smart Grid (SG) environment, a fundamental module to store all kind of SG data, and to solve problems of different data format diversity.

Main Output information is the visualization of electrical distribution network on a graph with the indication of power limits (Figure 3-15). The first step is to estimate the electrical power consumed per household, and given the contracted power, to determine the available electrical power for charging EVs. It was considered a power limit for the electrical distribution system of 80% of the nominal power of the transformer that feeds a set of consumers of each particular zone of the low voltage electrical network. So, depending on the percentage of existing EVs, we may have additional limitations. Table 3-5 presents data used and taken from the simulation of families, as well as the type of EV (we have assumed one per family), and the average distance traveled daily.

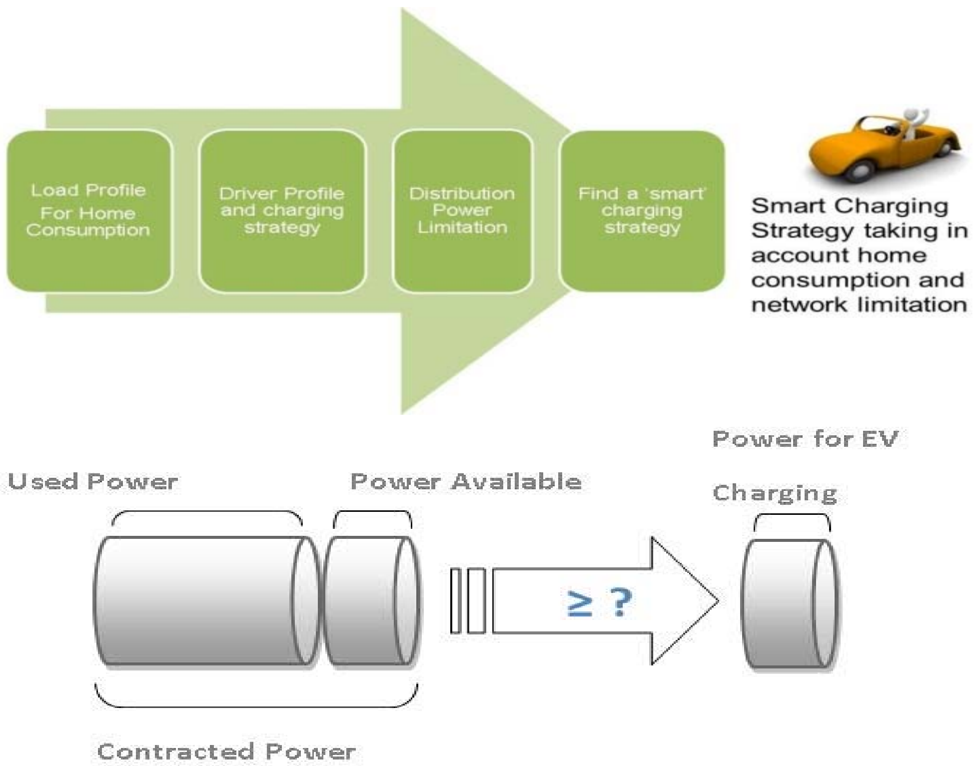


Figure 3-16: Smart Charging approach and goals

Table 3-5: Data used and produced in Netlog Simulation

	Family type		EV Type	EV Range(km)	Daily Km	Power Available (kW)	Power Needed for EV Charging (kW)
Building1	T2	Small Family	Nissan Leaf	160	10	56.67	120
	T2	Small Family	Volvo C30	150	30	56.67	120
	T2	Small Family	Nissan Leaf	160	40	56.67	120
	T2	Small Family	Toyota Prius	48	50	56.67	120
	T2	Small Family	Volvo C30	150	30	56.67	120
	T2	Small Family	Toyota Prius	48	20	169.11	120
Building2	T4	Big Family	Volvo C30	150	20	132.75	120
	T3	Medium Family	Nissan Leaf	160	40	169.11	150
House 1	T4	Big Family	Chevrolet Volt	64	50	169.11	120
House 2	T4	Big Family	Toyota Prius	48	40	169.11	120
House 3	T4	Big Family	Nissan Leaf	160	50	169.11	150
House 4	T4	Big Family	Chevrolet Volt	64	100	169.11	120
House 5	T4	Big Family	Volvo C30	150	20	169.11	120
House 6	T4	Big Family	Nissan Leaf	160	40	**1656.54**	**1740**

The main results obtained are showed in Figure 3-17 and Figure 3-18. For more details of these results see [Ramada, 2010]. These studies were oriented to simulate domestic consumption and distances traveled, to determine the most appropriate forms of representing the power consumption of the families, also considering the EVs. In order to determine the time of the day when there is more available power to use to recharge the EV batteries, we have compiled the values of power consumption per hour, and it was found that, during the week, the ideal intervals for charging the EV would be between one and six o'clock in the morning (range A), or between nine and the sixteen hours (range B). In the weekend, the ideal intervals for charging the EV would be between one and eight hours (range A) or between fourteen and sixteen hours (range B).

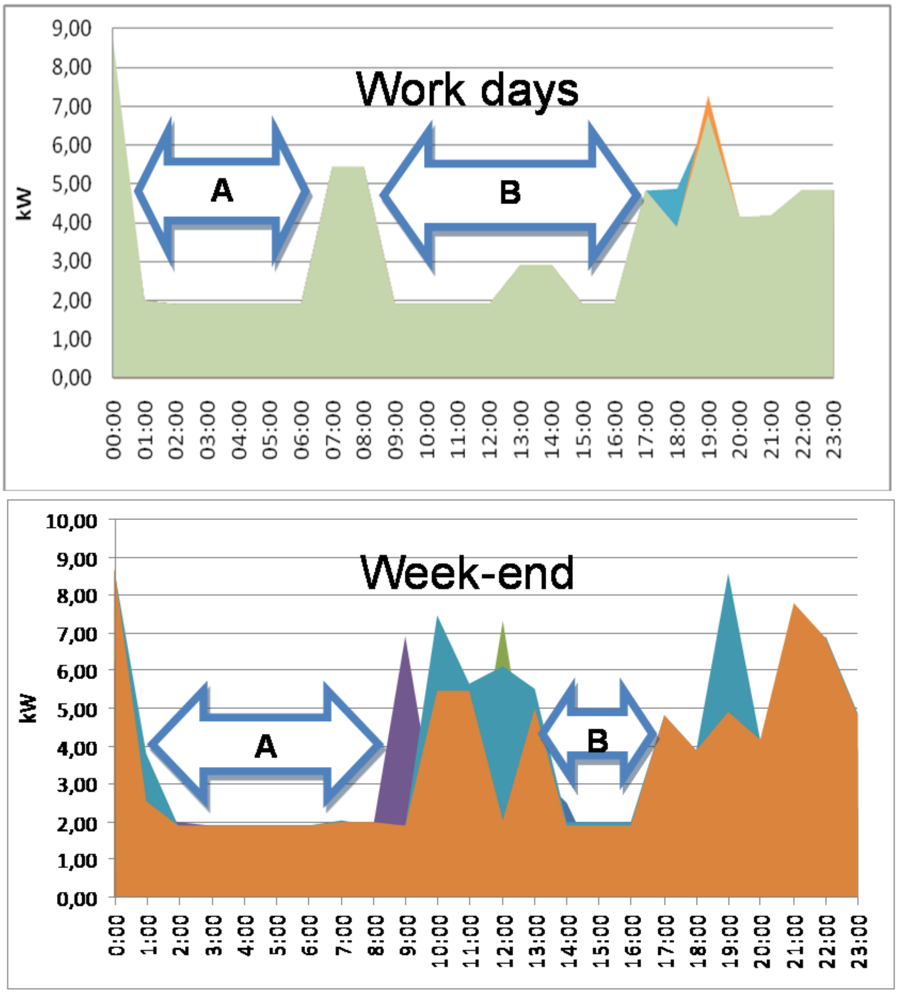


Figure 3-17: Power Consumption Distribution (all types of family)

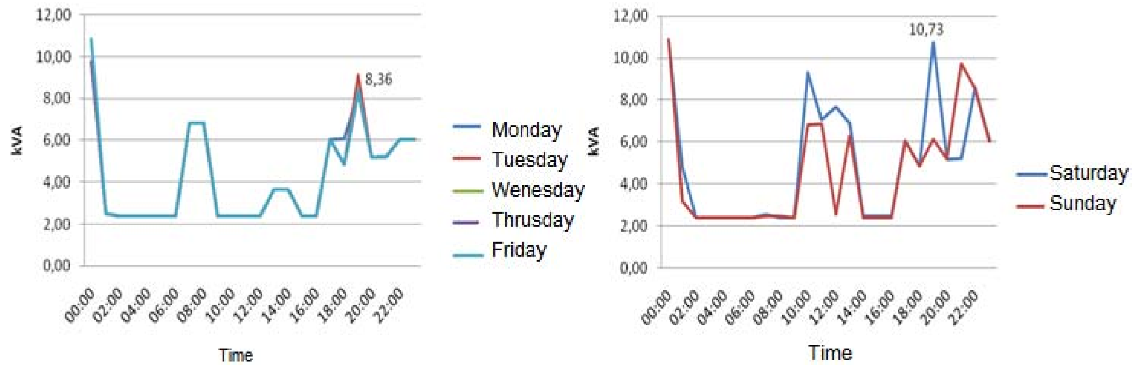


Figure 3-18: Large family consumption simulation results

Relatively to electricity market functions, it was aggregated energy production and consumption data, and based on this simulation estimate prices, and then determine the best periods for charging or discharging (returning energy to the electrical distribution network) the batteries of the EVs.

3.10. Range Prediction Functions

3.10.1. Range Prediction

Range prediction is the process of estimation of EV range based on three main dependency types (Figure 3-19):

- **The EV with its main variables**: the model of the vehicle (mainly its performance under different scenarios, speed, and acceleration), the chemical technology of the batteries (as lithium-iron-phosphate, lithium-titanate, or nickel-metal-hidride) the batteries characteristics (mainly, variation of SOC, lifespan, performance, specific power, specific energy, and safety), and the EV powertrain (electric motor and its power converter, as well as the other electric parts, as batteries charger, controllers, and power cables). This data is stored on an information repository, on a central server. All of these parts will influence the SOC and consequently the range prediction. The batteries SOC, and other relevant parameters, are provided to the main control system through CAN-bus communication, and then these information are stored in a data base (DB), in order to predict the available range.
- **The driver behavior**: speed and acceleration information are taken from EV through the CAN-bus communication, and the driver past behavior (e.g., SOC

level versus travelled distance achieved), are stored in a DB. Weight is a manual input, and driving directions are acquired based on the GPS information.

- **Environment**: current location, traffic conditions (taken from a web service), road information (in a distance graph), weather information (wind and temperature, taken from a web service), and altitude, taken from GPS.

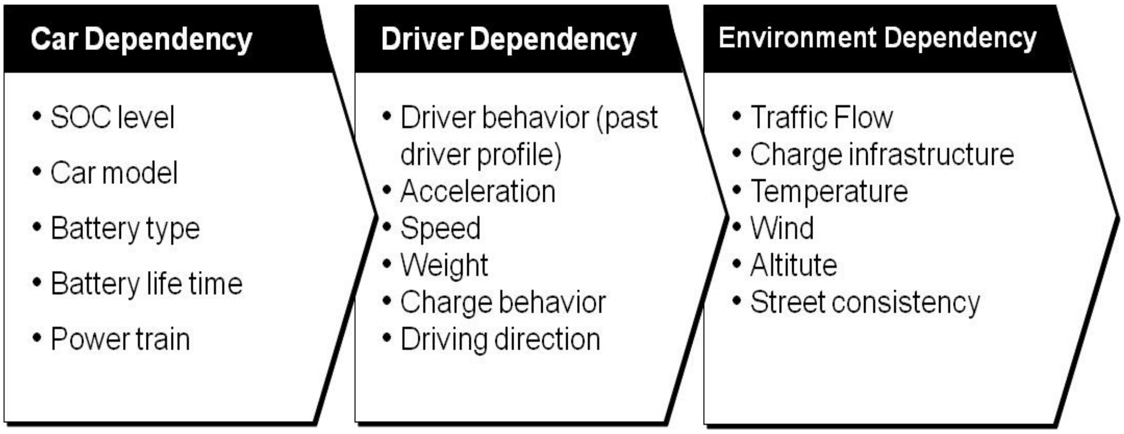


Figure 3-19: Main parameters for range prediction

The range prediction procedure is in a first step based on the batteries SOC level, and using driving behavior (relation of SOC level versus travelled distance achieved, from past experience, stored in a central information repository). This distance is tuned based on weather information: if it is hot, a percentage of the energy stored in the batteries is taken for air-conditioning; if it is raining, a percentage of energy is taken for the window cleaning process. For night drive, also a percentage of energy is taken for light services. A web service brings traffic information, and based on past experience (e.g., information about driving times and traffic information), a driving range is predicted. Current driving behavior (e.g., driving speed and accelerations) are taking into account in this process. Once it is achieved an estimation of EV range, it is started the calculation of possible reachable points based on current position. Most of these estimation processes were performed based on simple heuristics, and a deep study is prepared (current MSc dissertation, started in 2011 in ISEL). For example, if the weight is above a configurable threshold, a percentage of reduction is applied on the range (this value should be tuned from past experience data and depending on EV parameters). Also altitude was taken into consideration, using Google maps to obtain the altimetry of the desirable path, again several levels were configured, and also is applied a percentage of reduction in the range, in function of the altitudes to overcome in the path. Temperature is an important parameter, because of the relation with air-conditioning. The temperature was divided in five classes range: (1) less than 5ºC; (2) from 5ºC to 15ºC; (3) from 15ºC to 25ºC; (4) from 25ºC to 30ºC; and (5) above 30ºC. For classes 1 and 5 it was assumed that all drivers use air-conditioning, for class 3 no usage is performed, and for classes 2 and 4 it is considered that a percentage of drivers use air-conditioning (initial profile parameter, but past data can tune this behavior). Traffic information is used again as a parameter that can reduce range, because possible starts/stops on traffic jams increase consumption.

3.10.2. Range Representation

Once a range prediction is achieved, a topographical search starts with the current driver position, based in Figure 3-20. Main road nodes are used to check distances from current position and a polygon representation is achieved (see Figure 3-21, Figure 3-22 and Figure 3-23) based on Google API usage. A zone of uncertainty can be marked, based on the uncertainty parameters used to estimate the drive range (see Figure 3-24).

If SOC level is below 25 % (available range should be around 30 km-40 km) it is calculated every road option with guidance to the nearest charging point. Taking into account Figure 3-20, it was considered Lisbon as the starting point. Since the available range for the EV is around 160 km, the implemented process starts to look for main destinations in a radius of 130 km to 160 km. This distance calculation is based on GPS coordinates of correspondent places. For Lisbon as the starting point, the process identified the following cities (Figure 3-20, process (2)): Pombal, Leiria, Marinha Grande, Ourem, Tomar, Évora, Grandola, Santiago do Cacém and Sines. Then, the distances are calculated based on Google Maps query (Figure 3-20, process (3)), and the process identifies that Pombal are out of the EV range. The distances calculated to the other locations are within the available range of the EV. For example, the distance from Lisbon to Évora is 134 km, so the process (4) (Figure 3-20) looks nearby villas, and process (5) (Figure 3-20), identifies the 'real' distance. In the case of the present example (Figure 3-21) and using the city of Évora as destination, it is available more 26 km, which allows increasing the range representation around Évora with a radius of 20 km (see Figure 3-22). The output of this iterative process is represented in Figure 3-21. For every 5 km of EV movement this map is again calculated and represented. The Web range estimator represents range by the connection of main distances and putting the polygon together. To do so, our application uses Google maps API and shows the polygon on a mobile device display, as showed in Figure 3-21, Figure 3-22 and Figure 3-23.

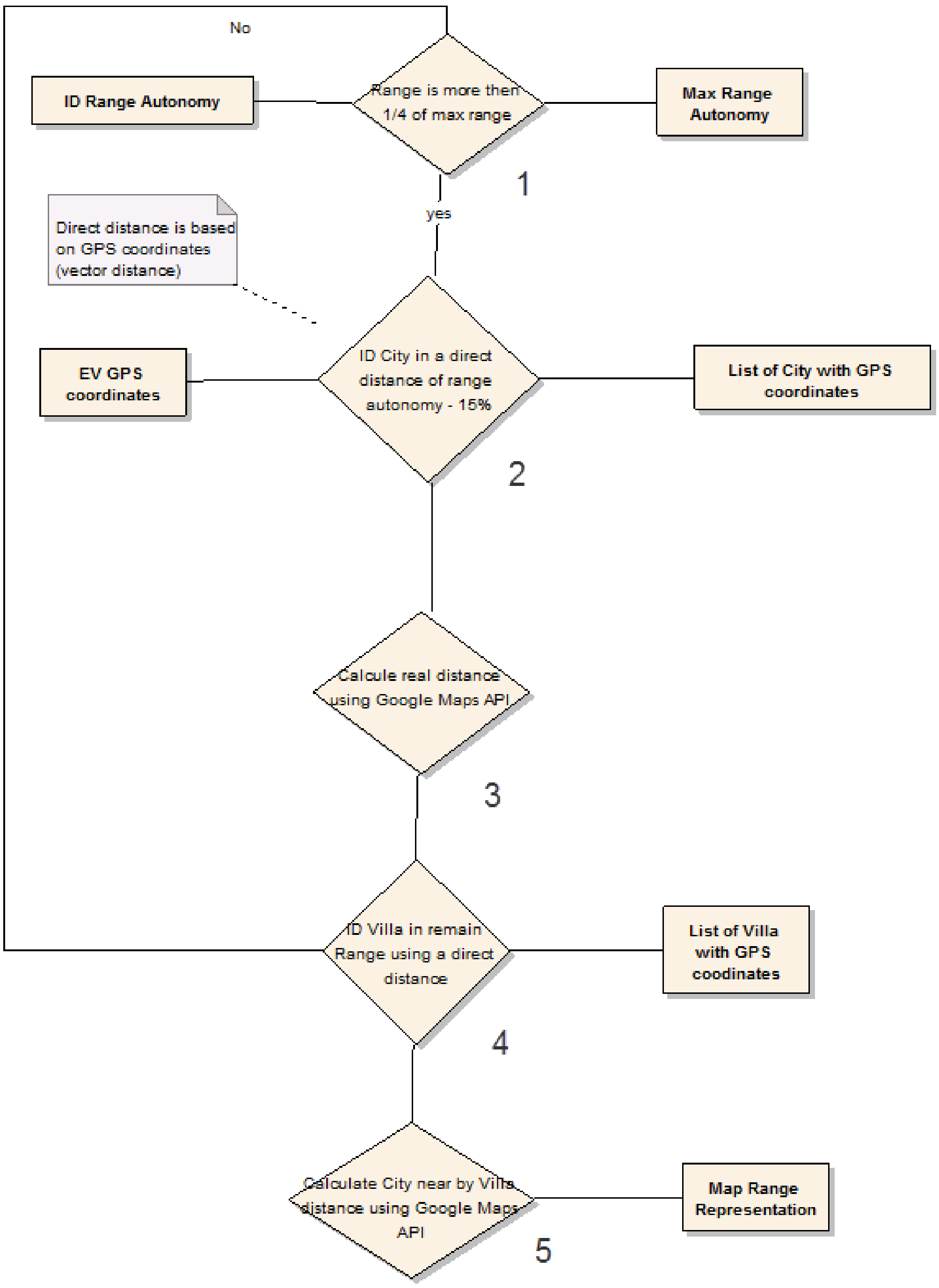


Figure 3-20: Range representation process using Google Maps API

Figure 3-21: Range estimation of a Lisbon trip to north. Four different cases are showed

For charging process the range prediction and representation is performed in the same way. Based on the charging level (SOC information) the application predicts the range based on previous driving parameters (past relations of SOC levels and distances achieved stored in driver profile) and based on this information represents using Google Maps the regions that is possible to reach with that charging level. System is prepared to generate alerts about charging levels needed to reach a charging station (it is assumed that a charging process is always performed in a charging station, in the driver's home or in the work place). The range prediction process has several uncertainty factors that reflect driving behavior and external condition (e.g. traffic, road topology and weather). These factors showed in Figure 3-19 can be used to estimate a safe range (green shadow in Figure 3-24) and a maximum range. The red shadow in Figure 3-24 is a range that is possible to achieve but the driver needs to perform driving optimization (air condition off and avoid big accelerations). This could be helpful information because driver can customize his behavior function of the range it needs to achieve in their trip. This process is can be continue updated and when SOC level is low this uncertain gets low.

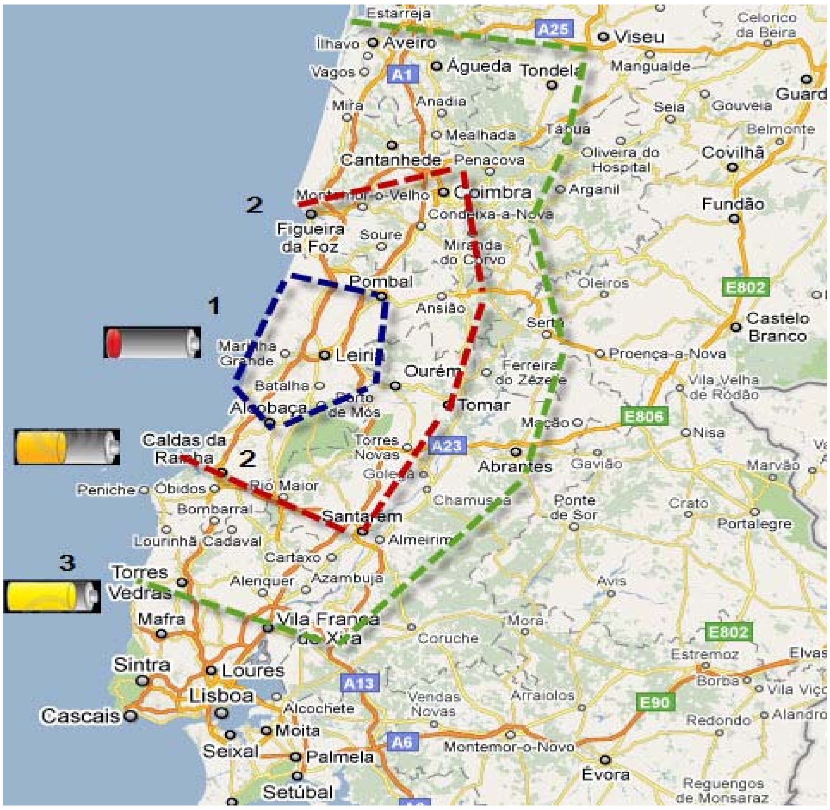


Figure 3-22: Representation of charging range for different SOC levels at a charging process

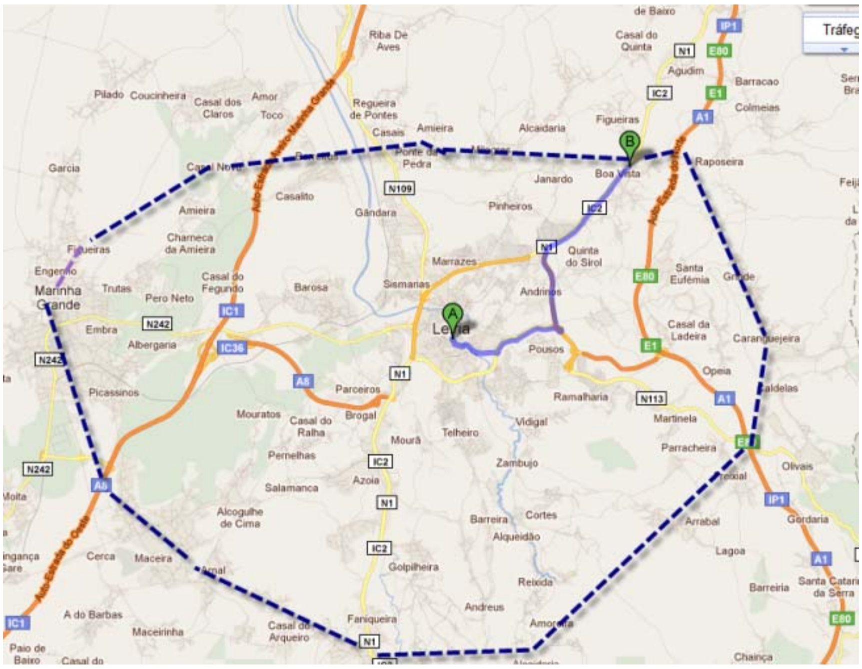


Figure 3-23: Range estimation with a low SOC level

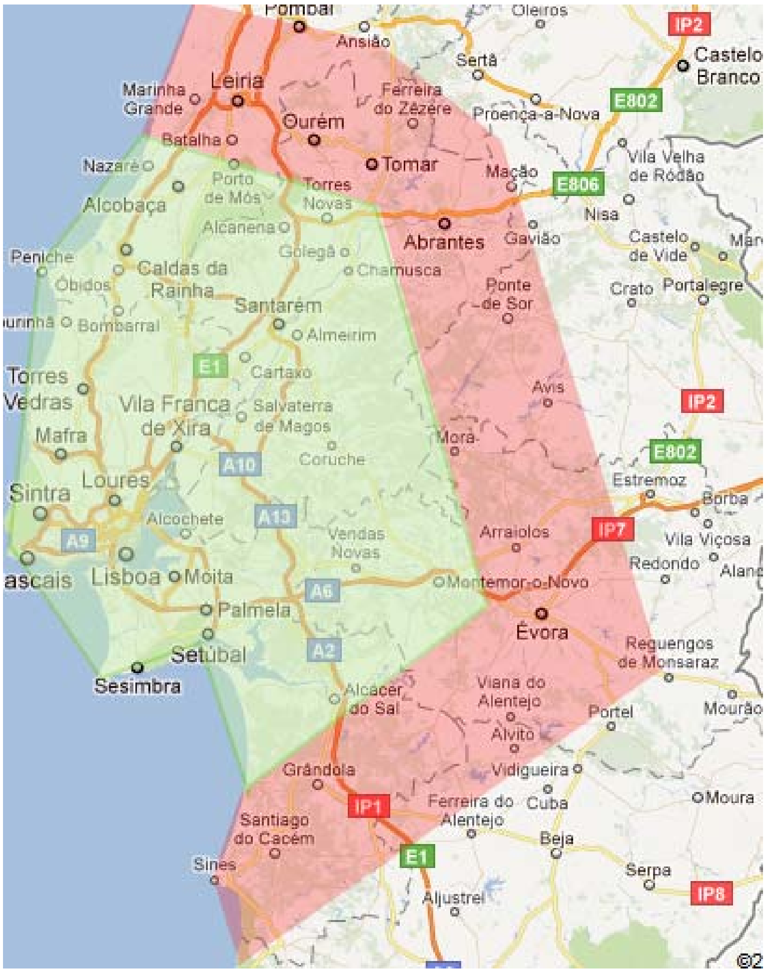


Figure 3-24: Range estimation based on the uncertainty factors showed at Figure 3-19

3.11. Recommendation Engine and System

Given the success of recommendation systems in automatically delivering the relevant information in numerous areas of usage, it can be applied in this scenario as well, with the objective of maximizing the relevance of the information presented to the driver, which should be the strictly needed for him/her to make decisions, filtering out the unnecessary one.

Based on the available information, the information repository of the Mobi-System, the recommendation system will choose (recommend) the ‘right’ information, based on user pre-defined preferences expressed in a profile. This system uses *n* dimensions to calculate utility function (information relevance measurement) for all input information: user *D1*, information *D2* and context *D3*. A diversity of recommendations is displayed. So, a recommended function has a new dimension d (means context), and is a three dimensional vector $u(\text{User, Item, Context})$ (Figure 3-25):

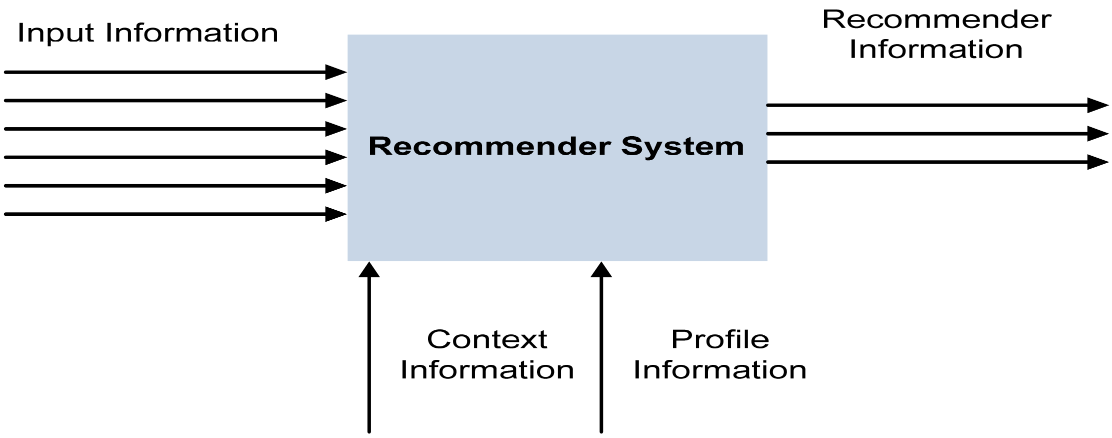


Figure 3-25: Recommender System

Input Information: Is the available information and represents charging places and other information related to EV driver. A recommender engine information module selects and stores all related information.

Profile Information – Historical Data*:* Represents past user options in a three dimensional matrix based on selected information. In our implementation this field has only two values: value 1 represents a user choice, and value 0 signifies user disagreement.

Context Information: Is used to improve recommender system performance, based on the fact that user preferences change based on the context. For example, in a tourism recommender system, the year period changes the user's preferences, among others. Several authors, [Gediminas, 2005] and [Tuzhilin, 2001], suggest that context information is used based on a bi-dimensional space, (User, Information), in a multidimensional matrix, u (utility):

$$u : D_1 \times \ldots \times D_n \rightarrow \Re \quad \text{[Equation 2]}$$

Each D dimension is represented by an information vector and the algorithm to find the best tuple *(d_1,…,d_n)*, that maximizes the utility function [Gediminas, 2005]. Our implementation uses as context information based on four main types: (1) function mode: "leisure" or "direct"; (2) day period: "morning", "afternoon" or "night"; (3) destination:

"home" or "work"; (4) trip status: "starting" "middle" or "ending". This information is stored on information repository and is obtained by interaction with the driver, (1) plus (3), and (2) plus (4), by the system based on pre-defined rules. So, day period is pre-defined on system, morning is until 12 am, afternoon from 12 am to 19 pm, and night in the remaining hours. Trip status is based on target distance, the first 25% km are considered starting and the last 25% km are considered ending.

Recommender Information: Generates new system output information, ordered by a utility function. In this pre-release phase our system takes care of the charging point.

Each information type is represented by a vector, with class values. The PCSs (Public Charging Stations) are based on:

- Charging Mode: Slow, Fast and Drop-off;
- Operator: "MOBI.E", "Better-Place", "EDP";
- Location Type: "Street", "Small Station" and "Big Station";
- Services: "Without Services", "Reservation", "Washing Services" and "Others":
- Public Transportation Interface: "1","0";
- Nearby Points of Interest (POI): "1","0" – only if operator mode is on travel mode.

Utility (u) Calculation

User recomendation is based on utility function *(u)*, where only three items are showed to the user (this is a configurable parameter). After distance measure is introduced (Manhattan distance, others could be implemented), it is calculated the utility based on context information, for each piece of input information, item I_i:

$I_i = \{I1_i, I2_i, I3_i, I4_i, C1_i, C2_i, C3_i\}$ [Equation 3]

Where $\{I1_i, I2_i, I3_i, I4_i\}$ are the characteristics of input information I_i and $\{C1_i, C2_i, C3_i\}$ are the context characteristics. The utility function is based on the nearest neighbor algorithm, see Figure 3-26, where it includes context and distance function. For details see [Pereira, 2010].

μ = utility; α = distance; c = user; S = selected items (candidates); d = context

H = context list (past data); $R(\mu, item)$ = list of items with u measure

1. Start $R(\mu, item) = \{\}$
   1.1. For each S item:
      1.1.1. Add context information = $S(i) + d$
      1.1.2. Start $\mu = 0$
         1.1.2.1. For each H item:
            1.1.2.1.1. Calcule distance α to $H(i)$
            1.1.2.1.2. Calcule $\mu' = \begin{cases} 1 \text{ se } \alpha = 0 \\ \frac{1}{d} \text{ se } \alpha \neq 0 \end{cases}$
            1.1.2.1.3. If $\mu' > \mu$ *then* $\mu = \mu'$
      1.1.3. Insert $(\mu, item)$ in R
2. Sort R from highest value to the lowest
3. Return three highest elements of R

Figure 3-26: Nearest Neighbour Algorithm used to calculate the function *u*

3.12. Conclusions

In this Chapter Mobi-System main EV functions were identified, taking into account the defined objective.

An information system to support V2G (Vehicle-to-Grid) or G2V (Grid-to-Vehicle) processes was created to assist EV drivers. This system takes transactions information from charging devices and is able to give charging or discharging commands. Due to the diversity of charging equipment and the lack of standards, an approach of XML files to data exchange was considered. This approach has been successfully implemented in several problems of data exchange in the computer area.

Regarding driving assistance with useful information, the following topics were covered:

- **Address user range anxiety**: (1) display SOC (State of Charge) level, remaining km for next charging; (2) looking for the nearest charging station (with guidance);

- **Drivers useful functions**: (1) give remote charging or discharging commands; (2) define a smart charging strategy taking into account home consumptions and contracted power limitation; (3) report about electricity transactions with pricing information; (4) give POI (Points of Interest) and guidance; (5) enable online advanced booking of charging spots with a penalty algorithm to avoid users failures; and (6) EV news.

Also, this Chapter was the basis for the project submitted to FCT, "EV-Cockpit: Personal Mobile System for Electric Vehicle Control" (PTDC/SEN-TRA/118302/2010), with the following partners:

- GuIAA Group (Information Systems Group);
- Daily Work, main expertise in vehicle-to-vehicle communication and telematics;
- Department of Electrical Engineering and Automation, and the use of VEECO vehicle as a case study. VEECO (*Veículo Eléctrico ECOlógico*) is a QREN project where ISEL is a partner;
- CEIIA, as a OEM partner and a case study on MOBI.E;
- GSI in Inesc-ID, on information systems and mobile devices;
- Centro Algoritmi of University of Minho, main expertise in charging devices and Power Electronics.

The main project goal was to create a commercial product from these Chapter ideas in a mobile device, and to explore the EV data extraction through the communication standard CAN (Controller–Area Network).

4. Mobi-System: Electricity Market Functions

This Chapter reflects the initial work performed with the EV Aggregations (Section 4.1), the Microgenetation and the Distributed Energy Resources (DER) (Section 4.2), and the Collaborative Aggregator Broker System for DER (Section 4.3), and it is dedicated to the participation of EV in the electricity market and the integration with local renewable energy resources.

4.1. EV Aggregations

EV behavior can be quantified in a user profile, like time of trip, travelled distance, daily hours connected to the grid and minimum energy stored. These profiles can be clustered in communities by a similarity measurement (taking into account the trips time), and also by the identification of the electrical distribution network mapped in a graph (see Section 3.7). This graph geo-reference points correspond to end users locations and low voltage distribution points. The biggest problem of this approach is the work involved in the identification of geo-reference of each of these points. Having collected this information any geographic database can easily handle the problem.

The basic idea behind such community is the aggregation of the EV (Figure 4.1) taking into account the electrical distribution network represented in a geo-reference graph, so that together they represent a load or a resource of a size appropriate to exploit economic opportunities in the electricity markets. The created community is a new player whose role is to collect the EV (profiles) by attracting and retaining them, so as to result in a megawatt capacity that can beneficially impact the grid. This impact is even bigger, because we take into account that the electrical distribution network minimizes losses of energy transmission and distribution. The size of the community is indeed a key to ensuring its effective role (100 EVs of 24 kWh can store 2.4 MWh, and around 300 EV of 24 kWh can reach 7.2 MWh). In terms of load, a community of EVs represents the total consumption of all vehicles, an amount in megawatts that constitutes a significant size, and allows each EV to benefit from the buying power of a large industrial/commercial customer. There are additional economic benefits that grow as a result of the economies of scale. The aggregated collection behaves as a single player that can undertake transactions with considerably lower transaction costs than would be incurred by the individual EV owners.

It is the role of the Aggregator to create and manage the community behavior by determining which EV to select to join the community, and by establishing the optimal deployment of the community. A single community may function either as a controllable load or as an energy resource. We first discuss the EV community utilization as a controllable load and then as a generation/storage device.

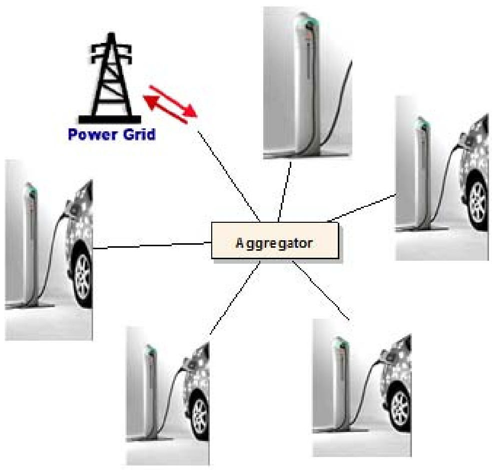


Figure 4-1: The EV community may act as a controllable load or as a generation/storage Device

First, the larger scale of the aggregated V2G power resources commanded by the Aggregator, and the improved reliability of aggregated V2G resources connected in parallel, allows the electrical grid system operator to treat the Aggregator like a conventional ancillary services provider. This allows the Aggregator to utilize the same communication infrastructure for contracting and commanding signals that conventional ancillary services providers use, thus eliminating the concern of additional communications workload placed on the grid system operator.

In the longer term, the aggregation of V2G resources will allow them to be integrated more readily into the existing ancillary services command and contracting framework, since the grid system operator need only to communicate directly with the Aggregators. The communications infrastructure of the Aggregator (central server) and the vehicles is a standard communication system, using available technology (Wireless, GPRS, Wimax, among others). Since there are no standards defined among EV infrastructure, the data exchange was performed on the Internet standard XML. This approach allows picking and giving information from different proprietary systems, since they provide and interface with XML data exchange. This Internet standard facilitates the application of data mining approaches to extract relevant information from the past experience (previous transactions performed).

User Profile is defined by: type of EV (this feature characterizes the battery size), minimum SOC allowed, time and date of trips (working days and weekends), geographic data, personal data and log files of energy received or dispatched, and time intervals of the grid connection. Most of this information can be acquired (without costs) if the drivers run a tracking application in an offline mode (only transmitting the information when a wireless communication is available) in a mobile device.

Aggregation is based on geographic distribution, taking into account the distribution of transportation lines and power stations, in a semi-automatic process. The system calculates the power available in a circular distance of a pre-defined point.

Aggregated EV has the potential to play a very important role in improving system operations both on the demand and on the supply-side. However, there is a huge variability in the behavior of the individual EV owner. This variability is a challenge for the Aggregator in order to assess the size of the resource available from the community EV. In order to study the impacts of such variability, we develop a modeling approach for the EV community.

A community of EVs can act as an effective distributed energy resource once it is interconnected with the distribution grid. However, we must keep in mind that the principal utility of EV is to provide clean and economic transportation to their owners rather than to generate electricity for grid operations. As a result, the aggregated EV may not always be plugged into the grid. Since EVs may travel different distances every day, they may have different levels of energy stored in their batteries any time they become interconnected to the grid. The community of many EV serves to smooth out such heterogeneity and to make the aggregated entity behave in a more homogeneous manner. The time dependence of EV travel may impact the level of participation of an individual EV to the load and the generation/storage device roles of the community. The variability in the contribution of each EV to the community creates considerable uncertainty in the capability of the community to act as a resource at any point in time.

Due to the personal preferences of each EV owner, the Aggregator cannot know with certainty the individual EV owner schedules and the amount of energy stored in each vehicle's batteries when the EV gets plugged in. Mobi-System analyzes the nature of this uncertainty and constructs an appropriate model under a set of reasonable assumptions. Mobi-System deploys this model to simulate the impacts of an EV community as a load and as a generation/storage device.

The principal sources of uncertainty for an Aggregator are: (1) the duration of the periods during which each EV in the community is connected to the grid; (2) the distances travelled by each EV; and (3) the SOC level of each EV at any point in time.

We propose and intelligent system based on agents' approach, to support the community and to achieve a predefined performance. To analyze the nature of the resulting uncertainty, we need to introduce assumptions to allow quantification of the resulting randomness. Specifically, we limit our analysis to the following set of assumptions:

- Losses in the EVs batteries are neglected, because the losses due to conversion efficiency in the charging stations, or in the EV batteries, or due to transmissions losses, are small – less than 10%;
- The storage capability of each EV battery remains unchanged during the study period, and it is a known quantity based on the car model;
- Parking lots have big capacities;
- EVs are always plugged in when they are parked;
- Charging stations and outlets at a particular location do not have any power limitation and are adequate for the EV which gets plugged in at this location.

4.1.1. Aggregator System Main Modules

The Aggregator System main modules are identified in Figure 4-2:

- **V2G System**: Is the system that controls the EV and PHEV connections to the power grid.
- **Users' Profile**: Is the module that interacts with the user, and is divided in the following modules: user registration module, user communication interface, and user profile. The user registration module is the responsible for detecting if the

user is a registered user or not. If so, it shows its information, the number of credits that he/she has, allows him/her to change personal data and driver profile, making suggestions, and also allows buying more credits. If it detects that the user is not a registered one, it asks for the registration. The user communication interface formats the information for the end-user device (e.g., PDA, mobile phone). The size of the information to be transmitted depends on the communication bandwidth and on the visualization capacities of the end-user device.

- **Aggregation**: Is the process of community creation by the selection of users. For the aggregative architecture, the Aggregator's ability to enter into contracts with the electrical grid system operator is independent of any individual vehicle's presence at the charging station. Because the Aggregator can vary the size of its power contract when fewer vehicles are present at charging stations, it is available to bid for ancillary services contracts at any time of day or night. This function identifies EVs in predefined areas (community areas) and identifies available distribution power in a week. Historical data is analyzed (basic statistics functions are applied to time values) to determine safety values for electrical energy markets contracts.
- **User Credits**: This module try to measure the users' participation towards the common goal of the community.
- **Agent System**: The Aggregator system receives ancillary service requests from the grid system operator and issues power commands to contracted vehicles that are both available and willing to perform the required services. Under the data mining of available past data as community capacity aggregative architecture, the Aggregator can bid to perform ancillary services at any time. From the available power in community (based on plugged EVs) the Aggregator bids into the hourly ancillary services market, and compensate the vehicles under its control for each minute that they are available to perform V2G. As such, this aggregative architecture attempts to address the two primary problems with the direct, deterministic architecture. We need to determine a good distribution algorithm to extract electricity smoothly from all available EVs.
- **Transitions Record**: All transactions between EVs and the electrical power grid are stored in a database. This information would give a better insight into limits

to charge/discharge which, in turn, would allow understanding the users' behavior. To keep user data privacy, the data is stored without a direct relation to the user.

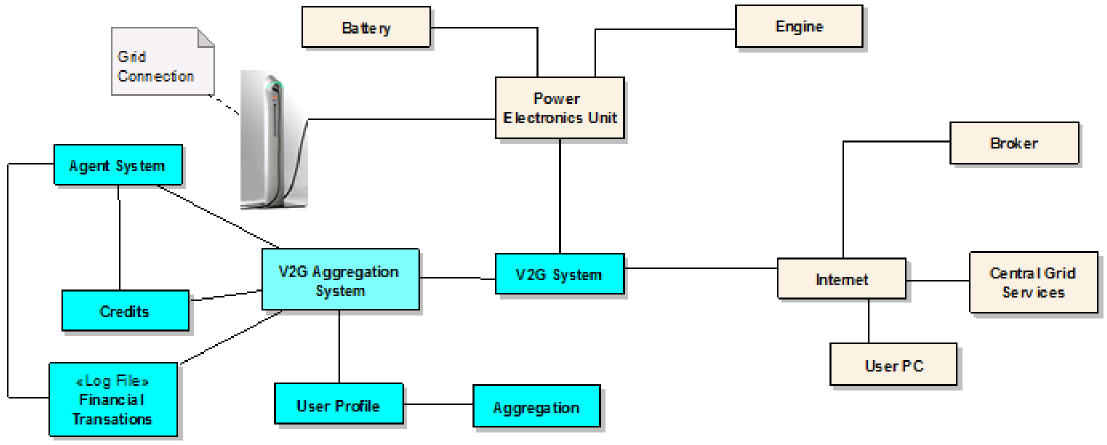


Figure 4-2: Main modules and interfaces of the V2G Aggregation system

Different communities should be established (when the number of EV increases), mainly in function of their geographic location, and created based on the electrical distribution networks, in order to avoid investments or charging overloads. This community should follow pre-defined rules implemented by the Central Grid Operator, Figure 4-3.

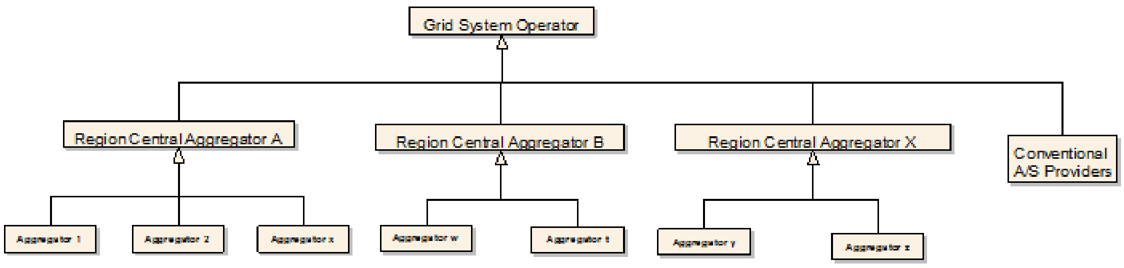


Figure 4-3: Aggregation hierarchy

4.1.2. Managing User Behavior

Drivers express their behavior in a profile. Based on user's profile, the system calculates community aggregation efficiently based on individual data aggregation. However this pre-defined data will have changes due to unexpected situations, like failures, among others. Community goals are defined with a good failover gap, but system should manage the user behavior towards a common goal. For that, it is proposed in this work a novel approach based on the stock exchange metaphor, illustrated in Figure 4-4. This idea has been used in a collaborative system [Silva, 2007], [Ferreira, 2008]. The main idea is to promote a heath environment, where users look for a common goal and this effort is converted in credits mechanism that can be converted in money. The system looks for users' data and transactions performed to identify critical hours (when less EVs are connected). This analysis divides time in several periods. In this work it was proposed 5 periods: (1) night period, when more than 99% of EVs are plugged; (2) when 99% to 90% of EVs are plugged; (3) when 75% to 90% of EVs are plugged; (4) when 75% to 50% of EVs are plugged; (5) critical period, when less than 50% of EVs are plugged. The tracking system was used to associate time to these periods. Credits are based on the time intervals in which the EVs are connected, on the power available for the market, on the energy delivered back to the electrical grid, and on time criticality (in our case, based on the criteria described above) for community goals.

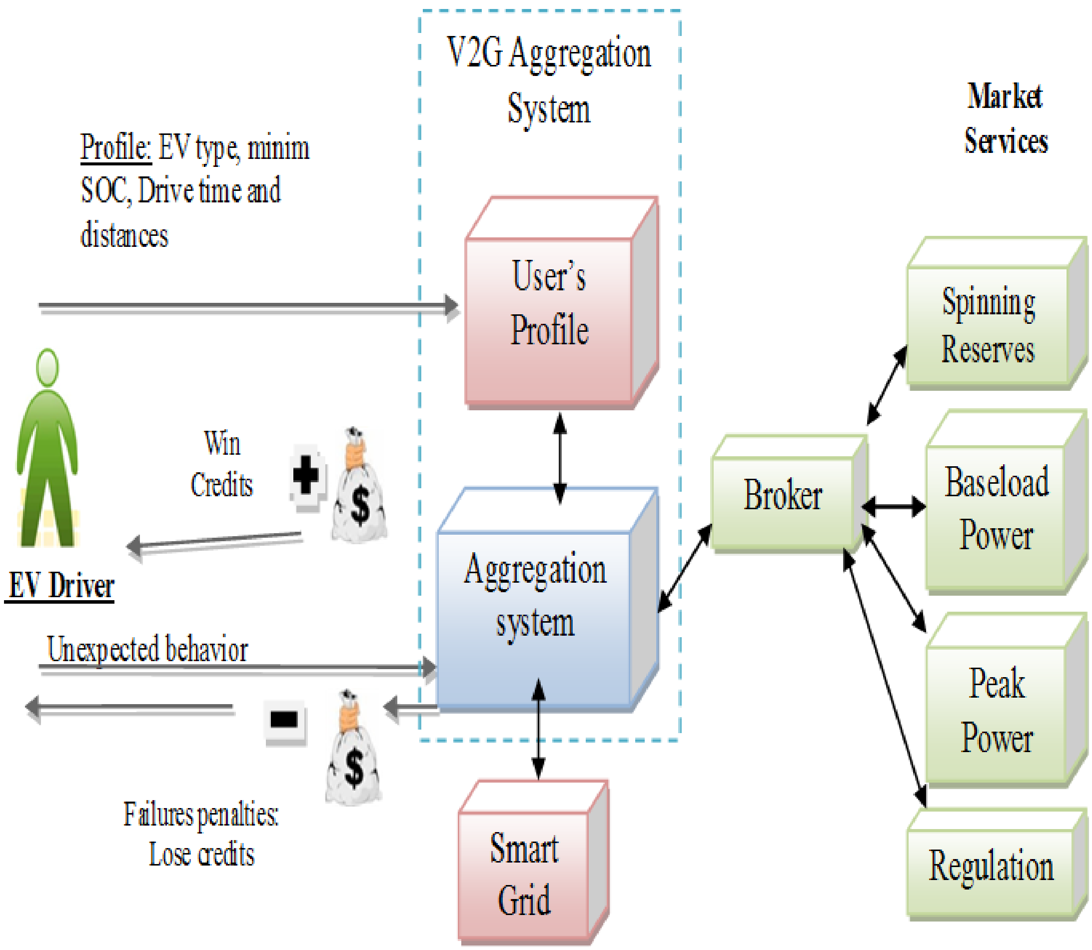


Figure 4-4: Proposed credits mechanisms

Users' failures are measured by the unexpected changes on the time that EV should be plugged (defined by the user in their profile). These failures, if not reported to the

Aggregator system before, are penalized with loss of credits. If the user replaces automatically his failure by other user, no penalty is applied. If the failure is not reported previously, the system penalizes heavily this behavior and forwards the failure report in order that the system finds a solution. An important research issue is how to implement the right credits mechanism. This collaborative environment can be applied for charging processes of the EVs, where users help each other to find the cheaper price.

4.1.3. Collaboration Features

Users can also interact and collaborate among themselves to improve their knowledge, or by allowing them to express their needs and preferences. The features presented below are created to keep users informed, motivated and with intention to collaborate more frequently:

- Punctual Changes on User's Plugging Time: Users that identify in advance changes to their committed plug-in time can find a substitute among community members, avoiding system penalties.
- Cooperation Area: An area where users can ask questions or provide different kinds of knowledge to cooperate in EV related area. For example, one user that is good in dealing with information resource tools could provide prices and other helpful information to others, but if he knows nothing about the batteries or EV working processes, he can ask any user if they want to cooperate with him.
- Helping Area: An area where users can post questions and answers and some sort of help on any topic. This space could be accessed and viewed by any registered user. System gives credits to users that provide good helping answers to posted questions.
- Abuses or Faults Reporting Area: An area provided to report abuses of different kinds, like comments or bad use of the system. The system manager can penalize users for it. The reason for providing this area is essentially for discouraging users to commit abuses or faults.
- Request: An area where users can ask for specific questions. The system manager can use those requests to tune the community.
- Awards: Created in order to promote and recognize outstanding behavior (for example, no changes in the profile). The awarded users receive extra credits.

- Community Newsletter: The system manager publishes a digital newsletter with community information and EV related information.
- Users Rankings: Users rankings are created to represent the most valuable collaborators, calculated by adding all credits earned by each user.
- Alerts Subscription: Users can subscribe different kinds of alerts: notifications, comments, or other EV interactions.

4.1.4. Simulation Results Towards Aggregation of Available Electrical Power

To have some results regarding the proposal aggregation approach it was used data from tracking system (trips time and distances), and based on EV efficiency, it was estimated the remaining battery energy of each EV (SOC – State of Charge level). Based on these individual parameters it was achieved the community SOC level (sum of all individual community SOC levels). The studied population (from Lisbon area), with 50 cases, contains a mixture of ISEL (Lisbon Superior Institute of Engineering) students and their parents. In Portugal, the Nissan Leaf was introduced to the market with a 24 kWh battery pack and autonomy of 160 km (value considering a careful driving style). Once there is a diversity of EVs, with different energy storage capacity of the batteries, it was assumed that in average each EV has 15 kWh of energy available for the electrical energy market (each EV owner can choose the battery type of his vehicle from a pre-defined list, and define the value of energy to be available for the electrical market), and that during working hours only 75% of EVs are plugged.

From tracking data it was identified three main time intervals, with different profiles regarding energy consumption or availability: (1) From 19 h to 23 h (return home and home peak consumption hour). In this period test community have around 2 MWh of available energy (the minimum community available energy is reached in this period). In this case it was assumed 1.5 MWh as a safe value for the energy market. (2) From 23 h to 7 h (EV batteries charging period at home). Maximum community available energy is reached in this period, after the charging process of EVs is finished. (3) From 7 h to 19 h (Remaining hours – travel home-work, EVs plugged at work place, and travel work-home) Assuming that 75% of EVs are plugged, it has a community available energy ranging from 3 MWh to 4 MWh. These charging profiles were created through clustering data on a excel graph, presented in Figure 4-5. For more information see [Sousa, 2010], [Ferreira, 2010a].

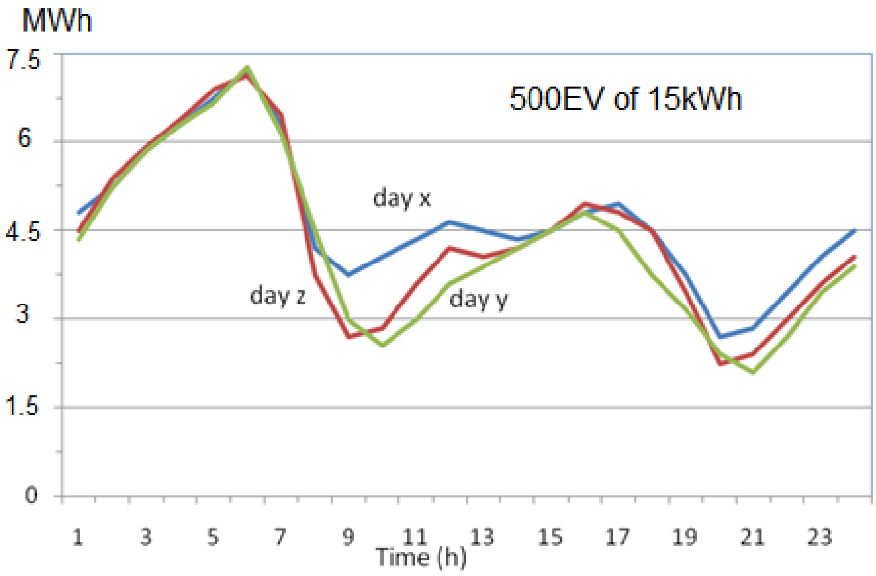


Figure 4-5: Electrical power available during day for 500 EVs of 15kWh of energy stored in batteries, taking into account the movements identified with the tracking system

4.1.5. Power Market Community Revenues

Main power markets for EV and PHEV are Regulation and Spinning Reserve (SR). Regulation is contracted and paid for the available power capacity at any one hour, with a separate and typically much smaller payment for the amount of energy provided. This means a generator sitting idle with the ability to provide regulation is paid the same capacity payment as the generator that was called upon to provide regulation. SR is the generation capability that can provide power to the grid immediately, and reach full capacity within 10 minutes when called upon by the ISO/RTO (Independent System Operator / Regional Transmission Organization). This power must be provided by equipment electrically synchronized with the electrical grid. Typically, requests for this generation to provide power are made around 20-50 times a year.

Major economic advantages for EV and PHEV comes from Regulation, because prices in average are three times higher than those obtained with SR, and in addition, the cycling of the storage device is much more frequent for Regulation than for Spinning Reserve. Regulation is controlled automatically, by a direct command from the grid operator (thus the synonym “automatic generation control”). Compared to Spinning Reserves, it is called far more often (for instance, about 400 times per day), and requires a faster response (less than a minute), and is required to continue running for shorter durations (typically a few minutes at a time). The actual energy dispatched for Regulation is some fraction regarding the total power available and contracted for, since the time in which power is delivered is very small. We shall show that this ratio is important to the economics of V2G (Vehicle-to-Grid), so it was defined the "dispatch to contract" ratio as:

$$R_{d-c} = E_{disp} / (P_{contr} \cdot t_{contr}) \quad \text{[Equation 1]}$$

Where R_{d-c} is the dispatch to contract ratio (dimensionless), E_{disp} is the total energy dispatched over the contract period (MWh), P_{contr} is the contracted capacity (MW), and t_{contr} is the duration of the contract (hours). R_{d-c} is calculated separately for regulation up or down. Kempton, in [Kempton, 2001], uses a value of 0.1 for R_{d-c}. Based on previous studies of Kempton and Tomic [Tomic, 2006], and taking into account $30 MWh for Regulation services and $10 MWh for Spinning Services, it has the following revenues, presented in Table 4-1, for European power markets. These values are calculated in an individual basis, but in a collective approach they should increase, mainly the SR values.

Table 4-1: Annual Revenue of EV and PHEV in the Electricity Market (values are given in US$, assuming that vehicles are plugged in 85% of the time) [Tomic, 2006]

	Regulation	SR	Total
2 kW	400	100	500
6 kW	1200	300	1500
10 kW	2000	500	2500
15 kW	3000	700	3700

4.2. Microgenetation and Distributed Energy Resources

Microgeneration study is out of this thesis scope, but due to a large synergy that can be established between microgeneration and EV, this Section is dedicated to this subject. Part of proposed approaches can be reused for this topic. This is part of a new reality of Distributed Energy Resources (DER), as part of intelligent power systems to construct a hybrid, fundamentally different architecture for an ICT-network, enabling the power grid to flexibly accommodate novel devices or clusters of devices. Several initiatives are taking place on this topic: (1) Intelligrid [Dolle, 2009], a program in the United States executed by EPRI; (2) Gridwise [http://www.gridwise.org]; CRISP project [Andrieu, 2005]; (3) European initiative under the program EU_DEEP-project [http://www.eudeep.com] and the activities; and (4) IREDcluster [http://ired2.iset.uni-kassel.de]. As described in various articles in literature [BenHabib 2006], [France, 1986], there are many implications for the grid when making a transition from centralized to decentralized control with merely some central coordination. When compared to hierarchically operated electricity grids, with power centrally generated at high voltage levels on a large scale, delivering electricity to consumers on lower voltage levels in the network, SG [Thanh, 2008] offer a number of challenges for technological research. Our work proposes the creation of a collaborative broker system to handle EV and microgeneration integration on electricity market, supported by users collaborative process, transaction data integration and central information repository knowledge, where it stores past experience to help on solving problems such as:

- The excess of energy produced by microgeneration should be distributed locally (to avoid transmission loses) to the EVs (that can act as storing devices) or to consumers, minimizing the use of the transmission and distribution networks. In this context, arise the Energy Storage Systems (ESS), which can store the excess of energy produced by microgeneration, and deliver this energy when it is necessary, and that includes the EVs. These ESSs are controlled by the broker.
- The price of the electricity should be determined taking into account the production capacity, because the microgeneration is based on renewable energy sources with different profiles of production.
- The interaction between the microgeneration and the consumers should be implemented taking into account a maximization strategy to the user. To obtain a good contribution of electrical energy to the electrical power grid by the microgeneration producers, the electricity market should implement attractive benefits to buy or to sell. The control of energy flow between microgeneration producers and the electrical grid, taking into account the electricity market, the consumers and the sellers, is coordinated by the broker.

The proposal central information repository can store and manage historical data on electricity consumption and production. From this central repository it is possible the development of tools to extract knowledge from past electricity exchange log files, electricity market prices, renewable energy availability and capability, consumed or delivered energy if EV is plugged at home, and electrical distribution network constraints. Also, the social networks are integrated as a tool to share and spread useful related information. This central repository will be later in a Smart Grid environment, a fundamental module to store all kinds of SG data and to solve the problems of different data format diversity.

4.2.1. Microgeneration and Micro Grids

Nowadays, the microgeneration emerges as a necessity to reduce the greenhouse effect caused by pollutant sources of energy. However, associated with the electricity market and the increasing in the technological development, the microgeneration of electrical energy has a great potential to the consumers, and to the distribution grid.

The main sources of energy in a microgeneration are the wind and the sun, and the electrical energy is obtained from micro wind turbines and solar photovoltaic panels. These sources of energy are the most common and the easier to implement in microgeneration facilities. Presently, this produced energy is provided to the electrical power grid without any concern about the electricity market or the electrical power grid capability to receive energy. In a Smart Grid context with Energy Store Systems (ESSs), like batteries, EVs, ultracapacitors or flywheels, the energy produced in excess from the microgeneration can be stored in these systems. Posteriorly, this stored energy is used to help the electrical power grid, taking into account:

- **The energy produced by other sources of energy.** When it is required to provide a great amount of energy, as during EV fast charging, this energy can be delivered from the ESS. It is also important to provide energy to the electrical power grid in transitory moments, as during consumers' consumptions peaks.
- **The electricity market**. It is very important to the EV owners to buy or to sell electrical energy with the best price possible. EVs plugged in conjunction with microgeneration have the potential of charging the batteries when there is available energy form the microgeneration production, and of discharging part of

the energy stored in the batteries, until a maximum value allowed, when the electrical grid demands energy (during a registered peak of consumption in the grid). This is why the Vehicle-to-Grid (V2G) has a fundamental role in a Smart Grid.

In this context, from the point of view of the electrical power grid, with the proximity between the microgeneration and the consumers, there are reduced flows of power along the transmission and distribution lines, and consequently, the losses are lower. With this proximity, encompassed in the microgeneration, the possibility of failures occurrence is reduced.

4.2.2. Distributed Energy Resources and the Energy Markets

Distributed Energy Resources (DER), small-scale power generating technologies close to energy loads, are expected to become an important part of the future power system. Microgeneration and EV will play an important role in this process, and nearby community will use the power made available by them, because the electrical distribution network allows it. Since distributed energy resources are installed near the loads, they are likely to be installed on low-voltage distribution systems. The distribution systems also account for the higher percentage of system losses compared with the higher voltage transmission systems, thus, local production of energy by EV and microgeneration causes an improvement on the overall efficiency of the system. DER has the problem of variability (changes in production and consumption of energy), uncertainty (supply contingencies) and unpredictability (renewable generation depends on uncertain weather conditions).

Main important fact is that EV can store local microgeneration production excess and users' can tune their consumer behavior in part based on microgeneration production, i.e., they can develop a collaborative process based on energy production information, so that they can start/stop washing machines and other equipment that do not have an obligatory time constraint.

The energy market has historically been monopolized and governmentally regulated because of its utmost importance. Like water, energy is essential for life and firm grip on it was a logical choice of policy makers. With general globalization, such monopolized, nontransparent and market detached approach has become economically and politically unacceptable. To leave political influences aside, as they surpass the scope of this thesis, it is important to state that global economic development demanded a change. Despite the efforts to save energy and use it as rationally as possible, which are getting more serious every year, the energy consumption is inevitably growing. This is especially significant as the large part of the world is starting its development, and large countries, as China and India, are demanding their share of life standard. New stakeholders appear in this new open market: (1) A broker of electrical energy services is an entity or company that acts as a middleman in a marketplace in which those services are priced, purchased, and traded. A broker does not take title on available transactions, and does not generate, purchase, or sell electric energy but facilitates transactions between buyers and sellers. If a broker is interested in acquiring a title on electric energy transactions, then it is classified as a generator or a marketer. A broker may act as an agent between producers, or an aggregation of generating companies, and marketers; (2) An Aggregator is an entity or a company that combines customers into a buying group. The group buys large blocks of electrical energy and other services at cheaper prices. The Aggregator may act as an agent (broker) between customers and retailers. When an Aggregator purchases power and re-sells it to customers, it acts as a retailer and should initially qualify as a retailer. Our collaborative system has the function of these two entities.

4.3. Collaborative Aggregator Broker for DER

Our investigation proposal is to bring computer science work on software development, Web 2.0, geographic information systems, mobile computation and wireless communications, to create a system to support DER (Distributed Energy Resources) energy exchange, defining local prices and coordinating energy exchange from local community to big producers. The main modules of the proposed system, illustrated in Figure 4-6, are:

- Central Information Repository, that stores information about: (1) user energy consumption (amount and time); (2) energy production with available information of power; (3) energy supplier and source (e.g., hydropower, wind power, photovoltaic, etc); (4) energy prices; and (5) weather information (temperature, wind direction and speed, rain amount, solar radiation, etc). A proper interface is created for user profile, creation and manipulation. This information data is worked under data mining approach for consumption data analyses. We implemented a weather crawler, based on a web robot, to pick weather information from pre-defined sites and store this information on this information repository. Community creation is based on clustering available user profiles, based mainly on geographical position.

- Information Communication Tools (ICT), those mainly are: communication networks for information exchange; and high-speed digital monitoring, to take care of energy transactions.
- Smart meters, to measure local energy consumption and production, and Mobile Application, an application to run on a mobile device (like PDA or IPhone) to receive and send control information for charging the EV batteries and also for system interaction.
- Geo-reference graph based on electrical distribution network (a description of this is found in [Ramada, 2010]).
- A collaboration software tool, that has as goal to help people involved in a common task. It allows several independent computers working together, through an Internet connection. In a Smart Grid context it is very important to establish patterns related to the produced and consumed energy from microgeneration and the profiles of the consumers.
- Energy Market functions.
- Power Quality monitoring.

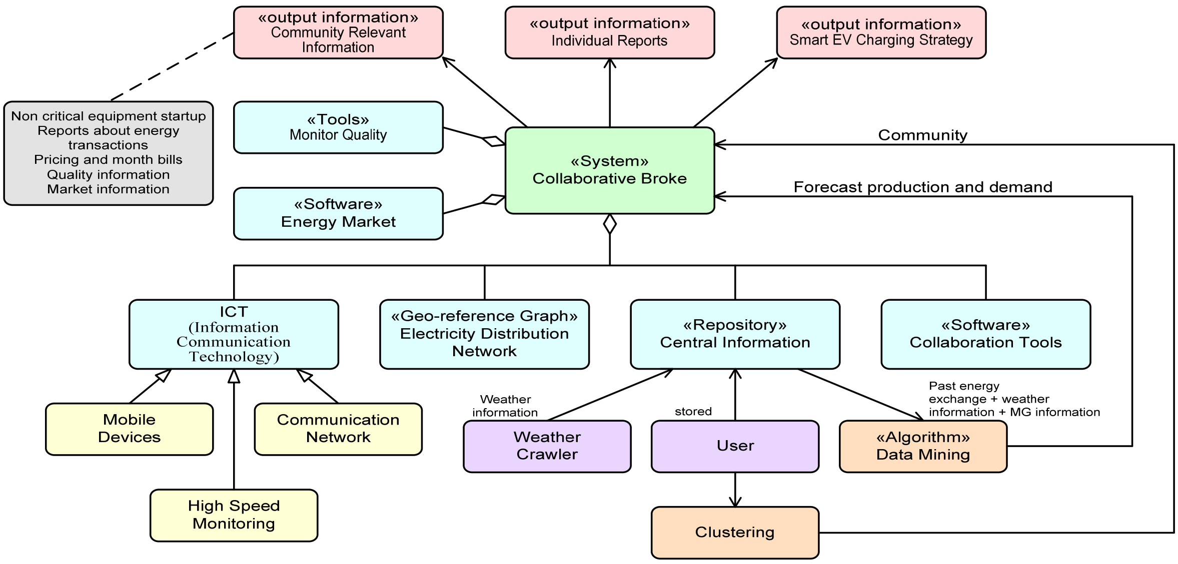


Figure 4-6: Main modules of the Collaborative Aggregator Broker system

4.3.1. Repository of Information, Weather Information and Data Mining

A deterministic approach to forecast microgeneration production is complex, because wind power depends on the type of turbine, location (urban versus rural), height, orientation and wind speed. In solar photovoltaic generation the power generation depends on the environmental factors, mainly the irradiation and the cell temperature. Each case should be analyzed and this should raise a complex scenario. A renewable production prediction is achieved based on data mining approach, where past stored production data is used with weather forecast (e.g., wind speed and direction, temperature and weather condition) to predict microgeneration production. For this task a database is used to store all transactions data (EV charging and discharging and also microgeneration production), weather information and user profile information. Several approaches using data mining algorithms can be used for knowledge extraction: past transactions data can be used to try to identify, with clustering approaches, main periods of consumption and production, and trends with the identification of the main behavior. We implemented a weather crawler, based on a web robot to pick weather information from pre-defined sites (in our case, a Portuguese weather site). Details on this can be found at [Ramada, 2010] and in Figure 4-7, that shows examples of information for wind and temperature. Also by manipulating available data it is possible to create several reports, like: home energy consumptions, weekly, monthly and annual energy expenses, price variation of electricity, and charging periods, among others.

A Naïve Bayes (NB) classifier can be used to relate consumption and microgeneration production to weather information (temperature, wind speed and direction, and also humidity, with raining information), and a small example is shown in Table 4-2. Production capacity is divided in n classes (a configurable number, gotten from clustering analyses of past data). In our implementation $n = 10$, and classes are defined based on percentage of production capacity: class 0 is zero production, class 1 is performed from 0 to 10% of production, and in class 10 it is reached maximum production (100%). Wind and temperature were also discretized in a pre-defined class. Time is also a discrete variable. In our example we simulate one day that have only one class (corresponding to all consumption and production in a day), but in a real case more classes should be added. In the literature several authors divide the hour in 20 to 10 minutes events, so the number of classes goes from 3 x 24 = 72 to 6 x 24 = 144. Wind speed and directions are correlated to pre-defined classes that characterize local Eolic production, and temperature is divided in interval classes. Wind production capacity was divided in 7 classes (0 to 6), (see Figure 4-7), and temperature in 5 classes (1 to 5). Renewable energy production from Eolic is more dependent on wind speed, than energy production from solar photovoltaic is dependent on solar radiation.

Latitude: *40º 08' 30" N* Longitude: *08º 52' 42" W* Profundidade: *9 m*

Data		Mar total (*m*)	Ond. (*m*)	Dir. ond.	Vaga (*m*)	Vento (*nós*)	Dir. vento	Sets	Temp.Água (ºC)
2011-07-29 (*6ª feira*)	H00	1.1	0.5	→	1.0	15.6	↓		15.4
	H06	1.0	0.4	→	0.9	13.6	↓		15.4
	H12	0.9	0.3	→	0.8	9.7	↓		15.5
	H18	1.0	0.3	→	0.9	17.5	↓	★	14.5
2011-07-30 (*sábado*)	H00	1.1	0.3	→	1.0	19.4	↓	★	14.5
	H06	1.1	0.3	→	1.1	19.4	↓	★	14.5
	H12	1.1	0.3	→	1.0	17.5	↓	★	14.5
	H18	1.1	0.3	→	1.1	21.4	↓	★	14.5
2011-07-31 (*domingo*)	H00	1.2	0.3	→	1.1	21.4	↓	★	14.5
	H06	1.1	0.3	→	1.1	19.4	↓	★	14.5
	H12	1.0	0.3	→	1.0	15.6	↓	★	15.5
	H18	0.9	0.2	→	0.8	13.6	↘	★	15.5
2011-08-01 (*2ª feira*)	H00	0.8	0.2	→	0.8	15.6	↓		15.5
	H06	0.8	0.2	→	0.8	15.6	↓		15.5
	H12	0.7	0.2	→	0.7	11.7	↓		15.5
	H18	0.7	0.2	→	0.6	11.7	↓		15.5
2011-08-02 (*3ª feira*)	H00	0.7	0.2	→	0.7	13.6	↓		15.5
	H06	0.7	0.2	→	0.7	13.6	↘		15.5
	H12	0.6	0.2	→	0.6	7.8	↘		16.6

Figure 4-7: Wind effect and weather information (windy and temperature) taken from a weather site for Lisbon (information in Portuguese language)

Since temperature and wind speed are continuous variables it was performed a discretization by the division of values into pre-defined classes. The number of classes introduced is a configurable parameter. Table 4-2 shows a small example on how a NB algorithm works, showing the occurrence probability of an event. In this case we want to know the expected production taking into account the forecast of sun and temperature and wind values in the range of pre-defined class 2. Based on historical data (in case 10 events) NB shows the probability for *p1* to *p10*. For more details see [Ramada, 2010]. From this particular case of renewable energy production capacity based on current approach, *p3* and *p4* have highest probability. Assuming an installed capacity of 3 kW this means under these conditions that the renewable production is around 1 kW.

Table 4-2: NB (Naïve Bayes) classifier approach for a small example

Day	Weather	Temperature	Wind	Production
1	Sun	2	3	3
2	Cloudy	1	5	4
3	Rain	4	1	2
4	Sun	5	4	9
5	Sun	3	2	4
6	Rain	1	2	1
7	Cloudy	3	2	2
8	Cloudy	4	6	5
9	Rain	3	3	3
10	Sun	3	2	4
11	Sun	2	2	???

P (production) = 0.1 (10 classes)

P (sun|p3) = 1/2 (appears one in two examples of P3)

P (sun|p4) = 2/3 (appears two in three examples of P4)

…the same for the others examples

P (p1|sun + T2 + W2) = P(p1) x P(sun|p1) x P(T2|p1) x P(W2|p1)

P (p2|sun + T2 + W2) = P(p2) x P(sun|p2) x P(T2|p2) x P(W2|p2)

…

P (p10|sun + T2 + W2) = P(p10) x P(sun|p10) x P(T2|p10) x P(W2|p10)

4.3.2. Energy Market and Smart Grid Integration

Energy market participation will require a detail control about electricity flow, and registered users would like to control charging or discharging processes, in association with the electricity prices. These prices are depending on the electrical energy supplier and time, and local broker picks from a pre-defined server on a standard XML file. Related to the microgeneration the main function is to manage the produced and consumed energy in conjunction with the needs of the consumers.

In this scenario, in Figure 4-8 is shown an electrical power grid with: solar photovoltaic panels (which only produce energy), micro wind turbines (which only produce energy), EVs (which can receive or provide energy), and energy storage systems (which, like the EVs, can receive or provide energy). Beyond the flow of energy between these parts, there is also the sharing of information, controlled by the collaborative broker. Also in this figure are shown the blocks of the Maximum Power Point Trackers (MPPTs) (for the solar photovoltaic panels and micro wind turbines), and the blocks of the AC-DC and DC-AC converters to adjust the levels of the voltages and current between the parts.

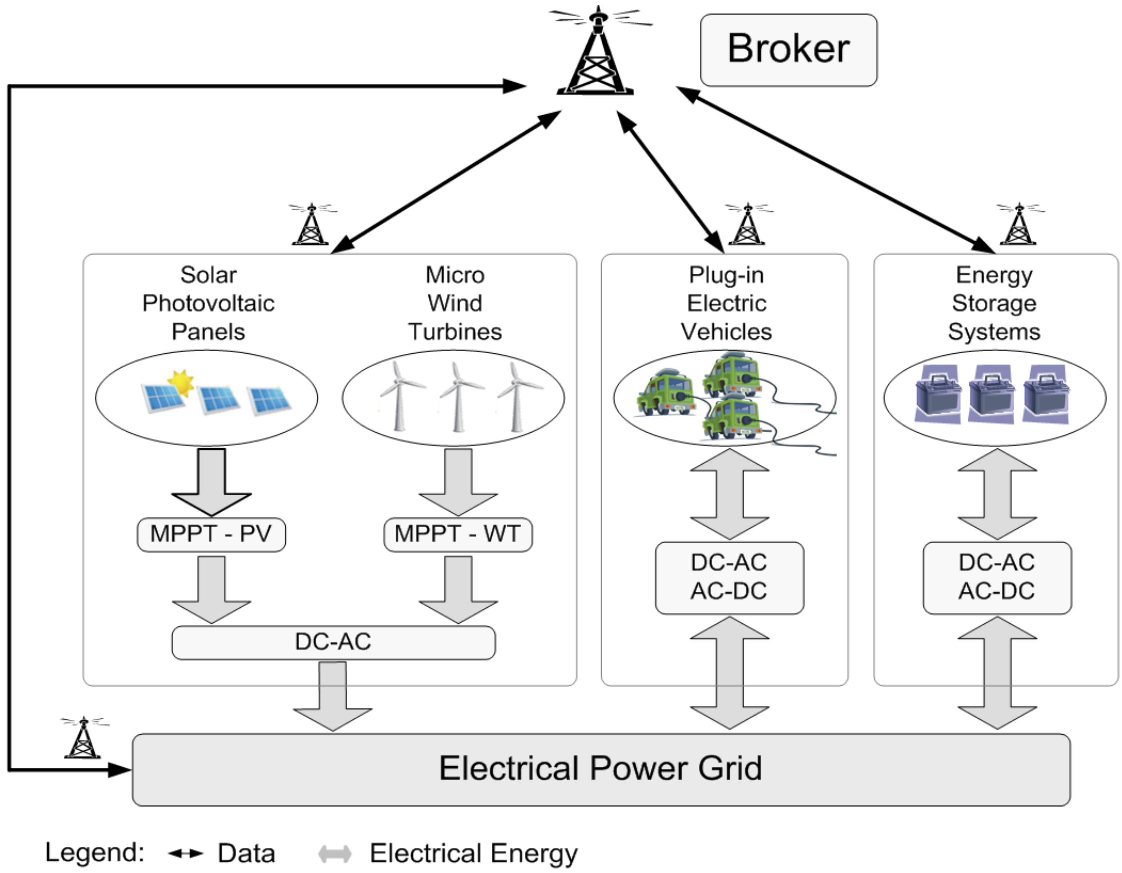


Figure 4-8: Integration of microgeneration, EVs and ESSs in an electrical distribution network controlled by a broker

4.3.3. Collaboration Tool

This is a tool for the users, based in two main characteristics:

- The batteries of the EV: the technology of the batteries (if Lead-Acid, Nickel or Lithium), the energy storage capacity of batteries in kWh; the characteristics of the batteries for receiving and delivering energy, taking into account different rates of charging or discharging; and the SOC (State of Charge) and SOH (State of Health) of the batteries.
- The utilization of the EV: considering the profile of the user and of the community; important characteristics, like the data and the time of the travels,

and the distance planned to be travelled, which is particularly important to define the energy that the EV owner can sell, or the energy needed to charge the batteries in fast charging mode.

How does a group of interested stakeholders collaborate to create real-world DER (Distributed Energy Resources) pilot programs that benefit multiple stakeholders? The following lines outline important questions to address and steps that can be taken towards a common goal. In a Smart Grid scenario, there must be a collaborative process between electrical power grid, EVs, microgeneration and the Electricity Market. In this collaboration, the distribution network uses the shortest path (with less impedance) to deliver energy production excess, and EVs, if available, can store this local production excess. If the electrical grid does not have local EVs, the network can deliver to the nearest neighbor EVs, establishing a collaborative process. Also if EVs SOC (State of Charge) is above drivers' requirements, homes at neighborhood can take EVs energy. Non critical equipment (e.g., washing machines and others) can be started when there is a local production excess. Recording data can show periods of low consumption and the operation of these equipment can be scheduled these periods (in a Smart Grid it is possible to start the operation of equipment taking into account real time information). This collaboration is controlled by the central broker, for accounting purposes, and the price is established according to local production and local demand. The system will work always practicing better prices than the ones of big electrical energy distribution companies, and will always try to minimize energy transitions outside the community. The community is mainly defined by the electrical distribution network topology, that could be reached and controlled by a collaborative broker, and the energy can flow in different ways, as shown in Figure 4-9.

As previously said, the flow of energy is controlled by the central broker. This control is useful in many aspects, mainly when the users have capability to produce energy through microgeneration, but the electrical power grid does not need to receive energy. In this scenario, with the collaboration within the different parts in the Smart Grid, the energy produced by microgeneration can be distributed to EVs or to other home consumers. This distribution of energy should take into account the production and sale costs. Prices should change based on production capacity and energy needs. So the prices of electricity vary in time, but for that a measurement capability should be available at the consumer's side. These meter devices have as only inconvenience their high cost. If the price of electrical energy varies significantly during time periods of the day, customers can respond to this price variation structure with significant changes in energy use, reducing their electricity bills if they adjust the timing of their electricity usage to take advantage of lower-priced periods and/or avoid consuming electrical energy when prices are higher. Based on energy price, customers' load use modifications would be entirely voluntary. Market based solutions also give solid background to develop new business opportunities, for example, to Aggregators. The main obstacle to introduce more price granularity at consumer's level is the cost of installing and monitoring the electrical energy meters that allow remote data acquisition.

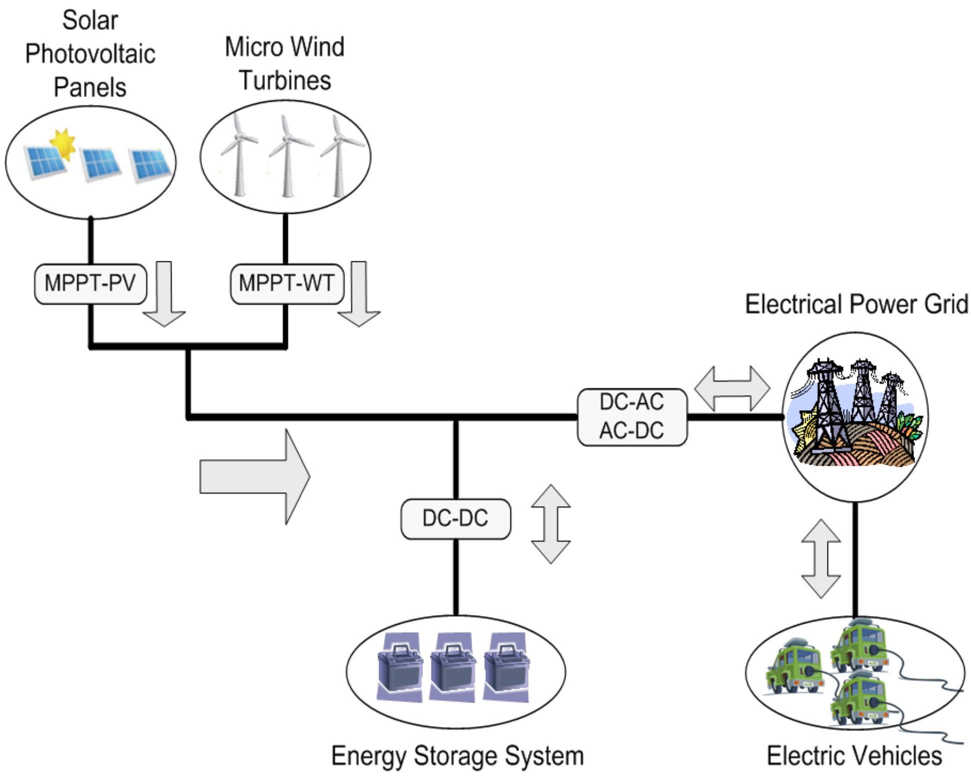


Figure 4-9: Energy flux in an electrical distribution network with microgeneration, EVs and ESS

4.4. Conclusions

In this Chapter Mobi-System main energy market functions were identified, taking into account the defined objectives. On electricity market functions, the main systems developed were: EV Aggregator, EV community creation, and the collaborative broker for DER.

EV Aggregator is the main contribution, where is proposed one system to create and manage the EV community, with a credit-based approach that can be converted into money to incentive user's participation. In the author's point of view, the use of this credit-base system, together with rankings, promotes an open and healthy competitive environment. Also, in the future, to increase the market share of EV and PHEV, there is a need of these types of systems to explore the energy market potential of these types of vehicles. Also, renewable energy sources integration can benefit from a community coordination action, where users can captures renewable energy produced in excess at lower prices. This work was presented in the Conference EVS-25 (The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition), in China, last November 2010, and the collaboration with the American company ElectronVault was initiated. This cooperation can be on a module of ElectronVault system for EV, where community identification and collaborative work could increase the package attractiveness.

5. Mobi-System: Sustainable Mobility Functions

In the European Union (EU), over 60% of the population lives in urban areas (information from Eurostat), and thus, air and noise pollution are getting worse each year. Urban traffic is responsible for 40% of CO_2 emissions, and 70% of emissions of other pollutants arises from road transport [Paper, 2007]. Increasing traffic in town and city centers is responsible for chronic congestion, with the many adverse consequences that this entails in terms of delays and pollution. Every year nearly 100 billion euros, or 1% of the EU's GDP [Paper, 2007], are spent by the European economy to deal with this phenomenon. Several solutions have been proposed to these problems, such as a diversity of intelligent transportation systems and solutions.

Transportation systems have witnessed significant advances in the past decade, such as, improved traffic monitoring and control systems, new vehicles with higher fuel efficiency, and on-board devices with navigation capability based on the Global Positioning System (GPS). These and other technologies have had a very direct and positive impact on human mobility, quality of life, trade, employment, global supply chains and territorial cohesion.

In most European cities, travelers can choose among different modes of transport, including private vehicles, taxis, railways, buses and other forms of public transportation. However, providers of transportation services operate independently, rather than collaborating in a holistic fashion. In such an uncoordinated setting, travelers are in charge of planning their own travel route and are typically unaware of the current conditions of the various transportation networks at a given time of day. In addition, travelers are often unaware of the exact monetary costs and of the environmental impact that a certain mobility option may incur. All of these factors add to the lack of attractiveness of public transport and risk of inefficiency in today’s transportation systems.

EVs that are presented to the market nowadays have a reduced autonomy range when compared with traditional internal combustion engine vehicles, mainly due to the significant lower energy density of current batteries used on these types of applications. Vehicle designers and Original Equipment Manufacturers (OEM) must balance the size of the battery pack in the vehicle with its weight and its price, in order to get a final solution that the market may accept through a compromise of vehicle cost and available autonomy. In fact the battery pack is the main component that dictates the higher vehicle price and the lower autonomy when compared with internal combustion engine vehicles. This lower autonomy and the significant higher time required to charge the vehicle batteries (in normal mode it takes usually from 6 to 8 hours, and in fast charging it usually takes about 30 minutes) limits the distance that each driver is able or is comfortable to drive, without reaching the battery end of charge. All this limitations and use constraints are reasons for FEV (Full Electric Vehicles) to have a small acceptance in the market.

Mobi-System develops a solution that supports the driver with the appropriate and relevant information to decide and plan his/her journey using an EV, reducing the constraints related with the vehicle autonomy and allowing the driver to perform the journey with reduced anxiety about vehicle range. The proposed solution (Figure 5-1) integrates the data from the public transportation infrastructure, car and bike sharing systems, and carpooling, interacting with the driver through a mobile device that can be carried with the driver, in or out of the vehicle. This system is also able to, based on real traffic information, give decision for the best option taking into account pre-defined criteria (like fastest option, cheapest option, and also guidance), as Figure 5-1, suggests.

In the next Chapter sections are described briefly the systems: Real Time Information and Best Path, Car Pooling, Car Sharing, Bike Sharing, and Public Transportation Information Integration.

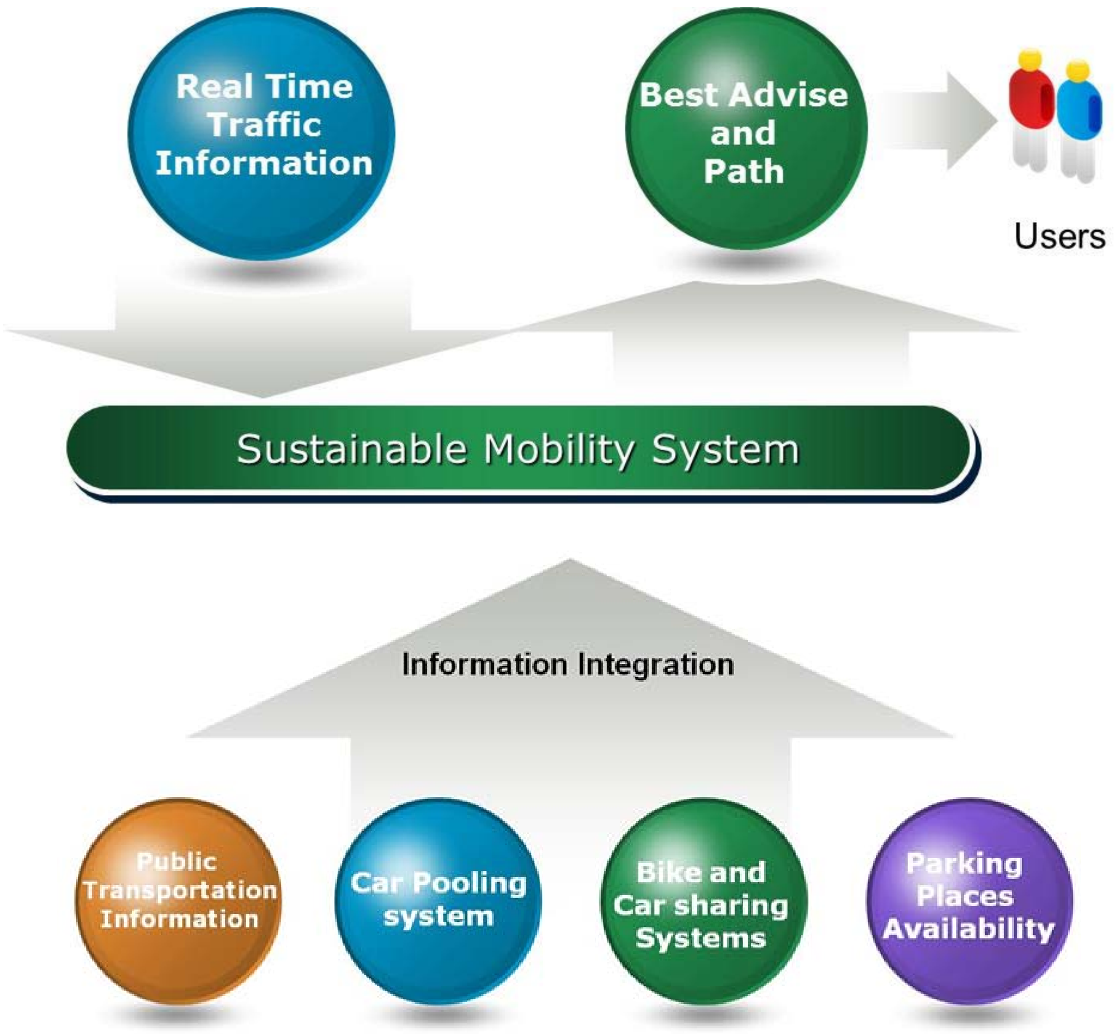


Figure 5-1: Main Sustainable Mobility System objectives and sub-systems

5.1. Real Time Information and Best Path

Real time information is available from road concessionaries, but outside these organizations the access to this information is most of times denied. There are technical issues to solve because each organization has its own data format, and data integration is a real problem. During current research work several approaches were performed to have access to these data (with the Municipal Chambers of Lisbon and Loures, and with the company Brisa), but all the requests have been denied. We turned around this problem by the creation of a web crawler to pick traffic information from specialized sites by pre-defined heuristics, and a XML file with traffic information was created [Fontes, 2008]. The XML file is an approach of future data integration from different source providers. In

Figure 5-2 is illustrated the process of XML file with road information oriented to a geo-reference graph.

Arc	Coordenates (lat,long)	Name
1	38.927410, -9.011100	Alhandra
2	38.894050, -9.048801	Alverca
3	38.848341, -9.089346	Santa Iria
4	38.790796, -9.114538	Sacavem
5	38.787406, -9.105337	Portela/Moscavide
6	38.717140, -8.948650	Montijo
7	38.740385, -8.931608	Alcochete
8	38.642651, -9.049044	Lavradio
9	38.607083, -9.019177	Nó IC21-IC32
10	38.583166, -9.017658	Coina
11	38.589418, -8.864434	Lau
...	...	...
50	38.689940, -9.177090	Pte 25 Abril
51	38.700951, -9.424789	Cascais
52	38.717284, -9.385188	Golf do Estoril

Arch	Road	Lenght (m)	Node Max. Speed (Km/h)
{1,2}	A1	5000	120
{2,3}	A1	6200	120
{3,4}	A1	7000	120
{3,5}	IC2	8500	80
{5,49}	IC2-A12	6600	120
{49,6}	A12	9900	120
{6,7}	IC3	4500	120
...	...	...	
{37,39}	A8-A9	11500	120
{39,40}	A9-A10	5800	120
{39,2}	A9-A1	3300	120


```
<graph>
        <node id="1" name="Alhandra" lat="38.927410" long="-9.011100"/>
         <node id="2" name="Alverca" lat="38.894050" long="-9.048801"/>
        <node id="3" name="Santa Iria" lat="38.848341" long="-9.089346"/>
        <node id="4" name="Sacavem" lat="38.790796" long="-9.114538"/>
        <node id="5" name="Portela" lat="38.787406" long="-9.105337"/>
        ...
         <node id="51" name="Cascais" lat="38.700951" long="-9.424789"/>
        <node id="52" name="Golf do Estoril" lat="38.717284" long="-9.385188"/>
        <node id="53" name="Pontinha" lat="38.768703" long="-9.209198"/>
         <arc id="1" name="A1" node1="1" node2="2" length="5000" maxSpeed="120"/>
        <arc id="2" name="A1" node1="2" node2="3" length="6200" maxSpeed="120"/>
         <arc id="3" name="A1" node1="3" node2="4" length="7000" maxSpeed="120"/>
         <arc id="4" name="IC2" node1="3" node2="5" length="8500" maxSpeed="80"/>
        <arc id="5" name="A12" node1="5" node2="49" length="6600" maxSpeed="120"/>
        ...
        <arc id="68" name="A10" node1="39" node2="40" length="5800" maxSpeed="120"/>
        <arc id="69" name="A9" node1="39" node2="2" length="3300" maxSpeed="120"/>
        <arc id="70" name="Eixo Norte-Sul" node1="18" node2="17" lenght="5000" maxSpeed="90"/>
</graph>
```


Figure 5-2: Semi-automatic creation of a XML file with road information to be used for graph creation

The Crawler (WebNews, version 1.0) was configured to pick traffic information from TVI web site [http://www.tvi.iol.pt/transito.php] and also a Web service from Sapo was implemented. Information about nodes were checked against a heuristic table, where a conversion factor (CVF) reduces the node speed traffic (if the rode is blocked, with no traffic flow, the CVF is zero). Figure 5-3 illustrates this process. The result is stored in an adjacency matrix, where the number aij represents the cost of going from i to j. This process creates a graph representing the map, where the arcs represent roads and nodes represent intersections or traffic areas. To determine the best path between two points on a map an algorithm could be applied to this graph to find the path with less weight between the two desired points.

The weight of an arc is basically the average time in seconds that it needs to be traveled, for this it is used the formula $(L / V) * 3600$, where L represents the size of the graph in km and V is the top speed allowed. For all arcs there is a speed limit which serves as the basis for the weight of the cases in which there is no traffic information. When there is traffic information for a particular arc, the weight of this arc is affected because the traffic influences the speed. For example, if an arc with heavy traffic has a speed limit of 90km/h, given the existing traffic, the reduction factor of the maximum speed has a value set between 0 and, based on current traffic information, causing the increase of the time required for this arc to be traversed, as much as its weight increases. If the transit is cut off, the factor of speed reduction assumes the value 0, and the maximum attainable speed is set to 0 km/h, what causes this arc to have an infinite weight.

If traffic is proceeding smoothly, without any problems, the factor of speed reduction has a value equal to 1, and the maximum attainable speed becomes equal to the speed limit, which makes this arc to assume the lowest weight possible, what is translated in a reduction in the mean time the arc needs to be traversed. This weight can integrate also public transportation information and a price associated with CO_2 emission of private transportation. Users can choose the impact parameters based on their strategies, in order to save money, to satisfy conveniences, or even to save time. See Final Year Project at ISEL [Fontes, 2008] for a complete description of this process.

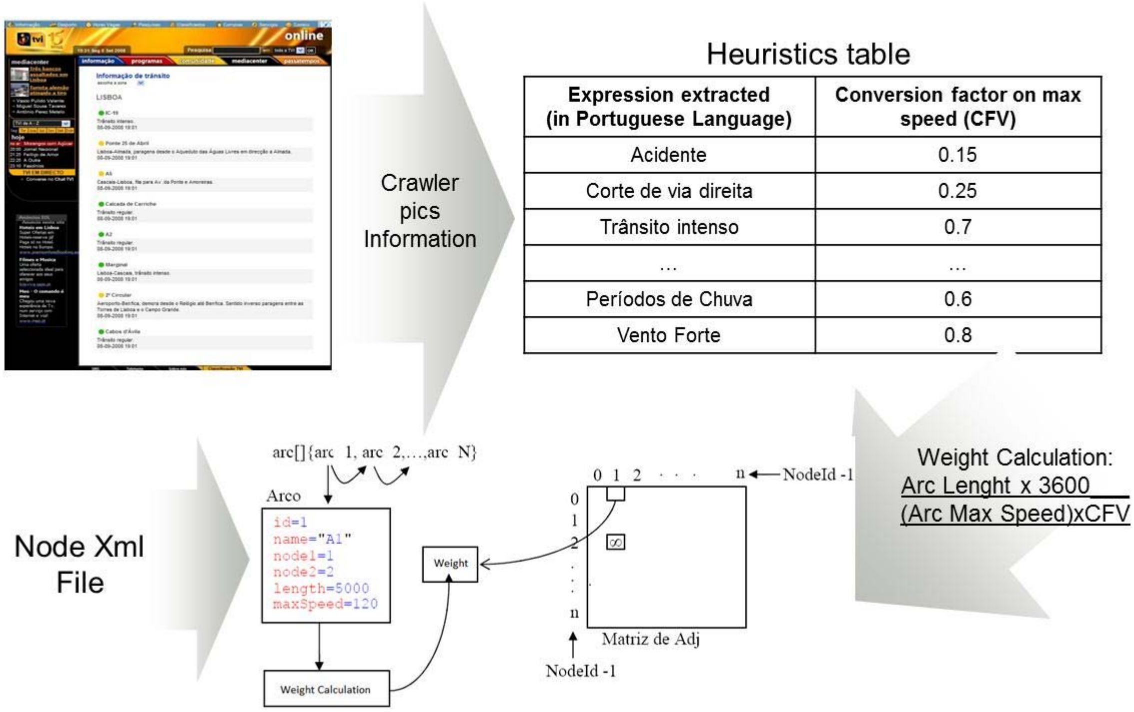


Figure 5-3: Graph node weight calculation based on traffic information from web sites (traffic information in Portuguese language)

Example: Path A1 (Alhandra – Alverca). Maximum speed allowed on this section: 120 km/h (motorway), but traffic information shows average speed is 84 km/h. Distance is 5km, so *arc weight* = *(arc distance / average speed)* x 3600 s= (5000/84000) x 3600 = 0,0595238 x 3600 ≈ 214 s.

Let's consider, in this example, that public transportation takes more or less twice the time spent with private transportation (by car), consisting in a time of 400 s. Transportation price is 1€ and car transportation is 2€, including the price for CO_2 emissions and fuel price. If drivers choose the same weight factor for time and price, then the arc weight for car transportation is 214 x 2 = 428, and the transportation arc weight is 400 x 1 = 400. In this case these values approximately the same, but if the process takes care of parking price of the vehicle in the city, the system increases again the arc weight for private car, and then the system suggests the option of public transportation (PT), showing the next PT arriving to the nearest PT stop. System is able to provide orientation to the nearest PT stop.

To determine the best route or the quickest route was implemented a Dijkstra's algorithm, where its running time is proportional to N^2, with N being the number of nodes in the graph. The graph to be used by this Dijkstra's algorithm is represented by an xml file. The best way to apprehend the quickest way is determined using the Dijkstra algorithm. In our web application there is a class called Dijkstra, which is where the algorithm is implemented. For a complete description method sees [Fontes, 2008]. Information exchanges with external systems are based on XML files.

5.1.1. Case Study

In this Section, it is showed a small example of this application approach to go from Sacavém to Almada without traffic in Figure 5-4, the trip time is around 12 minutes. In Figure 5-5 is showed the same path with traffic information, now the trip time is around 20 minutes. In Figure 5-6, is showed again the same path with a traffic cut in the "25 de Abril" bridge. Now the best path is through the other bridge "Vasco da Gama" and the trip time is around 30 minutes. For more details see [Fontes, 2008]. In [Costa, 2011] master thesis it was used this approach for an integrated best path (with a transportation decision – e.g., private car versus public transportation). Pricing is also a decision factor where it integrates CO_2 emission prices.

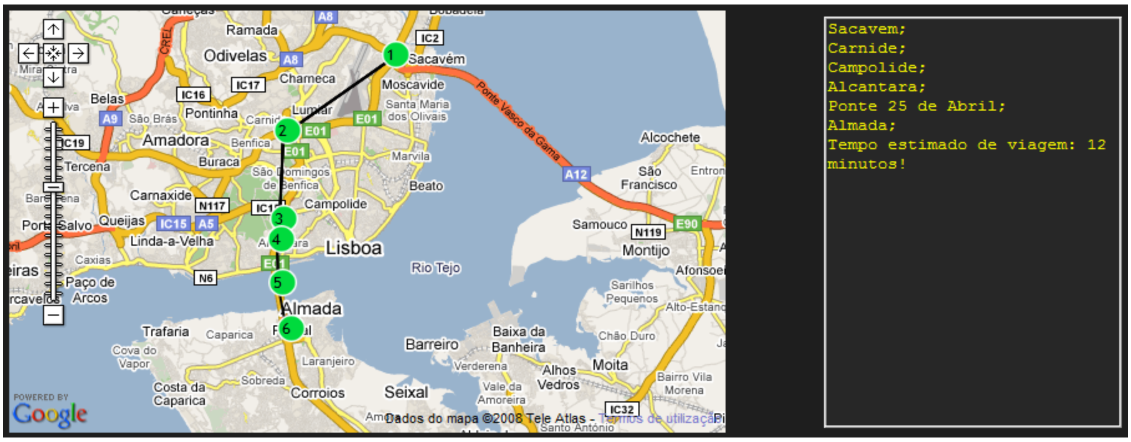


Figure 5-4: Application of the best path taking into account no traffic information (trip estimation time is around 12 minutes)

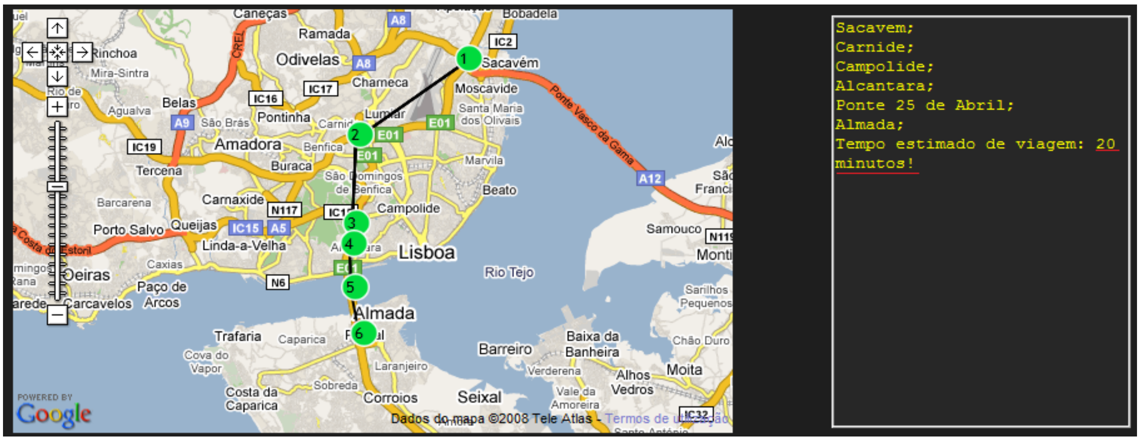


Figure 5-5: Application of the best path taking into account traffic information (trip estimation time is around 20 minutes)

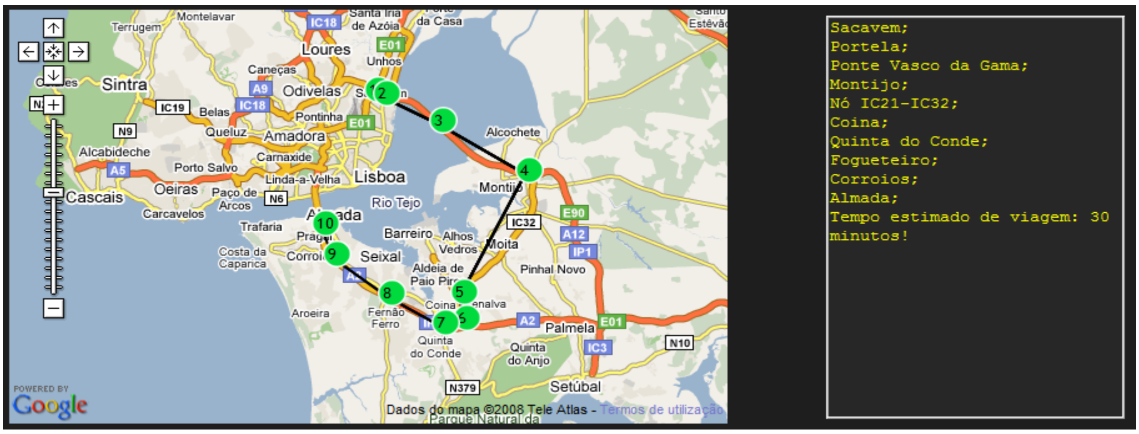


Figure 5-6: Application of the best path taking into account a serious traffic problem in 25 de Abril Bridge. Alternative path is showed as best path (trip estimation time is around 30 minutes)

5.2. Car Pooling System

Car pooling is the process of sharing daily trip with others with similar path and timing. This is important because the occupancy rate of private cars has reached a very low value of only 1.06 persons per car [Maniezzo, 2004]. It is clear that additional efforts are needed to utilize the free capacity in these vehicles. Against this background, is proposed a collaborative Car Pooling system, to raise vehicle occupancy based on a user collaborative environment motivated on a credits mechanism, which can be converted into parking licenses in facilities of big cities. The car pooling happens whenever at least two people ride the same car. Each person would have made the trip independently if the car pool had not been there. Driver and passengers know beforehand the trips in which they share the ride. This idea is not new and several initiatives have been tried in the past without considerable success:

- Dallastravel: [www.dallastravelsurvey.org/index.php?mod=3_carpool&side=none];
- Civitas: [www.civitas-initiative.org/measure_sheet.phtml?lan=en&id=282];
- Carpoolworld: [www.carpoolworld.com];
- Ridesharingonline: [www.ridesharingonline.com];
- Mitfahrerzentrale: [www.mitfahrerzentrale.de];
- Nctr: [www.nctr.usf.edu/clearinghouse/ridematching.htm].

Most of these systems allow convenient trip arrangements over the Internet, support trust building between registered users, and they implement billing systems to charge passengers and compensate drivers. Yet, these services have not become popular and did not significantly increase the average car occupancy. The main technical reason for this is that existing ride sharing services do not allow truly ad-hoc trip arrangements. Today's mobile computing with current advances on geographic location systems, mobile communications (e.g., GPRS, Wimax) new mobile devices (e.g., PDA, mobile phone), and navigations platforms overcame this limitation and enable for the first time truly ad-hoc ride sharing services. On top of this technology advances is proposed a new collaboration approach based on market share principals and on user profit, which is defined as credits that can be spent for advanced park booking and to reduce the payment fees in metropolitan areas.

5.2.1. System Concepts and Main Modules

Capturing requirements efficiently is crucial to the development of any system. It is proposed a software engineering requirement approach to try to identify patterns that can be later reused for similar systems developments. Based on these, follows a generic workflow of the several activities that compose the requirements, namely: (1) stakeholder analysis, where it is identified the main stakeholders that are likely to be affected by the activities and outcomes of the project, and are assessed how these stakeholders are likely to be impacted by the project and the relations between then; (2) problem domain analysis, it is performed in Lisbon Metropolitan Area (LMA) main transportation infrastructure (e.g., roads, parking places and public transportation); then it performs; (3) requirement elicitation; (4) requirement analysis; (5) requirement specification; and (6) requirement refinement. The main outputs of the system's specification, that meets user carpooling needs and the flow list of requirements, aiming to increase the average rate of car occupancy, are:

- Real time traffic information;
- Best route search based on traffic information, and based on dynamic route matching algorithms;
- Integration with public transportation information and parking facilities;
- Pre-booked parking place;
- Ad-hoc trip arrangements;
- Use of past-experience data to estimate time-to-pickup;
- User Profiles and credit mechanisms.

System main modules are illustrated in Figure 5-7. External information sources feed the system with public transportation time table and information, weather information, car parking facilities with available places, and road information (routes and traffic). Car Pool Driver profile, illustrated in Figure 5-8, and Car Passenger profile, showed in Figure 5-9, are used in a matching function to identify car pooling.

The car pooling design follows the use-case analyses (Figure 5-8 and Figure 5-9) for Car Pooling system with two main profiles: driver profile and passenger profile.

Driver profile is illustrated in Figure 5-8: user login, password, mail, cellular phone number, window travel time, start and ends points, credits, number of available seats, parking location, information to the system about delay on usual trip start time, parking number and parking timing slot wanted (date, start hour, end hour).

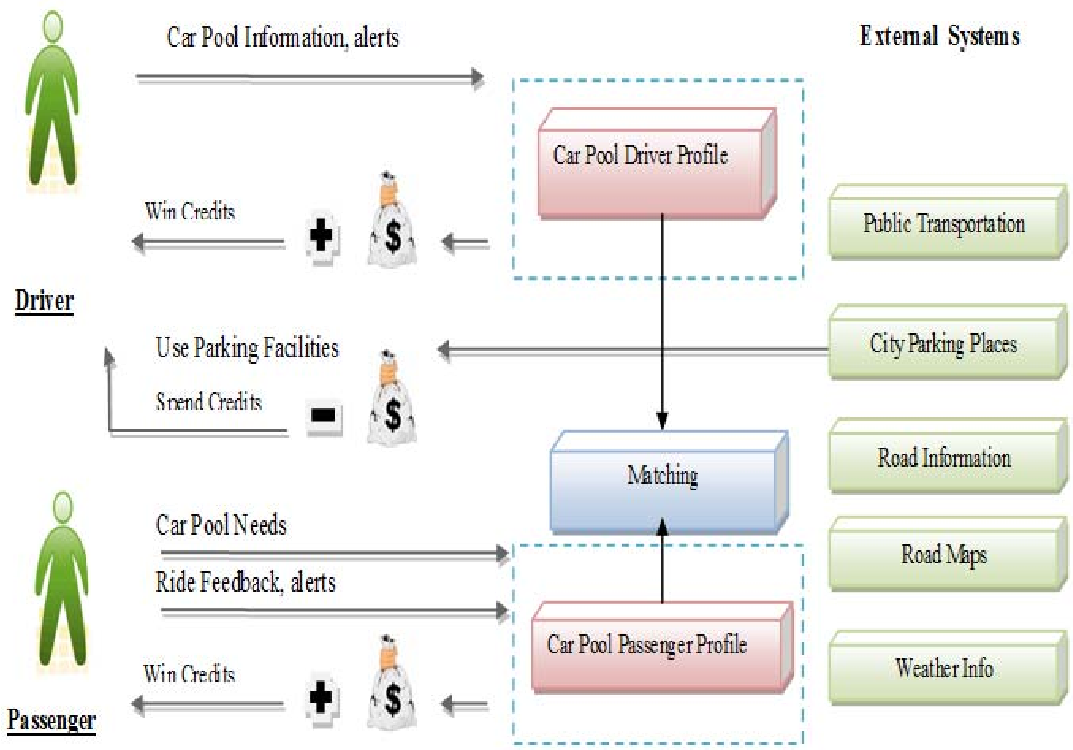


Figure 5-7: Car Pooling system main modules

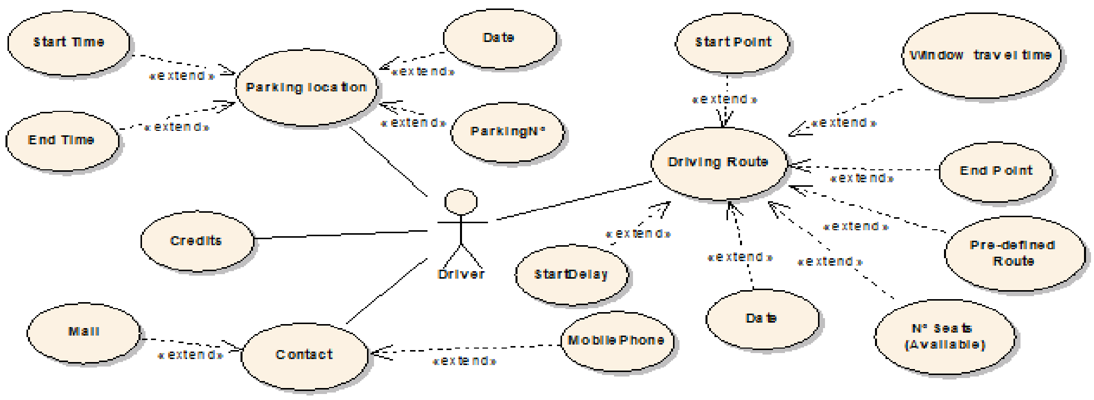


Figure 5-8: Use Case for car pooling driver profile

The passenger profile is illustrated in Figure 5-9: user login, password, mail, cellular phone number, window travel time, start and ends points, credits, user results preference (like driving distance to picking point), waiting time, and if the passenger wants, a daily updated information or relay on pre-defined information. Results visualization can use a graph visualization tool or a map using Google Maps interface, and it can receive notifications about delays of scheduled ride based on driver starting hour delay (only possible if the driver alerts the system), or based on road traffic conditions.

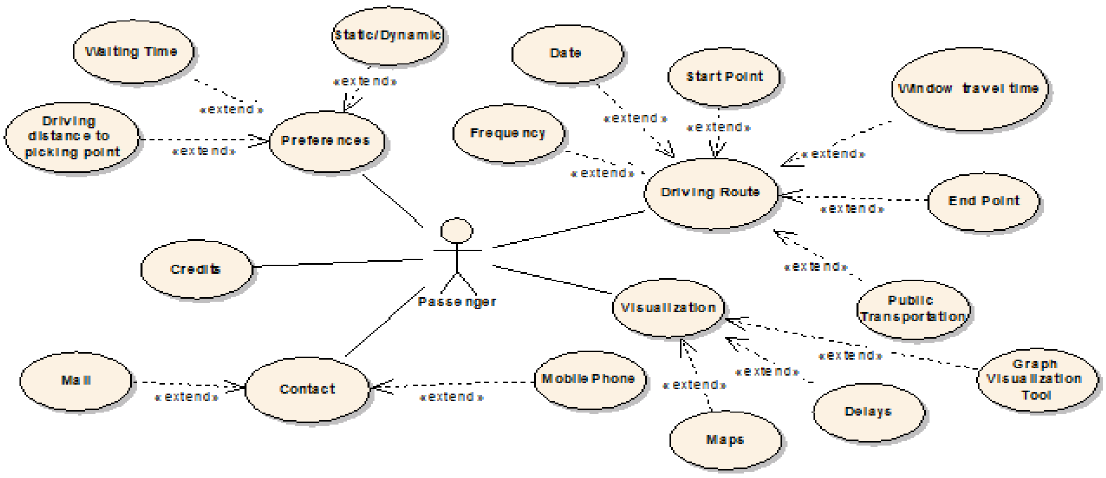


Figure 5-9: Use Case for car pooling passenger profile

Profile matching algorithm is illustrated in Figure 5-10, and is used to identify possible car poolers based on the matching of drivers and passengers profiles. First it is transformed the users routing plan in a nodes graph by defining the nearest node of GPS coordinates of start and end points. All node information comes from a GIS (Geographic Information System) application (GoogleMaps). Nodes distances are calculated based on node GPS coordinates. Then the system checks the travel time window based on matching nodes. If the user accepts public transportation the process adds graph information related with an alternative routing path. Return trip is independent and matching start with end points matching (user location car), time window and start point. A list of possibilities is always presented to the users based on pre-defined user's criteria chosen, like trip distance for picking point, waiting time and end point. Results can be shown in Google maps using public available API. Passenger's chosen trips are stored in a database associated to the user unless we ask for a new one.

The best routing path is based on graph optimization based on a Dijkstra algorithm (for detailed implementation see [Fontes, 2008]). Graph nodes correspond to road intersection or stop points and graph arc weight measures the time travel. This time is calculated based on node distance divided by road maximum speed. Traffic condition can perform a modification of road speed. When road information is available from sensors the system can use real information about the traffic speed. In the case study identifies a problem with heterogeneous data formats. When the information is missing our heuristics determines the traffic speed (for details see [Fontes, 2008]). To receive updated information in real time it is important to look for communications and end-users devices. End-users devices determine the communication interfaces and protocol. A user with mobile phone receives and sends SMS messages. If a user has a GPS and a GPRS (or even wireless) device communication (e.g., smart phone, PDA) the system is able to communicate and exchange information during the user ride.

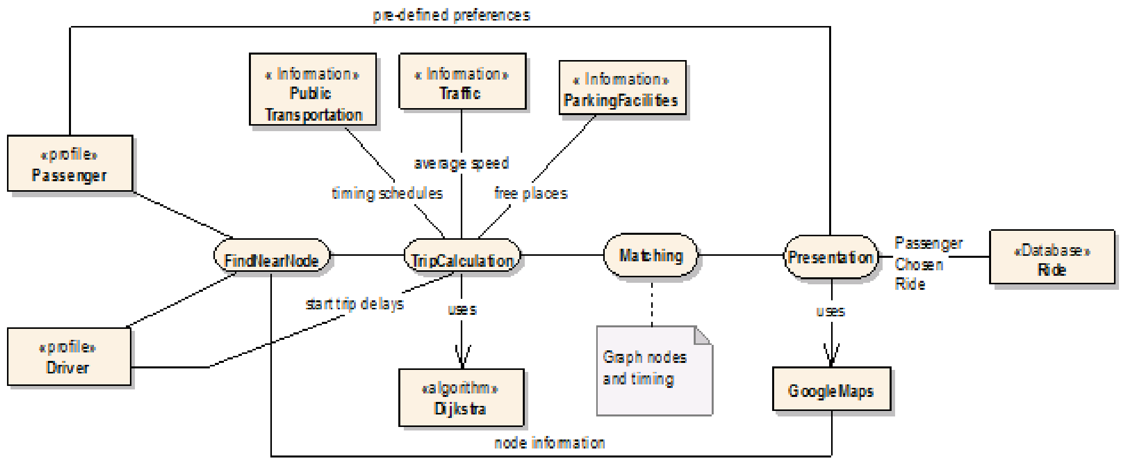


Figure 5-10: Driver and Passenger profile matching algorithm

5.2.2. Credits Mechanisms and Payments

The user does not pay his ride and can win credits giving alerts and feedback to the system about the way the driver steers. Credits can be mainly used in passenger ride or parking facilities, so it is necessary government incentives (for example, incentives given by municipalities) to cover some parking expenses related with credits. These costs can be compensated by less CO_2 emissions and less traffic during peak hours.

Users are handled by the following modules: user registration, user credits, user communication interface, and user profile. User registration module is the responsible for detecting if the user is a registered user or not. If so, it shows the user information, the number of credits that he has, allows him to change his personal data, driver profile, making suggestions, and allowing the user to buy more credits. If it detects that the user is not registered, it asks for the registration. User communication interface formats the information for the end-user device (e.g., PDA, mobile phone). User profile handles all issues related with the creation and change of driver or passenger profile.

Users Credits is an important research issue that addresses the system on how to determine the ride price (credit cost). In the current research is proposed a dynamic value determination, based on the stock exchange metaphor, following these listed main guidelines, and illustrated in Figure 5-11:

- A new user in the registration process receives 50 credits.
- A recommend action to the system given by the user gives 5 credits.
- A given ride is equal to a predefined value. Trip expenses (km = 1€, plus toll and parking) are divided by the number of passengers. If it is assumed the number of four passengers in a trip of 25 km, with 5 € toll and 10 € parking, is converted in 10 credits. So, the driver wins 10 credits per passenger (or less if the trip is shorter) and the passenger spends only half of trip credits. Agent simulation tasks were used to optimize these credit values in order to maximize car occupancy.
- Feedback of updated information over the ride gives one credit.
- By the end of each month the average occupancy rate of each poll car is calculated. This number is multiplied by the number of rides performed by the car, giving additional credits.
- User feedback (e.g., rating driver punctuality and flexibility) can act over ride credits. A positive feedback is used to increase by 1% the ride credit, and a negative feedback is used to decrease by 1% the ride credit.
- Each hour in a parking place is one credit.

If a ride car is fully booked (i.e., number of passenger rider's equal car seats), and a user wants to take that trip, he can initiate a process of increase the ride credits until one of the booked riders give up. Also in a monthly basis, through ride statistics of car occupancy, the system can raise or decrease the ride credits by 5%. If average ride occupancy is smaller than 2.5 (the value of our target), then the system decreases in 5% de ride credits, but if it is bigger than 2.5, it has an increase of 5%.

Payments: the system uses a credits mechanism. Users can buy credits (1 credit is equal to one euro) through bank account transference. Based on monthly reports (from historical data) the system proposes ways to maximize the gains of credit, by increasing car occupancy or even by proposing more rides of the user as a driver. We are currently working in an optimization algorithm based on ride request (that uses mainly time window and location) that can give suggestions to the driver to make small changes in order to increase car occupancy. If user wants to participate only as passenger, perhaps he will need to buy credits that will be used to cover parking expenses.

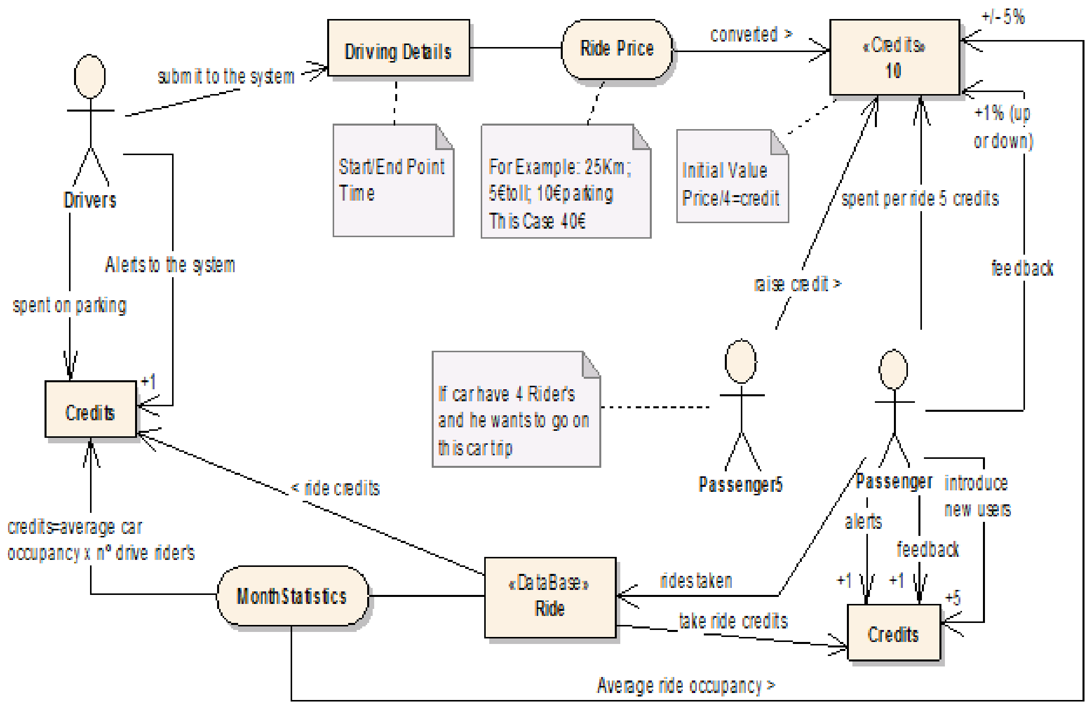


Figure 5-11: Credits mechanism

5.2.3. Application Scenario

Lisbon is the largest city and the capital of Portugal. Being the capital, it contains the headquarters of the main companies, many universities (both public and private), and the main seaport and airport. This results in a concentration of most economic activities which creates a synergy without parallel in Portugal. On the north side of the river Tejo, close to Lisbon, there are 8 municipalities: Amadora, Azambuja, Cascais, Loures, Mafra, Oeiras, Sintra and Vila Franca de Xira. On the south side of the same river there are 9 municipalities: Almada, Alcochete, Barreiro, Moita, Montijo, Palmela, Seixal, Sesimbra and Setubal. Lisbon is not only the head of the Lisbon Metropolitan Area - LMA (there are only two metropolitan areas in Portugal), but also a district capital (comprising 15 municipalities). LMA, is the largest population concentration in Portugal. Preliminary data from the 2001 Portuguese census puts the population of the metropolitan area at 2,641,006 (about ¼ of the Portuguese population), of which 20.8% lives in the city of Lisbon. About 27% of the population of continental Portugal lives in the 2,957.4 km² of LMA. Census 2001 (at the time this work was written no 2011 data was available), performed by INE (National Statistics Institute, www.ine.pt) shows the following facts: average daily trip home to work is around 35 minutes and is distributed as shown in Figure 5-12. There is no official data regarding car pooling usage in Lisbon or Portugal. Only 5% of vehicles travels with more than one passenger, and this 5% value reflects mainly family trips (husband, wife and kids). Due to a bad transportation system outside the Lisbon area, a growing number of persons living outside the Lisbon city area, limited parking facilities in the Lisbon area, and the continuous increase of fuel prices, this system for car pooling has a great potential for a successful application.

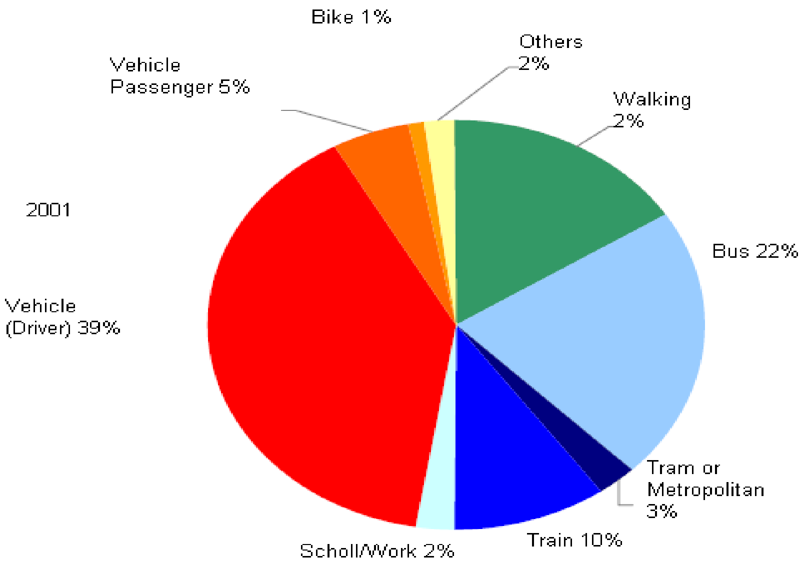


Figure 5-12: Lisbon Metropolitan Area (LMA) traffic distribution from 2001 census [www.ine.pt]

In Figure 5-13 it is possible to see the potential of car pooling system in LMA because there is a major movement into Lisbon city from distant places, without good transportation infrastructure supports. For instance, a person that lives in *Santa Cruz* (village in a cost at the north of Lisbon) at around 70 km distance, by car takes about 45 minutes (with costs of approximately 15-20€), but on public transportation the trip takes around 2 hours.

To minimize car cost or to avoid long trips in public transportation (like 4 hours, considering a round trip), several persons organize car pooling ride among neighbors or friends. Let's check the system behavior based on the following scenario shown in Figure 5-14. A user starts his daily journey from home to work. Starting point is near node A0. He takes 5 minutes to reach node A0, but our system assumes starting point in A0. By car the trip takes around 30 minutes (without traffic delays), however free parking place is always a nightmare, for which sometimes drivers wait more than 30 minutes without success. Pre-paid parking is cheaper, however daily prices are prohibitive (more than 10 € for an 8 hour time slot in Lisbon). Based on the drivers profile the system finds the driver's node routes within a waiting time previously defined (this case 5 minutes).

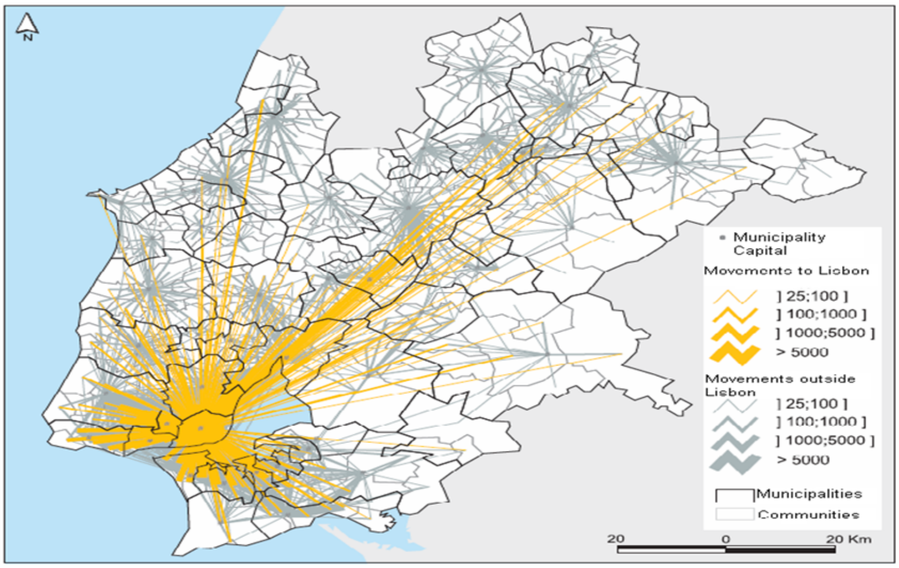


Figure 5-13: Lisbon Metropolitan Area (LMA) people movements from 2001 census [www.ine.pt]

Also public transportation routes with starting time of pre-defined (5 minutes in this case). In our system, as shown in Figure 5-15, the information is in a graph visualization interface (it is possible to represent the same view in a map using Google Maps interface). Based on the system information the user chooses the color node option and stores this information. The system notifies the user and in this case the trip time takes only 2 more minutes than a trip taken with the own car of the user, but this time in average should be higher. Another advantage of this system is the parking booking. Credits can be converted in periods of parking, but the rate changes from park to park. Also relevant is a saving for this trip of 30 km, since the cost for using a motorway toll can reach an amount of 25€/day, which gives 600€/month and around 6,600€/year.

The system also considers a delay report of user ride (for example 10 minutes), so that the system can advise users to take ride of drivers which start trip in C0 and catch public transportation at node A3. Also the driver that starts on node B0, can be considered in other day as a passenger, and catches a ride of driver A (starts in A0).

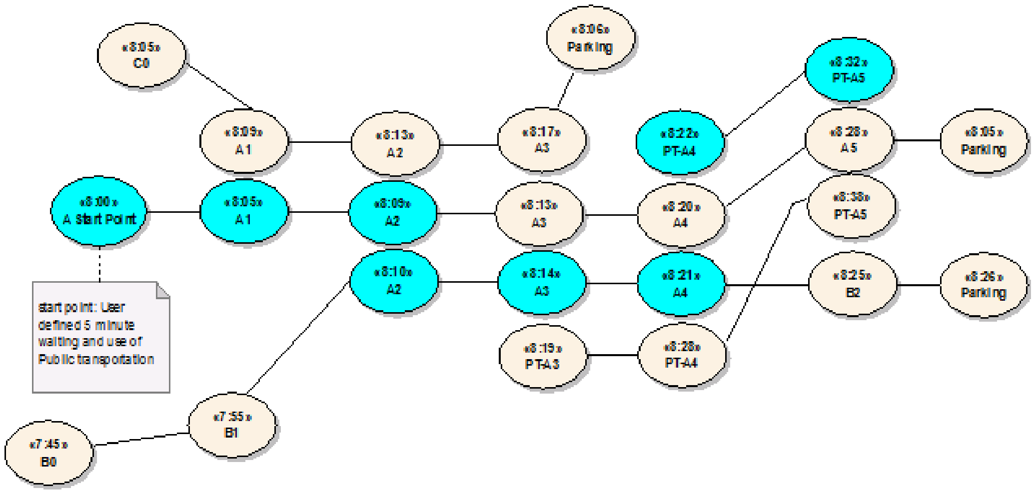


Figure 5-14: User match ride, with user preferences on a graph tool visualization, in a java prototype

5.3. Car Sharing System

Car sharing systems balance between private and public modes of transportation. They allow individuals to use a car when needed without having to buy one for their exclusive purpose. This, obviously, comes with some inconveniences, such as having to reserve the car for a predefined period, having to walk to the nearest parking lot, or needing to select another mode of transportation if no car is available. However, it also has a lot of advantages because it gives access to a private, flexible mode of transportation, without having the entire burden that comes with it. Hence, it is not that surprising to see that car sharing systems are becoming more and more popular and that people are willing to engage in this new mode of transportation.

Car sharing is not a new transportation mode. Years ago, when cars were luxurious goods, households were uniting to buy one. Its ownership and use were shared. It was for these households the only way to have access to an automobile. Nowadays, car sharing responds to new needs and is provided in an organized system. People want to benefit from the car's flexibility without supporting all its inherent costs: insurance, parking, maintenance, etc. Users are also attracted to car sharing because of its good environmental image [Steininger, 1996]. Figure 5-15 shows eleven car sharing parking locations in Lisbon, what represents a reasonable implementation of car sharing initiative. Car sharing services are managed by companies, like short term car rentals. Car Sharing

Organizations (CSO) usually manages a fleet of vehicles dispatched in several predetermined parking lots. Members have access to any vehicle at any time, given that they have made a reservation in advance. Car keys are usually located in a safe-deposit box located near the parking lot. Users can keep the vehicle during a fixed period of time that can vary from one hour to several days. At the end of the rental period, the vehicle has to be returned to a parking lot (usually the one where the car was taken). Traveled distances and rental durations are recorded and used for the billing of every user (fees depend on the total duration and mileage) [Barth, 2001].

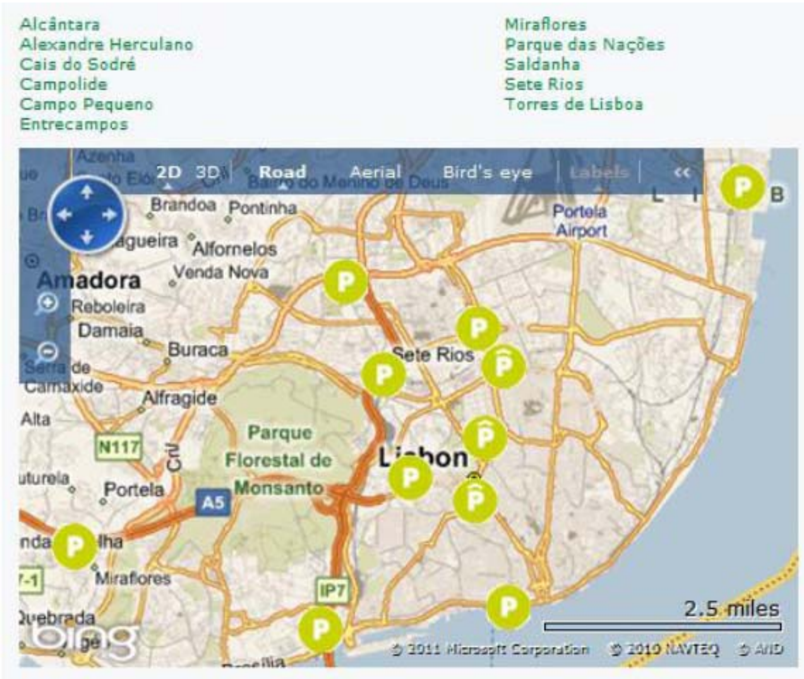


Figure 5-15: Car Sharing parking places available in Lisbon, status Jully 2011

Some studies have been conducted to estimate the potential of car sharing in urban transportation and changes in transportation behavior when a car sharing service is available [Shaheen, 2001], [Lee, 1998], [Cervero, 2002] and [Steininger, 1996]. Cervero et al. [Cervero, 2002] state that this mode could attract users towards individual car ownership for the San Francisco area. Other authors indicate that, on contrary, CSO helps to decrease car ownership because some users leave their individual car to enter the system. Positive impacts of car sharing on travel demand and on greenhouse gases (GHG) emissions were also reported by Morency [Morency, 2007]. Most of these studies are based on user surveys and can hardly characterized long run use of car sharing. Barth et al. demonstrated the potentialities of using individual data collected in a multi-station shared vehicle system [Barth, 2001]. On a pure economic basis, CSO can be both viable and profitable [Wright, 2001]. Several systems are running through the world, especially in Europe (UK, Germany, Italy, Netherlands), in Canada (Toronto, Montreal, Quebec City) and in the United States (Seattle, Portland, San Francisco area).

The proposed system is similar to the reservation slots of a public charging station and it was developed in a Final Year Project at ISEL [Xavier, 2011]. Main system functionalities are described in Figure 5-16.

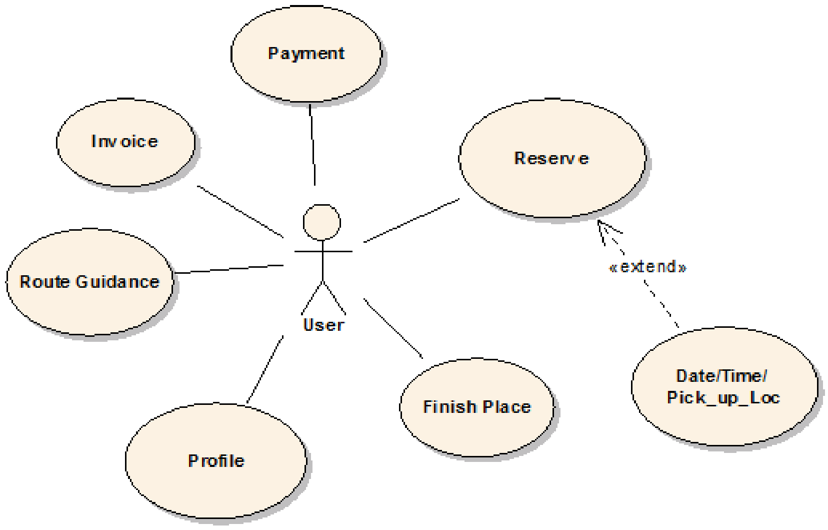


Figure 5-16: Use case for car sharing system

5.4. Bike Sharing System

Bike share is an emerging urban transportation concept based on collective paid use of a distributed supply of public bicycles. It is similar in function and programming to car sharing initiatives that have been very successful in several places. In general, bike sharing consists of strategically distributed "stations" containing ten to twenty bikes on average, with a centralized payment/control kiosk. Customers—who range from one-time users to long term subscribers, "unlock" a bicycle with a credit card or smartcard, then ride to any other station in the city where they can deposit the bike, concluding their trip.

Bike share fills a number of key "niches" in the urban travel market and is particularly useful for relatively short-range travel beyond the length of comfortable walking distance. Its key advantage is that it gives virtually everyone access to what in the past had largely been viewed as a specialized form of urban transport, promising increased use of bikes for short-distance travel, helping to decrease pressure on traffic and transit systems.

Main functionalities of the proposed Bike Sharing system are defined in Figure 5-17 and for more details see master project at ISEL [Costa, 2010].

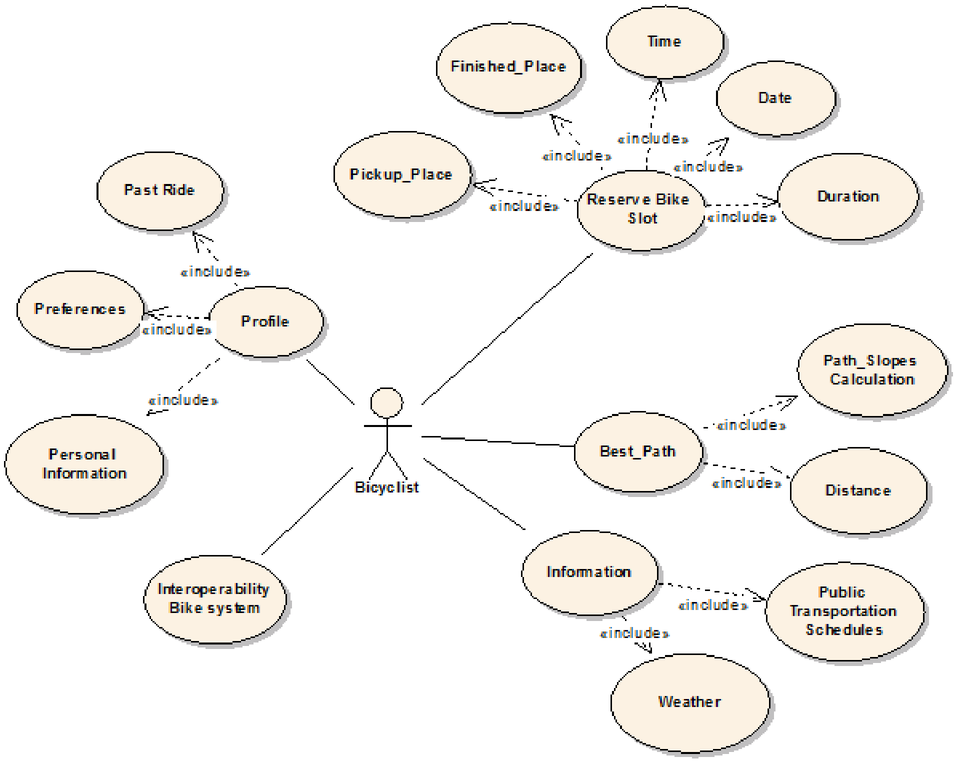


Figure 5-17: Main Bike Sharing system functionalities

Weather

The extremes of weather affect bicycling more so than any other practical mode of transportation, on both short-term (day-by-day) basis and longer-term trends. Extreme heat, extreme cold, and heavy rainfall are the top weather phenomena leading to decreased numbers of cycling trips. User Profile can be used to define if the user wants to use a bike under certain weather conditions (rain, too cold or hot).

Topography

Like weather, topography has an impact on the willingness of people to use bicycles, although in this case it is often limited to certain trip patterns rather than affecting system usage as a whole. This is apparent in the evaluated European bike share cities, which regularly exhibit shortages of bicycles at stations at the tops of hills or steep gradients, suggesting that many users are riding downhill but not back upwards.

The study of the slope is particularly important for cyclists and pedestrians. For the slope Google API allows the following operations:

- get the altitude of a particular point;
- get the altitude of *n* points in a straight line path, where *n* is the number of samples required;
- get the altitude of a set of points.

Figure 5-18 illustrates an invocation of Web service for calculating the profile of a set of points.

Figure 5-18: Google Web Service Elevation

Figure 5-19 presents an application of this service, where appears the bike path and the elevation in meters.

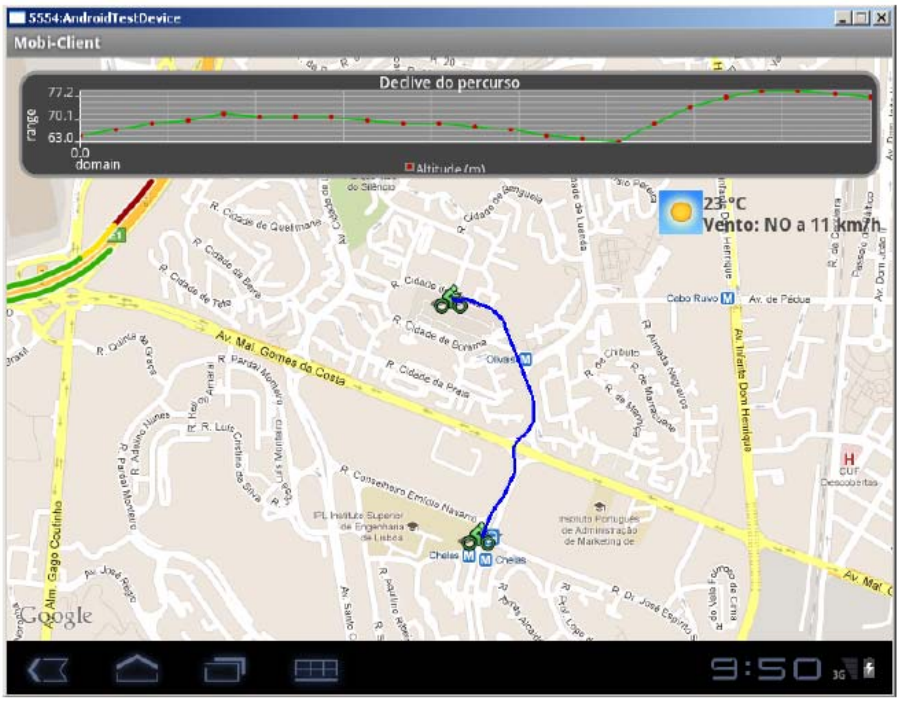


Figure 5-19: Example of a bike path with the elevation in meters (top of figure)

5.5. Public Transportation Information Integration

There is difficulty in obtaining information about traveling to, from and within a region, even in the same city, due to the diversity of transportation operators. Most of these operators have their own system, so that they work and plan the routes and schedules independently of nearby operators. Also public transport systems differ from region to region. It is therefore understandable that when reaching a destination, even for the most traveled user, it becomes difficult to use local public transport due to poor organization of information, and especially due to language barriers, for those who do not speak the native language of the country. In this context, is denoted the scarcity of appropriate information systems to assist travelers in the region, including providing practical information, essential to understand the operation of the means of transportation.

The availability of the Internet and the current development of Information and Communication Technologies (ICT), became the best way to disseminate information, inspiring the development of strategies to support tourism and culture. Additionally, the mobile guides are increasingly seen as an asset to offer an experience more appealing of visitation and interpretation to natural parks or historic sights. Technological advances allow higher processing in smaller devices, making possible the use of technologies such as GPS and Wi-Fi. In addition, the popularity of social networks, like Facebook, showed the willingness of users to share their experiences and be part of communities with similar interests.

Part of this research work was used in ISEL participation on the Seamless Travel across the Atlantic Regions using sustainable Transport (START) project. START Project is a European Commission's Transnational Territorial Cooperation Programme with 14 partners from the UK, France, Spain and Portugal. The main mission is the establishing of a transnational network of regional & local authorities to promote enhanced accessibility, giving tools to make easy to travel to, from, and around the Atlantic regions, using environmentally friendly, collective modes of transport, greater interconnectivity between transport systems, clearer information within regional gateways, airport hubs ports and rail interchanges. For more information see [http://www.start-project.eu].

Main contribution of ISEL on this project was the data integration of multiple transportation sources [Costa, 2011], and a system to support user on public transportation query data. The system should allow the interrogation of multiple sources of information through a single interface. The questions and answers to them should reflect a single data model. The existence of a single common data model takes the client applications with the difficult task of dealing with various technologies and their relational schemas different. Different public transportation systems can be added with total transparently to the end user. From START project different public transportation data and data base schemas were tested. Also this integration allows the creation of mobile systems oriented for tourisms purposes, other main goal of START project, where “low budget tourism” can be guided, to reach POI (Points of Interest) by public transportation.

This integration task is performed taking into account Figure 5-20, based on a domain ontology definition for public transportation, where a local public transportation data base is mapped.

5.5.1. Public Transportation Data Integration

In Figure 5-20 is illustrated the public transportation different sources data integration approach, where is possible data information integration from different operators of public transportation. This application output is a user Mobile Device, or Web Application SITP, that is described in Section 6.5. The data integration is based on a domain ontology (Ontology for Public Transportation - OPT), a wrapper that performs the mapping between different public transportation data base models and a mediator. If the public transportation operator data base is constructed under OPT the wrapper and the mapping definition are not needed. Wrapper is developed at each operator side based on operator information source and is a common interface for data access. In Figure 5-21 is presented the wrapper solution based on [Bizer, 2009]. D2RQ is a declarative language to describe mappings between relational database schemata and OWL/RDFS ontologies. The D2RQ Platform uses these mapping to enable applications to access a Resource Description Framework (RDF) view on a non-RDF database through the Jena and Sesame APIs, as well as over the Web via the SPARQL Protocol and as Linked Data.

SGBD Schema Publication is the mapping process between local data base and the vocabulary of the ontology (OPT) using R2RQ language. The Process is divided in the following steps: (1) entity definition; (2) adding of proprietaries to the entities; (3)

connection of entities; and (4) definition of conditions and aggregations (when necessary).

Mediator is based on MediaSpaces Mapping Framework, where it is possible to perform SPARQL queries based on OPT.

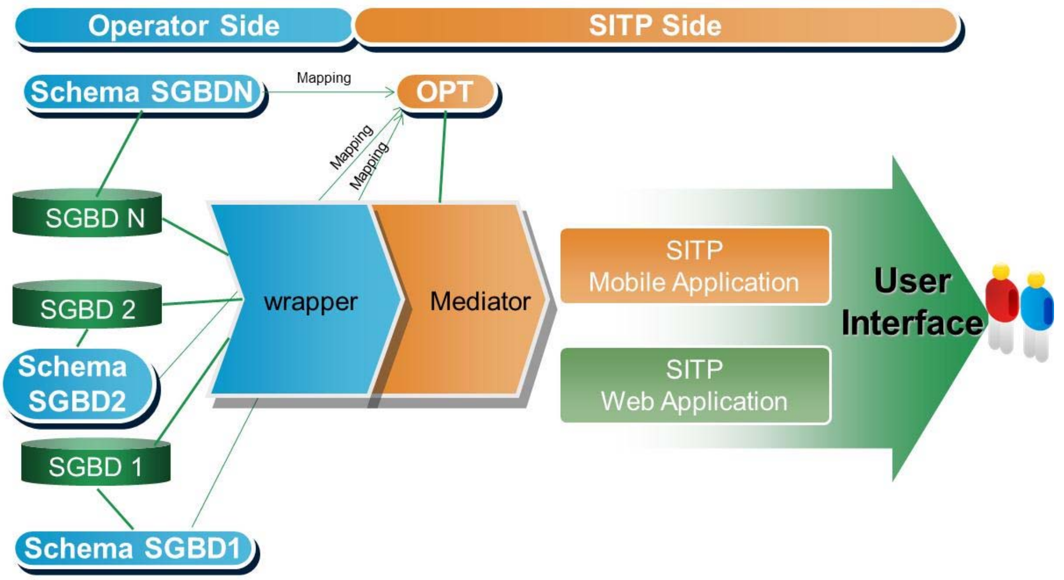


Figure 5-20: Different sources of public transportation data integration approach

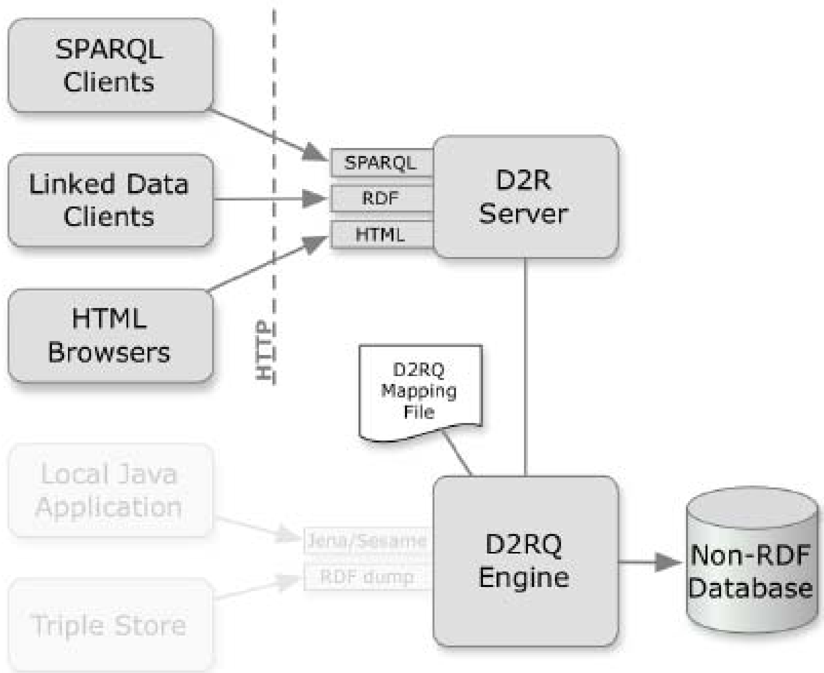


Figure 5-21: Platform D2RQ used at wrapper components [Bizer, 2009]

5.6. Transportation Best Advice and Green Route Planer

The main idea is to build an integrated system, as showed in Figure 5-22, that based on traffic and weather information, can give the best advice in terms of a diversity of options: public transportation from several operators, car and bike sharing system, and car pooling. The system can be configured to give the faster option to go from point A to B. This could imply a mixture of options. Also best advice could be the cheapest option.

All public transportation data (to the Lisbon area) were exported to a graph, where the arc length is defined by the time that it takes to go from one node arc to the other. The same procedure is applied for car sharing, car pooling and bike sharing systems. With all information in a graph, the best path algorithm, described in Section 5.1, can be applied. The big issue is the matrix size that could increase a lot with a large diversity of options, and could generate computer memory problems on handling this matrix. Some heuristics were defined to speed up this process.

Figure 5-22: Mobi Transportation best advice

The arc weight can be constructed from a diversity of options, time, price and $C0_2$ emissions. Next Sections explores this issue from a perspective of a green policy.

Also this integrated approach of a diversity of systems, with geographic information, could be important for transportation planners or to political decisions regarding transportation. Figure 5-23 shows the main systems and information involved in Mobi-System.

The main idea is to adapt arc weight to a combination of items that could reflect an environment policy. Arc node reflects time, price and CO_2 emission price and a good investigation topic is to find the best combination between time, price and CO_2 emissions price, in order to define the 'best' weight of arc path. This weight could also include a parameter function of city traffic conditions (overload paths should be more penalized). The system has potential to work and deal with different source diversity. This idea is materialized in a final year project at ISEL [Marques, 2011].

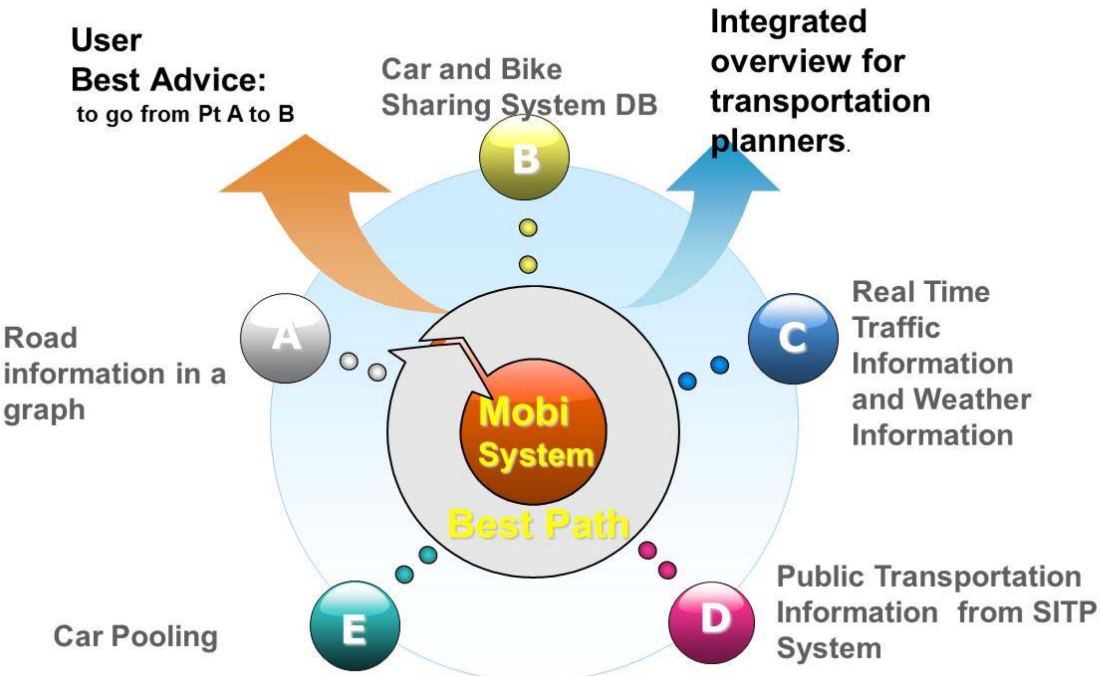


Figure 5-23: Mobi-System transportation related system

5.6.1. Green Route Planer: Case Study

Different approaches can be integrated in arc weight calculation: time, price, and a weight related with CO_2 emissions. Figure 5-25 shows a configurable application screen where the weights (from 0 to 500) can be defined and easily configured by a user.

Figure 5-24 shows a small example of the application usage to go from Chelas to Bairro Alto, in Lisbon, by walking and by metro. Weight configuration was based in the values showed at Figure 5-25. If the weights all equal the best path is based on the fastest option, see Figure 5-27 based on bus transportation.

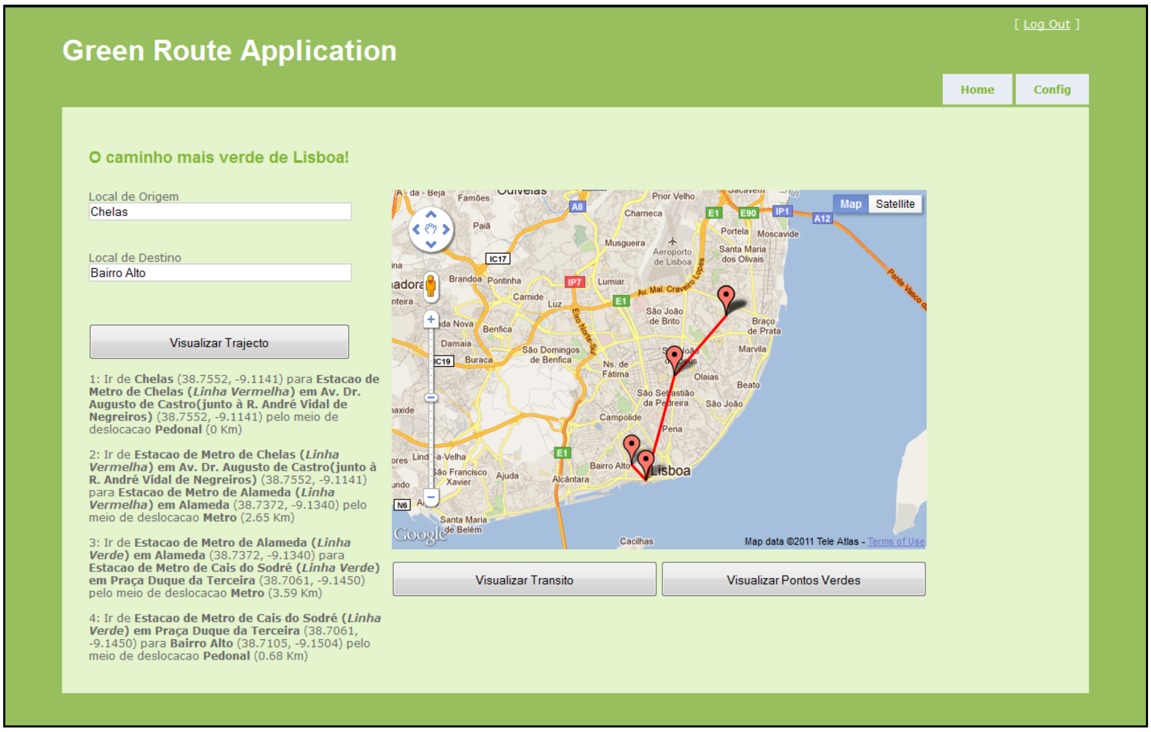


Figure 5-24: Green Route application (application in Portuguese language)

Figure 5-24 shows a first path 200m (walking): *Awwalk* =120s is the walking time (more or less 2 minutes). Then the metro with *Awmetro* = 900+600 = 1500s, these values are taken from a standard time table. Last path is again walking 680m, then *Awwalk* = 408s. Taking into account the weight for walking equal to 0.15 (see Figure 5-25, where table values are divided by 1000) and the weight for metro equal to 0.225, the *Awfinal* is:

$$Awfinal = 508 \times 0.15 + 1500 \times 0.225 = 414.$$

For other possibility, see Figure 5-27 with a total walking of 420m, which gives *Awwalk* = 252s and buses *Awbus* = 1250s. Taking into account a bus weight of 0.325 (Figure 3-26), the *Awfinal* is:

$$Awfinal = 252 \times 0.15 + 1250 \times 0.325 = 444.$$

In case of Figure 5-28 where the bus weight is changed to 0.225, then:

$$Awfinal = 252 \times 0.15 + 1250 \times 0.225 = 319$$

So the second is the best option now.

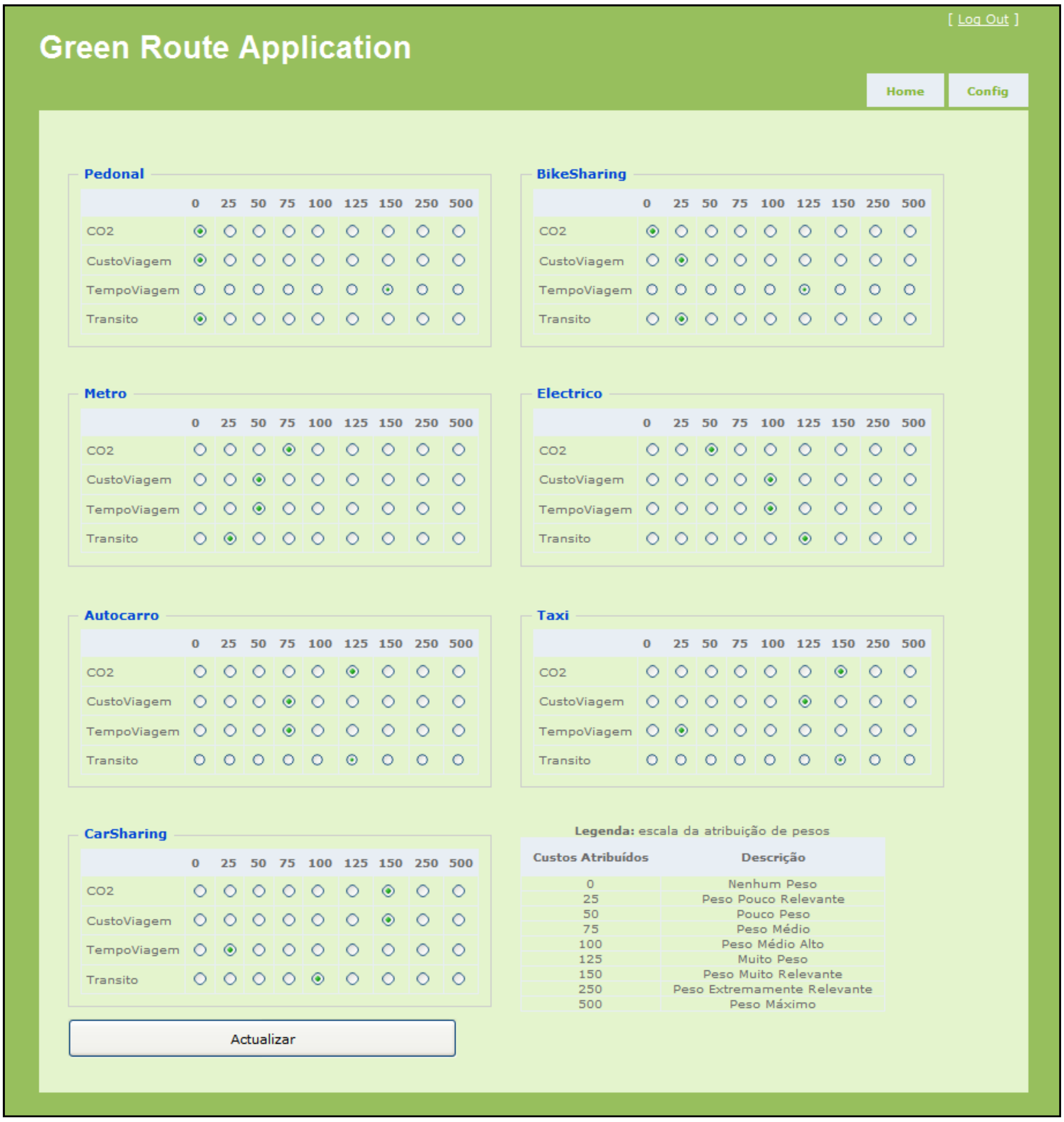


Figure 5-25: Administration application menu: weight configuration (in Portuguese language)

	CO_2 Emissions	Travel Time	Price	Weight
Pedestrian	0	150	0	150
Bike Sharing	0	125	1	200
Metro	50	75	2	225
Tram	50	100	2	300
Bus	75	100	2	325
Car Sharing	100	50	5	425
Taxi	100	50	15	400
Car	150	50	10	475

Figure 5-26: Weights used on current example

The transportation networks system is based on several options (own car, car sharing, public transportation, walking and bike sharing). This system is viewed as a multimodal graph and each mode network is modelled by a monomodal sub graph. The mode network structuring was used to speed up the computation of the multimodal shortest viable path and also to perform a new design for the multimodal path operator.

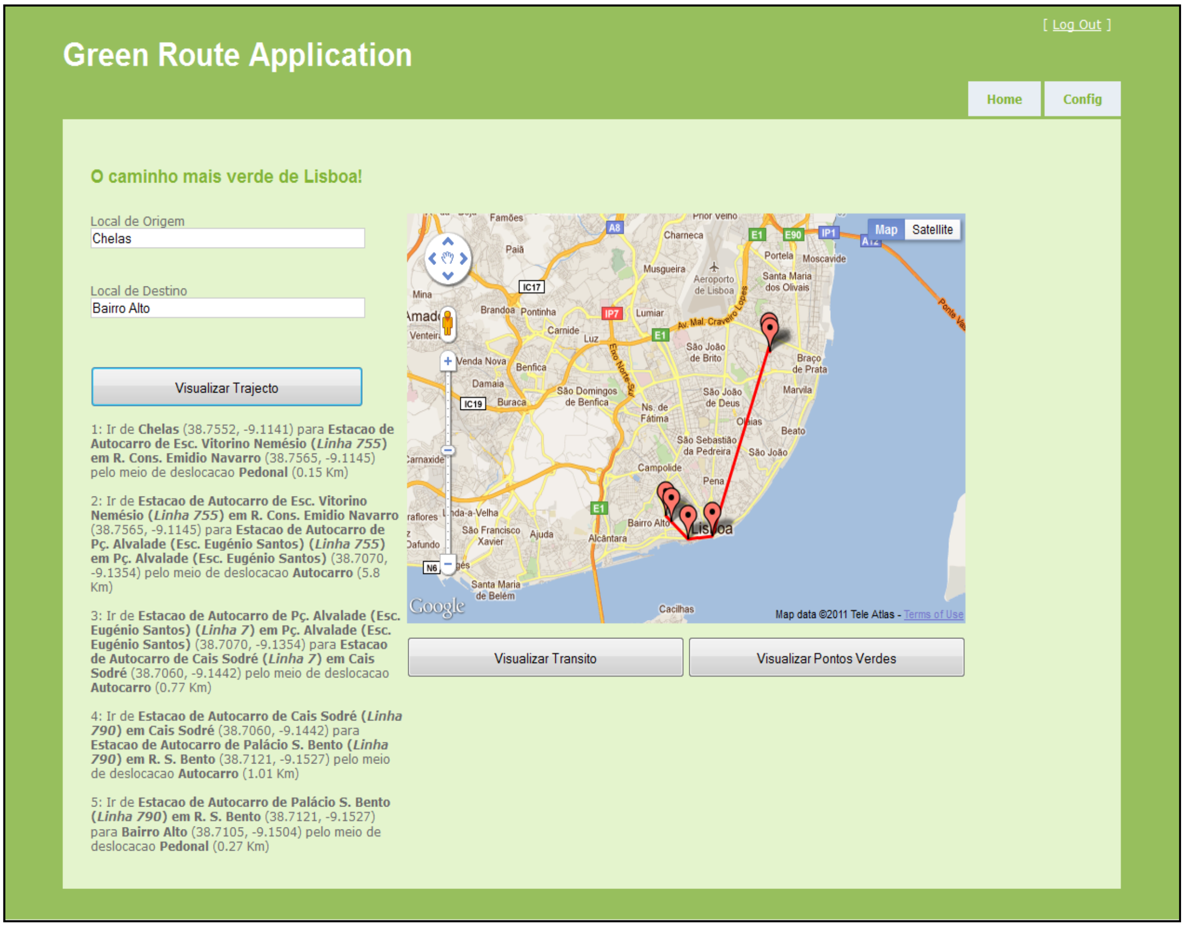


Figure 5-27: Green Route application results with all transportation weights equal (application in Portuguese language)

This study has examined sustainable mobility approaches towards a green environment policy. The proposed algorithm takes into account not only the expected travel time, but also additional constraints, such as: delays at mode and arc switching points, and CO_2 emissions. The transportation networks system is based on several options (own car, car sharing, public transportation, walking and bike sharing). This system is viewed as a multimodal graph and each mode network is modeled by a monomodal sub graph. The mode network structuring was used to speed up the computation of the multimodal shortest viable path, and also to perform a new design for the multimodal path operator.

5.6.2. CO_2 Emission Calculation

Also a CO_2 emission calculator was performed based on vehicle data, distance of current path and with estimation of the number of persons. An illustration of this calculator is showed in Figure 5-28. This module assist policy maker on the definition of transportation weights used in green route application.

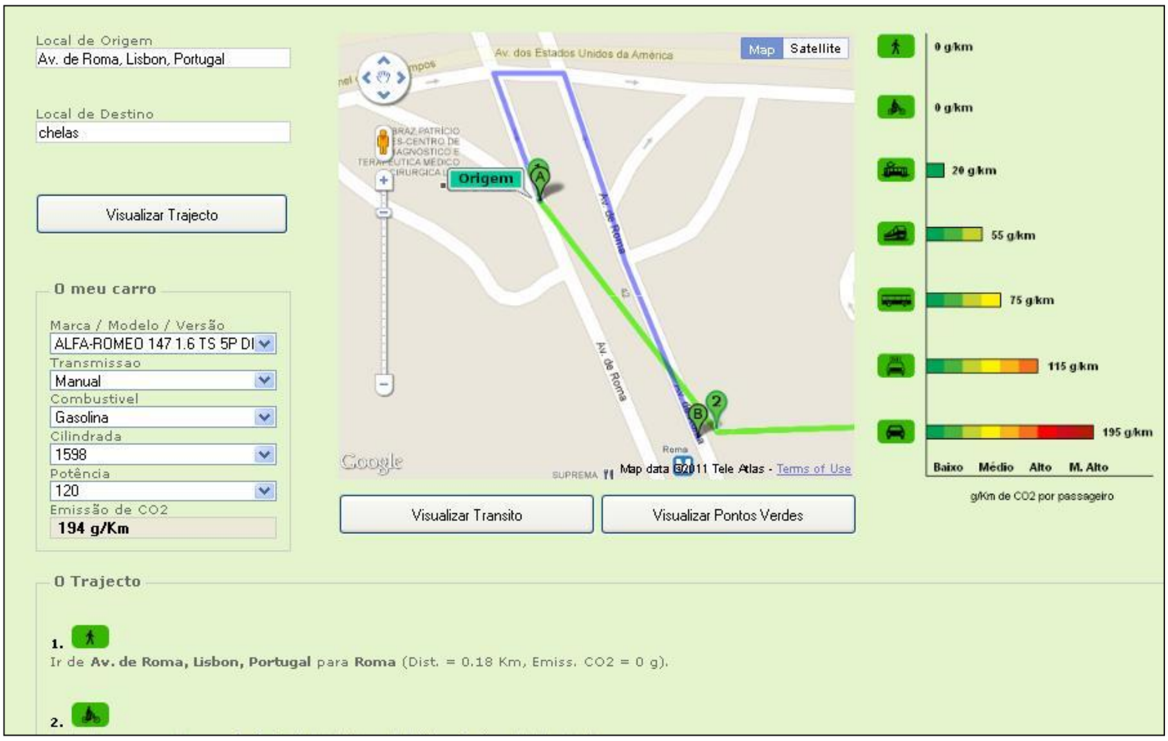


Figure 5-28: C0$_2$ emissions route calculation (application in Portuguese language)

5.7. Conclusions

From the guidelines that EVs change the way that drivers use vehicles, new realities and sustainable mobility in smart cities will increase the need of information systems to support a diversity of options and processes. Drivers need real time information about the diversity of transportation options, and the purpose of reducing the number of cars in the cities requires the integration of all diversity of transportation options, in order to present a good alternative transportation option to drivers, otherwise they will persist in using their own private transportation in the cities. This option could be interesting for EVs, due to autonomy purposes. A driver without range autonomy to go home-work-home could use this integration of information to stop in a parking place (with charging facility and nearby transportation options). In author opinion this approach (integration of public transportation information) will help the integration of EVs in future mobility concepts where the decrease of vehicles in the cities is a must towards the reduction of CO2 emissions.

The focus on this work is aligned with the "Integra Concept" [http://www.start-project.eu/en/Integra.aspx], whose aim is to provide a single brand that links together and provides information on the different public transport operations across the Atlantic regions. So, the system should allow the query of multiple information sources through a unique interface. The queries and answers to them should reflect a single data model. The existence of this common data model takes the software applications with the difficult task of dealing with various technologies and their relational schemas. Different public transportation systems can be added from the end user point of view. Also, this integration allows the creation of mobile systems oriented for tourism purposes. Another main goal of Integra is to provide guidance to "low budget tourism", helping tourists to reach POI (Points of Interest) by public transportation.

This Chapter introduces a new approach the "cooperative transportation infrastructure integration", by providing the driver with a collaborative holistic approach of different public transportation infrastructure sources that can be combined with real traffic information, parking places and charging slots and current driver position, to support the driver decision making process.

6. MOBI-SYSTEM: USER APPLICATION AND CASE STUDY

This Chapter is dedicated to the description of the applications developed not yet described and a case study. Figure 6-1 shows the main sub-systems developed for the Mobi-System application, grouped by main functionalities. In this Chapter our focus is the application for end-user (mainly the vehicle driver) in mobile devices (SiREV and IRecommendIt), the web application (V2G smart system and SITP system), and are presented some utilization results. Mobi-System is a central information system with two main mobile target platforms: (1) smartphones based on Windows mobile and android; and (2) vehicle dedicated system (to be considered by each manufacturer). All development was based on open source software. SiREV is the application developed for Android operator system and IRecommendIT the application for windows mobile.

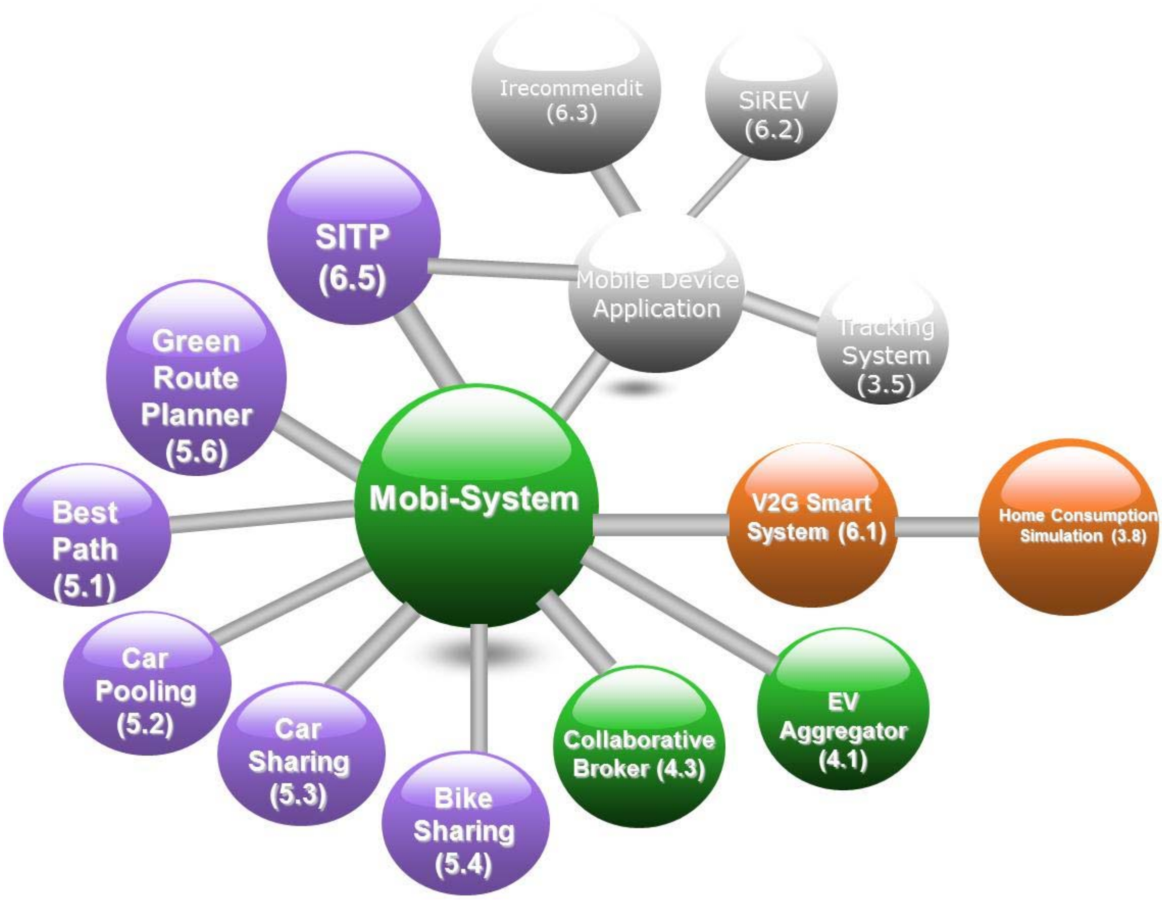


Figure 6-1: Mobi-System main developed applications. In brackets are the Sections where the applications are described

This chapter is divided in the following Sections: (1) V2G Smart System; (2) SiREV Application; (3) IRecommendit Application; (4) Mobile Application Usage Results (Case Study); (5) SITP Application; and (6) Conclusion.

6.1. V2G Smart System (Web Application)

V2G Smart System was developed under a final year project at ISEL in 2010 [Bento, 2010]. The main functionalities of this web application (V2G Smart System) are: (1) Registration: registration page form for new users; (2) Password Recover: form for password recovery; (3) Login: home page of the application; (4) Profile Creation: data creation related to driving habits, EV type; (5) Personalized Charge Profile: data related with EV usage, like minimum SOC (State of Charge) allowed for the EV batteries, electricity desirable prices to sell and to buy, desirable periods for charging and home charging limitations; (6) Statistics: home energy consumptions, weekly, monthly and annual energy expenses, price variation of electricity and charging periods, among others; and (7) Smart Charging taking into account the electrical distribution network and home power limitations.

V2G Smart System is divided into six main modules:

1. Interpreter of Downloaded Files: this module is responsible for reading and interpreting the charging files (e.g., files with electrical transactions or commands for charging device), giving the system a layer of abstraction over the file format of text issued by the charging station.
2. Smart Grid Interface: this module is responsible for the interaction with the electrical network, i.e., it controls the flow of energy from or to the electrical network, with the objectives of helping network stability and also, managing information on the variation of electricity prices, to optimize the possible profits obtained with the selling of electricity stored in the EV.
3. User Manager: module responsible for registering the users and their EV main characteristics (model, battery type), allowing the recording and editing of users data, as well as the removal of users (if defined rules are not accomplished by specific users). This module is also responsible for verification of user identity and ownership of registered vehicles (through the transmission of data received from

the user to the authorities), and for performing regular cleaning from the database of users categorized as "spam".

4. Manager Charging Profiles: a user can set one or more load profiles for each of the vehicles registered by him. A common practice is, for example, the definition of profiles and needs of different charging to be carried out during the week (weekdays) and over the weekend.
5. Smart Charging Module (described in Section 3.9).
6. V2G Central Core: consists in the main module of the V2G Smart System, interacting with various modules mentioned above, and managing the distribution of system information (from other modules and database).

In relation to the technologies to be used in the development of these applications, it was decided that, the management system database, using MySQL Server. The development of Web applications is held in Java, and all graphical development is carried out using the *ZK Framework*, which facilitates the development of Web applications with Ajax, and has the advantage of being open source. The development of the environment, using the Eclipse Project, is integrated with the *ZK plugin*, with main modules: (1) *ZK Loader*, consists of a servlet (server side component that generates HTML and XML data to the presentation layer of a Web application) that processes the requests for resources zk; (2) *ZK Client Engine*, is processed on the client's browser and is responsible for monitoring the events page and realization of their requests to the server by Ajax technique. This engine is generated by *ZK Loader* when processing HTTP requests, and is sent in response to the client in the form of JavaScript code; (3) *ZK Asynchronous Update*, another servlet that serves asynchronously requests made by the *ZK Client Engine*. These requests are caused by interaction of the user with the various components of the page. The *ZK Asynchronous* processes the events triggered by the user, sending the response to the *ZK Client Engine*, encoded according to a protocol's own framework, which typically consists of changes to the page content; and (4) Index, home page of the application, from which the user can perform the login in the application or access the registration page if it is his first access.

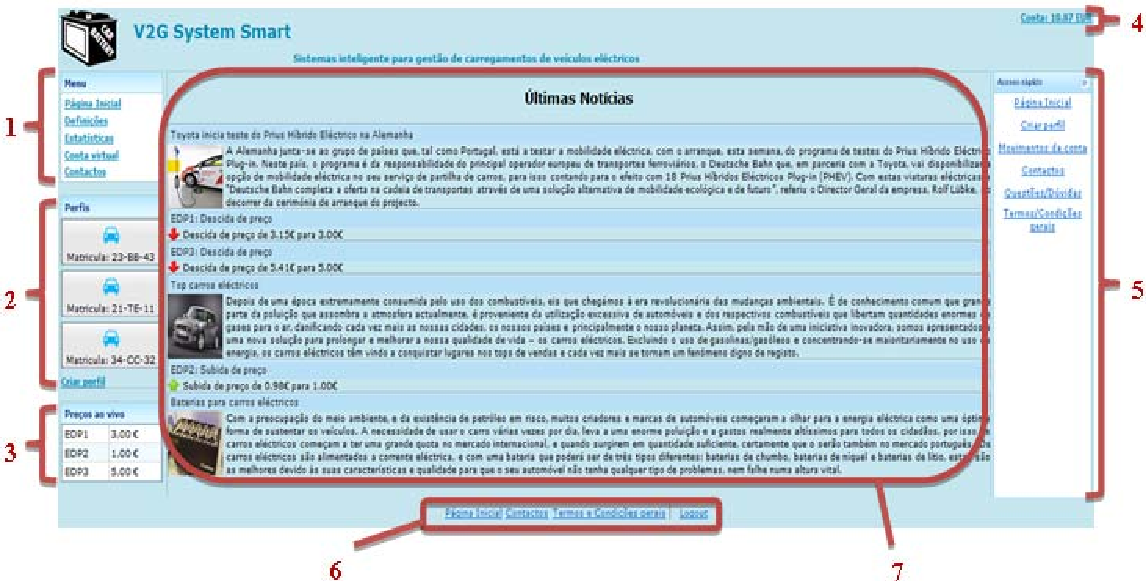


Figure 6-2: V2G Smart System Mobile Application (in Portuguese language)

Figure 6-2 shows V2G Smart System main application menus: (1) Main menu with information of user definition, statistics, and virtual account; (2) User profile; (3) Electricity market prices, simulated with base on microgeneration production (see Section 4.3.1), based on installed capacity and weather information (wind direction and speed, rain percentage, temperature, solar radiation); (4) User account related with the electricity market; (5) Personalized menu links for user's fast access; (6) Application default menus; (7) EV and electricity market related news, created from personalized web search robot.

Figure 6-3 describes the creation of a profile with pre-defined information, like EV type, and help tips to the user on this process.

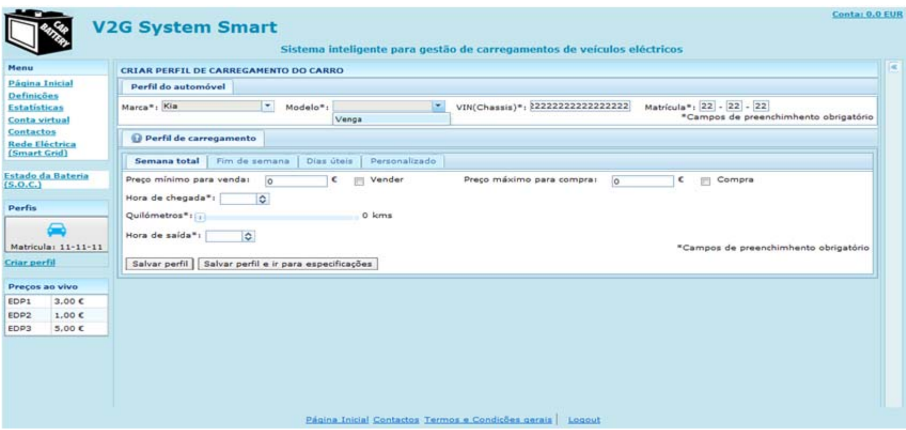


Figure 6-3: V2G Smart System - menu for charging profile creation (in Portuguese language)

Figure 6-4 shows a user profile with the identification of travel periods and electricity prices to sell and buy.

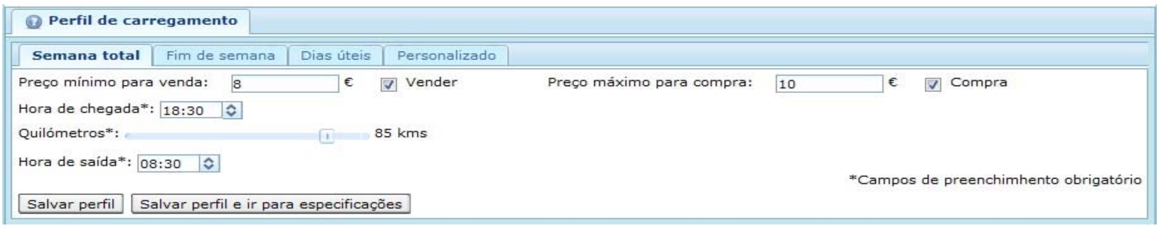
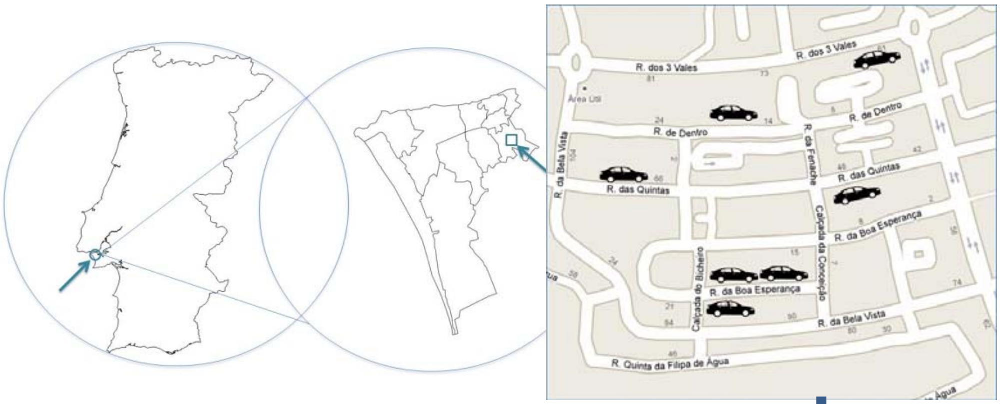
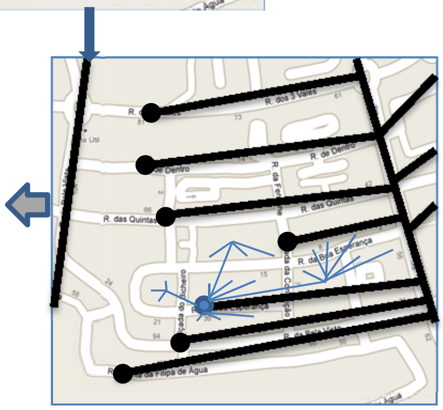


Figure 6-4: Driver profile visualization (in Portuguese language)

Figure 6-5 shows the smart charging process, where is identified an electrical distribution zone, power limitations are considered and the EV identified, taking into account a small example. A complete description and a user manual is available in [Bento, 2010].





User	Address	Zip Code
B	Rua da Boa Esperança, nº 7	2825-058
C	Rua da Boa Esperança, nº 22	2825-058
E	Rua da Boa Esperança, nº 33	2825-058

Charging Profile:

User	Time of home arrive	Time of daily trip start	S.O.C.	Battery Capacity | Charger Max Power
B	21h00	06h00	10%	24kWh | 3kW
C	23h00	08h00	5%	24kWh | 3kW
E	19h00	04h00	10%	24kWh | 3kW

User	Time (Hours)												
	19	20	21	22	23	00	01	02	03	04	05	06	07	
B			3	3	2	2	2	2	1	3	3	3		24 kWh
C					2	2	2	2	3	3	3	3	3	23 kWh
E	3	3	3	3	2	2	2	2	2					22 kWh

Figure 6-5: Small example of collective smart charging taking into account electrical distribution power limitation and user profile. At 3 am systems checks that user C needs more power, so V2G smart system limits user B charging.

6.2. SiREV Application

The SiREV system is based on three main layers, where SiREV is the designation for the mobile application for an Android phone. The SiREV main services are: (1) GPS position service; (2) Data storage service; (3) Internet connection service; (4) SMS service; (5) User notification service.

The SiREV system is based on three main layers, shown in Figure 6-6:

- SiREV Application for Android Operator System.
- Execution Services: The SiREV main services are: (1) GPS position service; (2) Data storage service; (3) Internet connection service; (4) SMS service; (5) User notification service.
- Mobile Application: These layers, as a group, form the Mobile Platform SiREV which the target is the mobile platform The Android platform is the platform for Google's mobile devices business; it is now one of the major operating systems used on smartphones, and the system that grew most in the market in 2009. The platform comprises an operating system, a middleware layer and a set of key applications. The development of applications for the Android platform is based on a well-documented Java API. For development of applications Google offers Android SDK that is a set of tools and documentation, integrated into the Eclipse development environment that allows the creation and test applications.

Figure 6-6: Main SiREV system platform layers

The development of applications for the Android platform is based on a component-oriented architecture. A number of types of components that make up each application databases:

- *activitie*: an *activitie* presents a user interface and represents a specific activity of the user. An *activitie* may for instance be used to display a list of options to the user and capture the interaction that the user produces.
- *Service*: a *service* has no user interface, runs in the background for an indefinite period of time. A *service* can be associated with one or more activities, which offer to the user the control of the application.
- *broadcast receiver* is a component used to receive advertisements transmitted by other components and may have different origins, such as low battery announcement, announcement of change in geographical position, announcement that a photography was taken or that the user has changed the language options of the equipment.
- *content provider* is used for data exchange with others applications. All data is stored in a SQLite database.
- *intents* are asynchronous messages that trigger activities, broadcast receivers and services and shows receptor component.

Each block in the Figure 6-7 represents a set of architectural components grouped by functionality, with the interfaces for communication with each other.

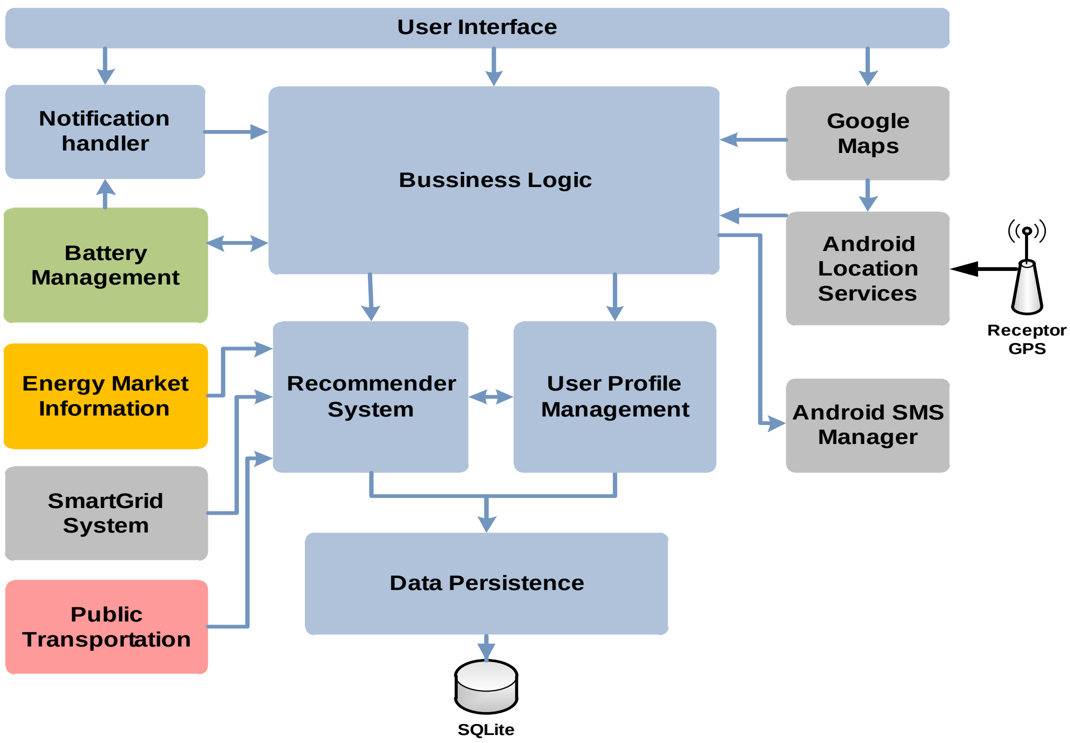


Figure 6-7: SiREV system architecture

6.2.1. Components Model

Android architecture is based on a set of components. The system model SiREV uses these components as follows. In Figure 6-8 there are two layers of the application and external systems: (1) user interface and business logic; (2) integration; and (3) external systems. The colors represent the functional subsystems, which correspond to functional blocks of the model architecture. The six cubes in the bottom of the diagram represent the external systems with which it interacts. In the case of a system for a mobile device makes sense for 2-tier architecture that there is one layer for the user interface and business logic, and keeping separated the integration layer to allow greater modularity and flexibility in integration with external devices.

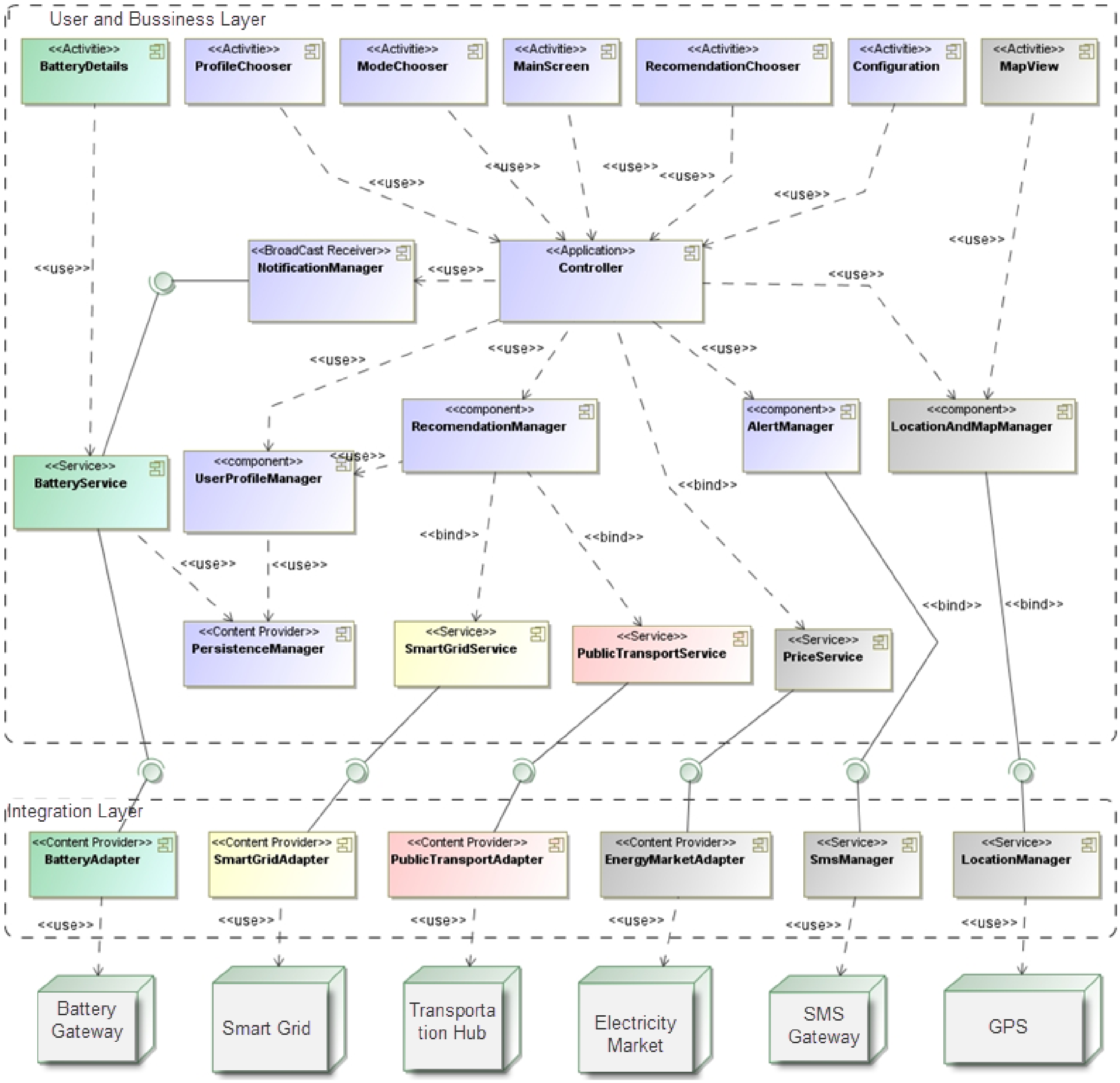


Figure 6-8: Components Models of SiREV application

6.2.2. User's Interface

The SiREV system has one *activitie* for each screen functionality: (1) *ProfileChooser*, chooses the user and associated profile; (2) *ModeChooser*, chooses EV usage mode (travel or working); (3) *DestinationChooser*, chooses home, work or other specific address; (4) *MainScreen*, with context data, position and SOC, presented in Figure 6-7 (left side); and (5) *RecomendationChooser*, recommendation screen, showed in Figure 6-9 (right side).

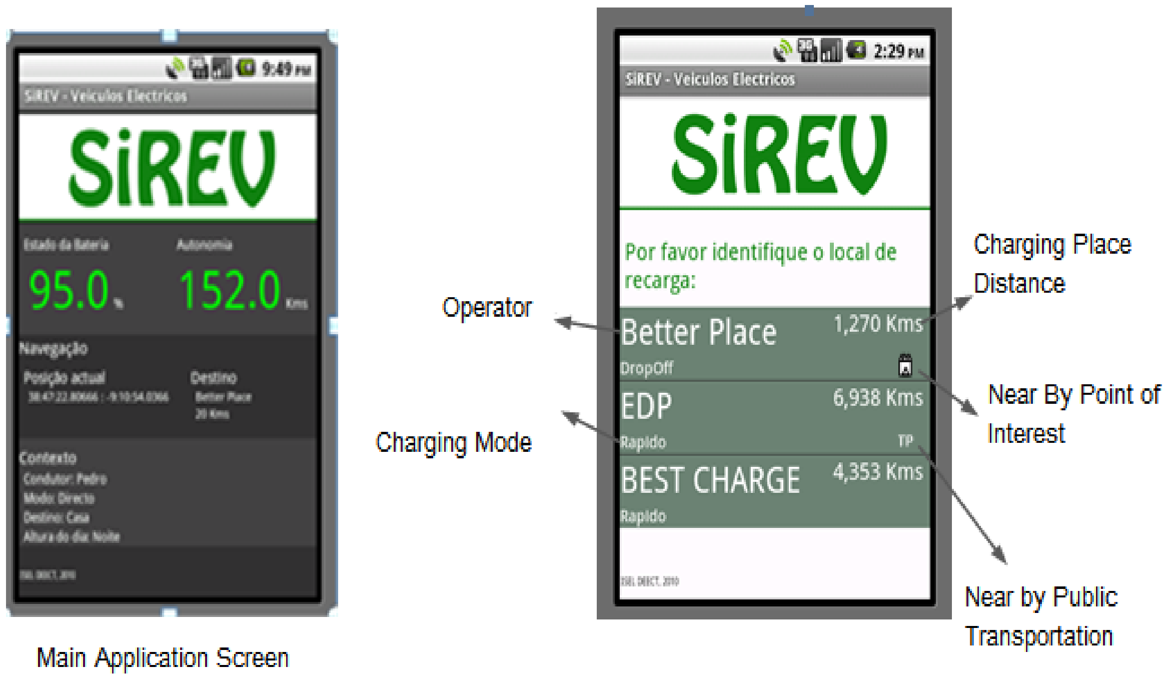


Figure 6-9: Screens of SiREV Application

6.2.3. Controller

The *Controller* is created when the application starts and the *Controller* checks application status, register the information in context and makes the connection between the presentation layer and the other *services* and *components*. This class is described by Figure 6-10.

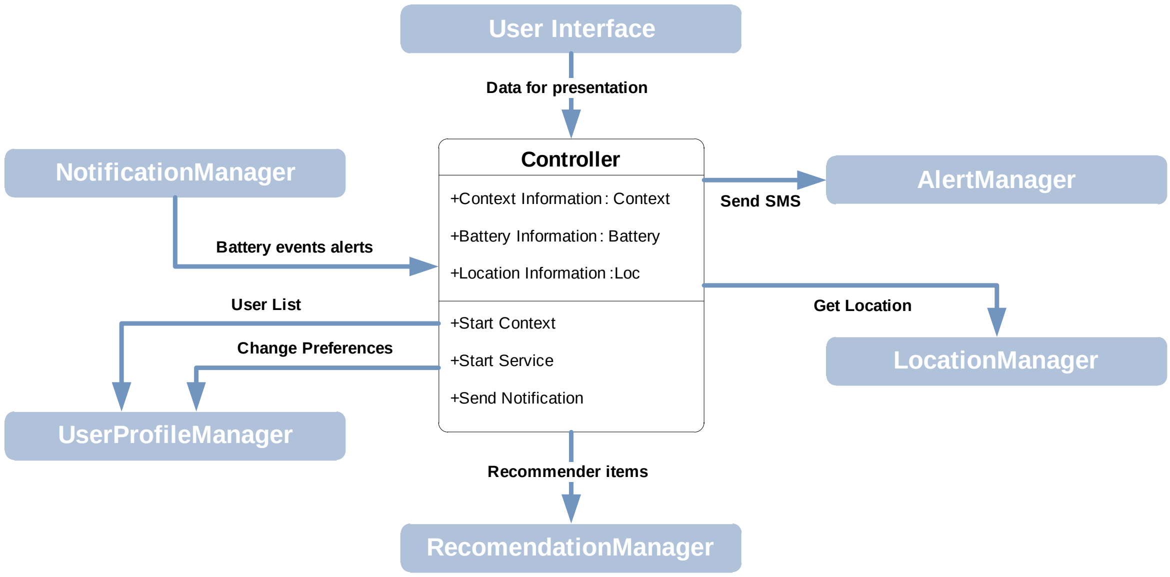


Figure 6-10: Class Diagram of *Controller*

6.2.4. Recommender System

Recommender System (description on Section 3.11) is a java class called *RecomendationManager*. This class is described in Figure 6-11.

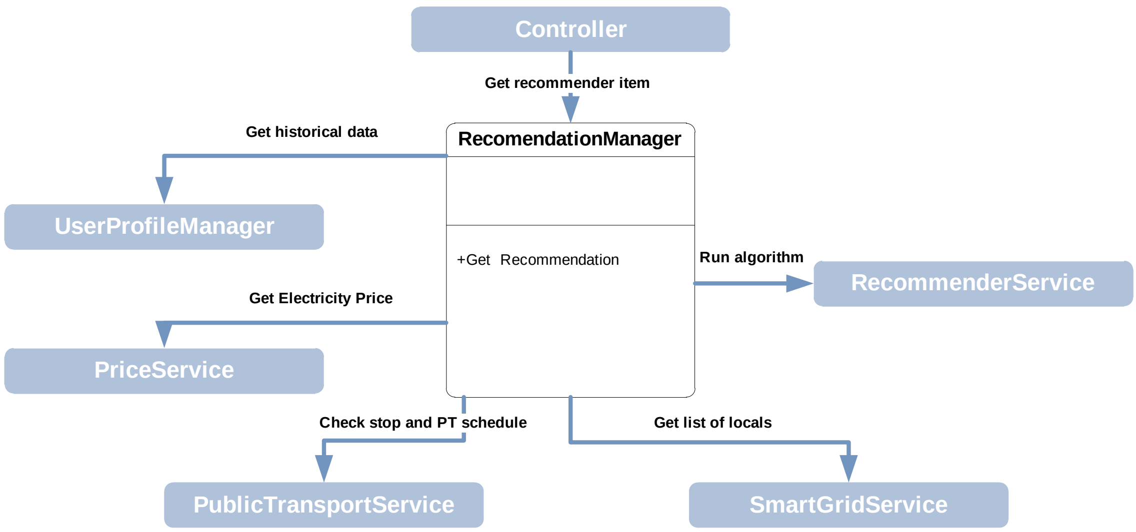


Figure 6-11: Class Diagram of *RecomendationManager*

6.2.5. Integration Layer

The system interacts with different and heterogeneous external systems, which implement different integration patterns supported on various communication protocols. For each external system it identifies the most widely used standard, or in case there is no set standard or a universally accepted one, an adapter that abstracts of one possible implementation of a standard pattern. The interface with external systems offers a complete abstraction of its implementation, with the purpose of isolating and decoupling the systems. The SiREV system is flexible to be integrated into any type of system, since the interface interaction is respected. The integration components are components Android-type *content providers*, and implement the standard architecture adapter [Pereira, 2010].

Smart Grid integration

Information on the charging points is received in XML files in KML format, which are obtained through the periodic synchronization with the smart grid. The synchronization is done via an Internet connection by going to an address configured on the system and using the classes in the API package android.net android. The component *SmartGridService* is a service to be launched to android who continues to run in the background, performing regular updating of the information file of the charging points. The service uses the component that is a component *SmartGridAdapter* android type of content provider. This component has the task to interface with external system that provides data on the charging points and makes the necessary changes to data in order to provide records that the service recognizes as *SmartGridService*. This class diagram is described in Figure 6-12.

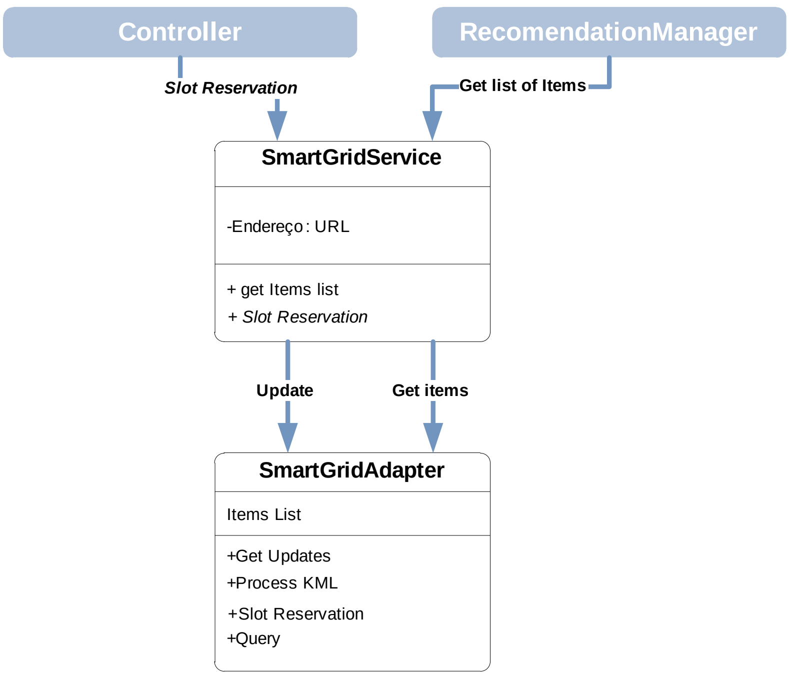


Figure 6-12: Class Diagram of SmartGridService

Battery management system interface

The battery management system consists of the following components: (1) *BatteryDetails*: Android architecture that allows applications, or subsystems, sharing resources, including the user interfaces, activities. This facility allows, in this case, the set within the subsystem *activitie Management Battery*, because that is where it really fits, but that can invoke the main component of the system controller. The *activitie BatteryDetails* is a screen with information about the current state of the battery and the mode of operation, i.e., whether it is charging or running. By putting this in a different package *activitie* it allows the screen to be customized for different constructors or battery management systems, providing data specific to each; (2) *BatteryService*: Android service responsible for managing and monitoring the battery. It also has the function of periodically monitor the battery status and trigger messages such as autonomy *IntentBroadcast* lower than 50 km; (3) *ChargingDeviceAdapter*: Component responsible for integration with the system device. As explained above, implements the standard adapter that can be developed by a component of this type for any battery system of any manufacturer that has been duly specified. This component also has to deal with multiple physical interfaces to connect to the battery system. The SiREV is designed to be implemented in both systems, integrated into the vehicle as smartphones. At that, it uses the API *ChargingDeviceAdapter* android to become fully achieved the physical connection to another system. It is possible to connect via USB or Ethernet, in the case of an integrated mechanism in the vehicle, or by Bluetooth or Wi-Fi, if the SiREV runs at a smartphone without physical connection to the vehicle. The platform provides all the necessary mechanisms to establish the physical connection, the application just needs to know the Uniform Resource Identifier (URI) that communicates. See description in Figure 6-13.

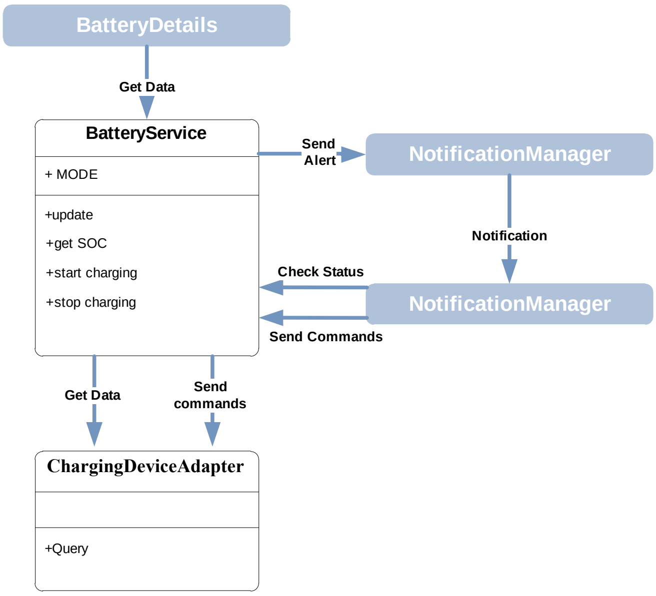


Figure 6-13: Class Diagram for Battery management system interface

Public transport interface

Information on public transport is available to the system in the form of an XML file that contains position information of the geographic locations of the transports stops. The recommendation system submits the items collection of items for the *PublicTransportService* that identifies each item to its proximity to an interface with public transport. If yes, the property *nearPublicTransport* item is placed with the value of one. The connection to an information system is made by public transport component *PublicTransportAdapte*r. See description in Figure 6-14.

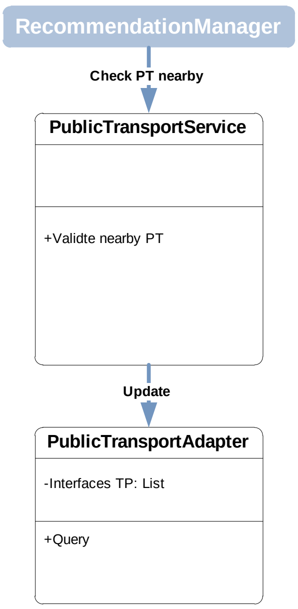


Figure 6-14: Information class of public transportation

Eelectricity market interface

The electricity market information is managed by *PriceService*, a service that periodically contact the information system of the electricity market in order to update the current price. The connection to the external system is the responsibility of the adapter *EnergyMarketAdapter*, which is a system that only returns a numeric value corresponding to the price of electricity. Information class in Figure 6-15.

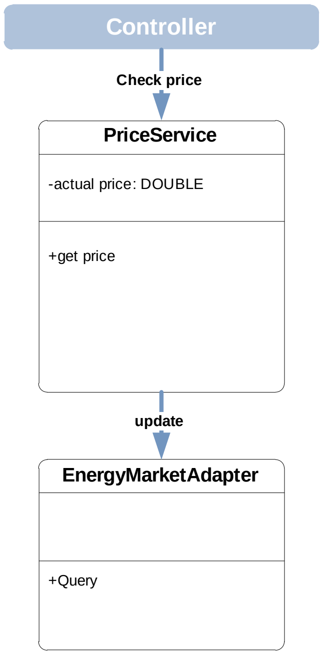


Figure 6-15: Information class for electricity market

Android Services are: Position system, Mapview, SMS Manager. For more details see this master project oriented at ISEL [Pereira, 2010].

6.3. IRecommendit: Windows Mobile Application

Similar application for windows mobile platform was developed by a final year project at ISEL [Borges, 2010]. Figure 6-16 shows the different modules that compose the system architecture:

- Application for mobile devices, IRecommendIt Mobile App;
- Web Service *EVService*;
- Service Layer;
- Data Access Layer (DAL);
- SGBD1;

- SGBD2;
- Recommendation engine.

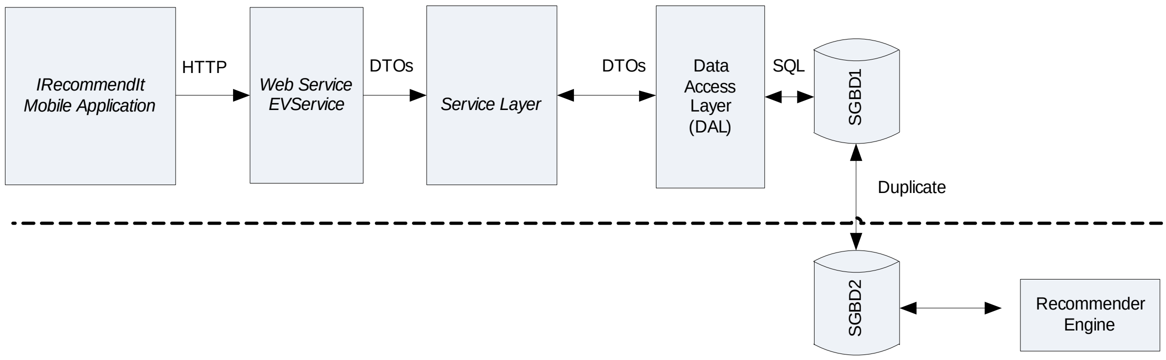


Figure 6-16: Main modules of IRecommendit (Windows Mobile Application)

Starting at the end, right to left in Figure 6-10, the system has a subsystem, the recommendation engine system. The management is responsible for the calculation of recommendations of places of interest. The calculation of the recommendations i occupy large amount of resources is a task whose execution can compromise system performance and therefore must be isolated from the rest of the tasks of the system to not affect their performance. To isolate the calculation of the recommendations and give some scale to the system was based on two DBMSs, and SGBD1 SGBD2. The SGBD1 owns all of the data stored by the system IRecommendIt while the second part has SGBD2 SGBD1 data that are needed for the calculation of recommendations. The two DBMSs perform data replication, so that the calculation of the recommendations on data to be consistent and fair. The DAL performs the data management system IRecommendIt, it operates on the SGBD1 questions in the form of SQL (Structured Query Language). This provides a centralized access and ensures safety and consistency of the database (SGBD1). Interaction with the data access layer is done using DTOs. DTOs (Data Transfer Objects) is a design pattern used to transfer data between subsystems of a software application. The service layer (Service Layer) is the business layer IRecommendIt system, this is where the services are provided by the centralized system IRecommendIt. Among the many services are services on the charging points, as the research and booking of charging points. To expose the system services IRecommendIt uses the Web Service *EVService*. Web Services are a solution used in systems integration and communication between different applications, enabling new applications to interact with existing ones.

IRecommendIt Mobile App is an application for mobile devices whose operating system is based on the set of Windows CE components, such as Windows Mobile 6.0. This application accesses to system services through the Web Service *EVService*, using http requests (Hypertext Transfer Protocol).

The Services Layer is a layer that is intended to expose business logic as services and thus serve as an abstraction of business logic. This layer was created and designed so that a future Web application can take advantage of the functionality of the system. These are services that perform operations on the system being Mobi-System that the Web Service *EVService* uses this layer to perform the operations on the Mobi-System. The services do not show any relation between them, its functioning being independent of others and consists of: (1) Service charging points (*IRechargingPointsService*); (2) Service Sights (*ISightsService*); (3) Service Recommendations (*IRecommendationsService*); (4) Service Ratings (*IClassificationsService*); (5) Service Directorates (*IDriverDirectionsService*); (6) Map Service (*IMapsService*); (7) Service Users (*IUsersService*); (8) Service Roles (*IRolesService*); (9) Service Categories (*ICategoriesService*); (10) Geocoding Service (*IGeocodingService*); (11) Car and Bike sharing service (*ICarBikeService*); and (12) Public transportation service (*IPublicTransportationService*).

6.3.1. Creating Functionalities Based on Existing Services

The way that this solution has been developed is very simple to add services and functionalities to the system, since this solution was developed in modular and incremental form. Given the suggestion of a set of users, if it would be interesting to have information on the location and availability of parking places, it is functionality fairly easy to add, which allows users to obtain directions to car parks in town and to get information on the availability of parking places. Similarly, if the user can interact with the application managing a car park, it is possible to reserve parking places and get guidance until the car park. For this task it is necessary to: (1) Add the local authority car parks to the conceptual model of the database; (2) Utilize or even replicate (in large part) the service of charging points; (3) Provide Web Service operations in *EVService*; and (4) Add a set of screens for the car parks in the application for mobile devices. The same principles were used to develop the car and bike share systems, which are described at [Daniel, 2010].

6.4. Mobile Application Usage Results (Case Study)

A system is not useful if it does not have practical application in practical situations. Thus, in this work, in the proposed definition of a model of information system, it is important to demonstrate real-world scenarios in which the system applies and is useful and important for users. Electric vehicles create new paradigms to mobility due to its limited range and long recharging times, and inevitably have impact on the day-to-day of the drivers, who have to plan their journeys and stops for recharging.

These problems will tend to decrease with the technological advances that increase the autonomy of the vehicles, and with the development of a network of battery charging places, with an increasing number of alternative sites, as well as with a larger geographical dispersion.

Current work shows three scenarios that could be considered as representative for most types of electric vehicles in the near future. The scenarios described below project what might be the reality for drivers of electric vehicles in early 2012, based on the following assumptions:

Table 6-1: Data used in the case study of Section 6.4

Caracteristics	Values
EV Autonomy	150 km
Charging Points in Portugal	1,300
Slow Charging	6 Hours
Fast Charging	30 Minuts
Change Baterry	10 Minuts

6.4.1. Scenario 1 - Day-to-Day Urban

This scenario shows the use of Electric Vehicle (EV) by a driver who lives on the outskirts of a big city, and uses the EV to go to the work. The driver takes the kids to school every day, and after the job, goes to a gym session before making the return trip. His typical driving day is:

- 07:30 - He leaves home with the EV fully charged, after charging during the night;
- 08:15 - He covers 30 km until reaches the school of the first son;
- 08:30 - He traverses 5 km to reach the school of the second child;
- 09:00 - He covers 10 km to came to his work place;
- 12:30 - He goes out for lunch in his EV covering a total of 10 km;
- 18:00 - He covers 10 km to the Gymnasium;
- 19:30 - He covers 10 km to the school of the child;
- 19:45 - He covers 5 km to the school of the other son;
- 20:30 - He covers 30 km in the way back home.

The driver returns home with 25% of the EV battery capacity.

This is the optimal scenario, appointed by opinion builders to justify the viability of EV, vehicles even with the current state of autonomy. However in this scenario an extra utilization of the EV cannot exist, as leaving home in the evening for dinner, or visiting friends. Besides, in this scenario all EV owners have to be able to charge their vehicles at home overnight. For the vast majority of the population that lives in metropolitan areas, it is not possible to charge the batteries of the vehicles during the night, since the vast majority of them live in buildings without parking or garage that make possible the overnight charging. For these cases the batteries charging must be carried out during the day, or in the middle of a travel, as with today's vehicles powered by fossil fuels.

Thus, maintaining the same schedule, but removing the batteries charging during the night, the driver will enter the vehicle with with 25% of the battery capacity. Figure 6-17 shows the main screen of the application with the indication of charging and battery life management system received from the battery through the adapter.

Figure 6-17: SiREV: Charging indication (SOC); EV estimated autonomy; A charging place identified (Better Place) at 20 km; and the Context Information (driver, mode, destination and day period) (in Portuguese language)

The SiREV asks for user login (driver identification), see Figure 6-18:

Figure 6-18: SiREV: Login menu with driver identification (in Portuguese language)

Then the system asks for operation mode (Direct or Leisure), see Figure 6-19:

Figure 6-19: SiREV: Operation mode (in Portuguese language)

Then ask for destination identification (usual destination appears in the application screen, such as home and work), see Figure 6-20:

Figure 6-20: SiREV, destination identification, usually destinations are highlighted (in Portuguese language)

The vehicle's range is 40 km, however the trip will have a total of 45 km and it will be necessary to recharge the EV batteries to get to the destination.

The SiREV presents an alert indicating the need to recharge the batteries, and shows the alternatives identified by the recommendation system. Since this is a trip to work, the goal will be to arrive as quickly as possible, so the recommendation system presents three alternatives for fast charging, and set the route, given the previous choices. The first step is to submit a recommendation to select the candidate items for the SiREV, and then it uses the information gleaned from smartgrid to create a list of all the charging points that can be reached by the vehicle. In this scenery the vehicle is in Odivelas, outside Lisbon, so the number of charging points is high. It is created a list of 30 possible charging sites. Then the list is sent to the component that manages the public transport information to validate the proximity of interfaces with different means of public transport. The component validates each of the candidate items and returns the updated list.

The next step is the processing of the recommendation. At the entrance of the recommendation system there is a list of 30 candidate items distributed as follows:

- 15 Points of slow charging:
  - 5 of EDP;
  - 5 of Better Place;
  - 5 of Mobi.E.
- 10 Points of fast charging:
  - 4 of EDP;
  - 3 of Better Place;
  - 3 of Mobi.E.
- 5 Points of drop-off (in which the batteries are replaced):
  - 1 of EDP;
  - 3 of Better Place;
  - 1 of Mobi.E.

The driver of this studied case never chooses the drop-off sites, nor it is important for him to select locations near public transport. This driver has a clear preference for places of charging of EDP, followed by Better Place, and he never charges his EV at places of Mobi.E. The algorithm returns a recommendation to run the utility with more than three items after comparison with the history of the driver choices.

The following screen is displayed to the driver, Figure 6-21:

Figure 6-21: Showing recommendation, regarding charging points that fits drivers' choices (in Portuguese language)

The driver selects the first recommendation of SiREV and sends the data on the location of the Public Charging Station (PCS) for the navigation system. Reached the PCS the charging process starts and SiREV presents progress and an indication that the vehicle performs in charging state. It is possible to visualize in a map the distance that the EV can reach with that charge. The driver can perform a charge until the desirable distance is reached (if less than the maximum range).

After the driver leaves the two children at school, SiREV continues to put a notification in the notification area that the vehicle's range is below the limit. Upon reaching the destination the driver selects the notice and recommendation system introduces three new options for charging, this time the system knows that the vehicle is at its destination because it is less than 5 km from the site displayed as a destination, so presents options for charging along three car parks within walking distance (see Figure 6-22). The batteries will charge while the driver is on his job.

After 4 hours, the driver receives an SMS notification on his phone, indicating that the batteries are fully charged (with 100% of energy storage capacity). The driver rests, assured that he can keep his routine the rest of the day, and that 150 km of EV autonomy are available until the next working day.

Figure 6-22: Recommendation of charging places nearby (in Portuguese language)

6.4.2. Scenario 2 - Long Distance Between Home and Work

This scenario presents the situation of a driver who lives at a considerable distance from his work place. The driver lives in a distant city but works in downtown Lisbon. The trip from home to work is 100 km. The driver lives in a building with a garage, but without a charging point for electric vehicle. A typical daily schedule of this driver is:

- 08:00 - Departure from home;
- 09:30 - He covers 100 km to his place of work;
- 13:00 - Out to lunch, traveling a total of 5 km;
- 19:30 - Return back home, covering 100 km.

This daily driver travel is 205 km long. Using the system SiREV, and assuming that, as in the previous case, in the morning the EV has 25% of its energy storage capacity. Upon entering the EV and after selecting the profile and identifying the destination the driver is alerted to the fact that he must charge his EV in a radius of 30 km. The system immediately displays the recommendations taking into consideration that the driver goes to his work place (see Figure 6-23).

The three options presented are of fast charging type, and have in common the fact that they are service areas that have cafeteria service. Whenever the driver needs to recharge the EV batteries in the morning, he chooses a service station with cafeteria service, because he takes the advantage of taking the breakfast as the car recharges. While having breakfast, the driver is alerted to the fact that the EV batteries are already charged. Back to the car, he follows his route to employment. Arriving at the entrance to Lisbon the battery pack is again with a low level of charge, with only 30% of stored energy, so that the driver is alerted to that fact.

Figure 6-23: Recommendation generated because SiREV detects that EV range is below 30% of initial range

The diver remains far from his destination, thus he is presented to all the fast charging options, and to an option of slow charging, but he is also near an interface to public transport, enabling the driver to put the car in a park covered with charging service, and continuing his journey by public transport. The driver chooses to deposit the car in the park, let the EV to be charged, and use public transport to go to the work.

After 6 hours the driver is notified that the EV batteries are fully charged, and so, he knows that can return home with his EV, because the energy stored in the batteries will be enough to cover the 100 km back.

6.4.3. Scenario 3 - Car Ride at Weekend

In this scenario, the same driver of the second scenario leaves home on a Saturday morning for a ride with the family in the western coastal zone of Lisbon.

When entering the vehicle the driver identifies himself and indicates that he will shift into drive, with no predetermined destination.

After an hour of travel, the system notifies the driver that the autonomy of the vehicle reached the configured limit of 30 km, and displays an alert, as showed in Figure 6-24.

In this situation the recommendation system will consider the following context:

- Operating mode: leisure, see Figure 6-19;
- Time of day: morning;
- Destination: No destination.

The system has the following three charging station recommendations:

Figure 6-24: Recommendation, because SiREV detects that range is below the configured limit of 30 km

All recommendations are slow and charging points have in common the fact that they are near centers of tourist interest, with places to visit. The full charge will take about six hours, so the driver and family can visit the Points of Interest (nearby), lunch in one of several restaurants. Just four hours after the driver decides to return home. The vehicle's range is 70%, and will not reach the destination.

After walking 50 km of new drivers are notified that you have to carry the load of the vehicle. In this situation the recommendation system will consider the following context:

- Mode of Operation: leisure, see Figure 6-19;
- Time of day: Afternoon;

- Destination: House.

By stating that the destination is home, the recommendation system provides fast charging points along the route (Figure 6-25), in this context because the driver always chooses this type of sites because they want to get home as soon as possible.

Figure 6-25: Recommendation for fast charging station

6.4.4. Scenario 4 – Looking POI with Guidance

The driver of the EV can use the Mobi-System to: (1) get directions (2) locate charging points and reserve slots, (3) get recommendations on his journey with great information needs, as local battery charging, whose handicaps are known involving the charging time and its autonomy, local information satisfaction, public transport information in case of failure, etc; (4) Points of Interest (POI); (5) smart charging strategy; and (6) electricity market participation (sell, buy, profit maximization).

After user login (authentication), there is a menu where the driver selects which operation he wants to make; this is organized as Figure 6-26 (left side). If he wants to know possible interest places, from Recommendations tab Places, he has the screen shown in Figure 6-26 (right side). The user defines which region the system should consider introducing the geographic center and radius, which can be obtained using GPS or an address. Pressing the button Get recommendations are obtained, and in this case the user wants to know Points of Interest (POI) near Seixal, in Portugal, considering a radius of 2 km. At the bottom of the screen the user will find the recommendations identified by the name and address of the location of interest. The user can get more information about the location of interest selected by pressing the Info option from the menu.

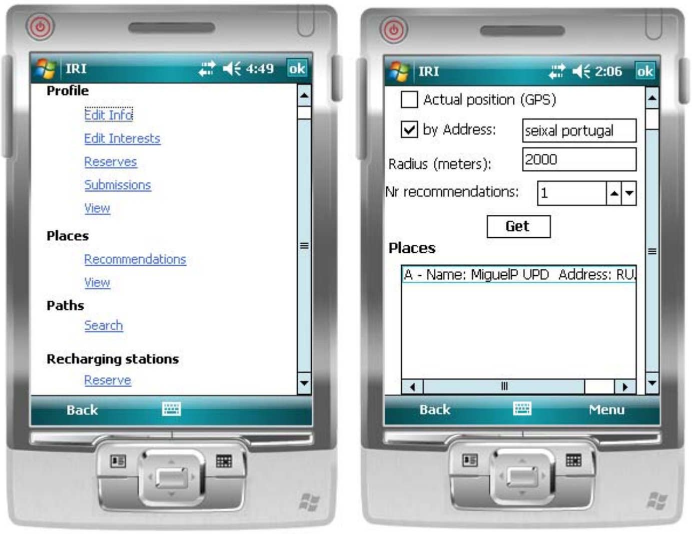


Figure 6-26: Main application screen and search for POI (Points of Interest)

Figure 6-27 shows the screens to identify a POI. Information from a point of interest is constituted by its name, address, latitude, longitude, brief description, associated categories, hours of operation and a display picture. In the user classification menu option, the user can rate the point of interest in order to help future recommendations to himself and to other users.

Figure 6-27: Screen for POI (Points of Interest)

The screen lets you annotate/classify the site of interest, with a degree of satisfaction, such as "Good." The following Figure 6-28 (left side) represents the screen. If the user wants help geographically he can access it from Map menu to display the selected site of interest, as is visible in the Figure 6-28 (right side). The site contains an identifier of interest (in this case is A), and in this screen the user has the ability to navigate the map, as well as zoom in and zoom out. In the menu he can change the map type view (Hybrid, Roadmap, and Satellite).

Figure 6-28: Visualization and classification of POI (Points of Interest)

If he does not like the recommendations generated, he can always get all the sites in a given area by accessing the item in the Places tab View. This screen is similar to the screen that lets the user get recommendations of sights, but this one shows all the sites in a given region with the possibility of filtering according to the categories of places of interest, as shown in Figure 6-29 (left side). After the user selects possible sites of interest to visit during the holidays, he needs to know which route to use in order to visit this place of interest. The screen is in the following Figure 6-29 (right side).

Figure 6-29: Get POI (Points of Interest) and get directions

6.4.5. Scenario 5 – Reserve Charging Slots in a Public Charging Station

On this screen the user enters start and end place and current location is taken from GPS. After pressing the button Get Directions application are indicated possible routes and also are indicated the travel time and distance. For each route the user can see the steps needed to guide him during the journey in order to reach the target site. Optionally the user can observe this route on a geographical map. After he gets the recommendations and the routes he needs to go, he also needs to know where he can recharge the EV batteries (charging points), during or after the path followed. To access the screen the user choses Book tab Recharging Stations. This screen is shown in Figure 6-30:

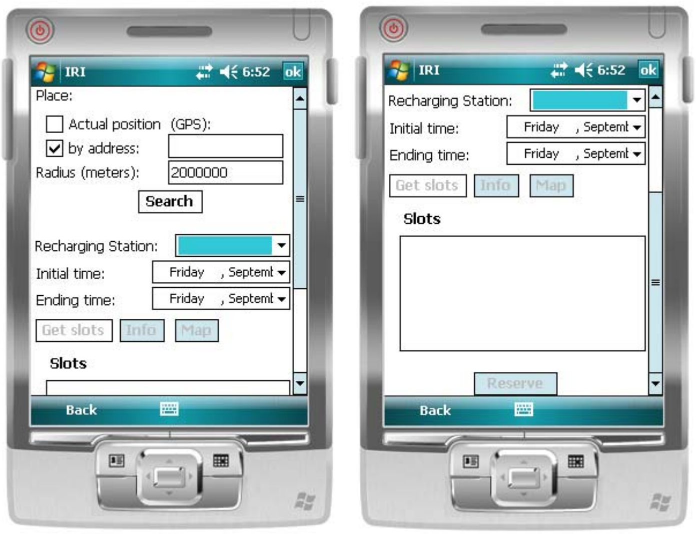


Figure 6-30: Availability and reservation of slots for charging stations

Figure 6-31 shows a PCS (Public Charging Station) slot reservation.

Figure 6-31: Reverse and submission forms on Mobi-System

Further usage possibility available in [Borges, 2010].

6.5. SITP Application

This Section is dedicated to the description of the SITP application developed for the public transportation data integration, using main ideas expressed in Section 5.5. In Figure 6-32, is illustrated a typical client operation from the client side: search for stops, search information of public transportation for a certain path, get price, schedules and best itineraries path options. From the operator are showed the registration and the registration of DB schema.

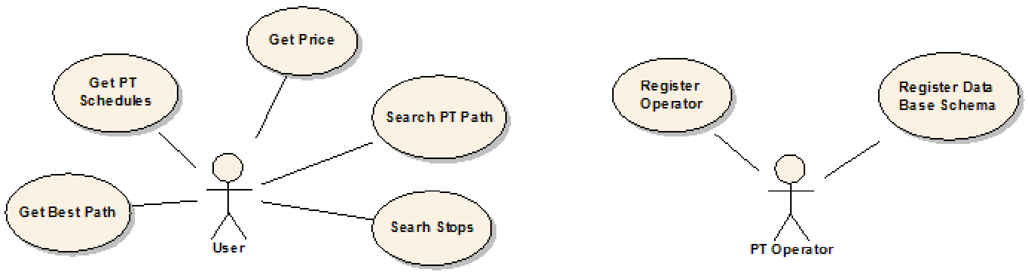


Figure 6-32: Use case for SITP application

Two Web applications were developed:

- SITP, to support queries from users;
- SITP, for the management of information by the public transportation operators.

These applications were implemented in ASP.NET MVC platform. For more details see [Domingues, 2010].

The SITP was implemented to allow the user to search for routes, stops, query times and fares. Figure 6-33 illustrates the application menu to support these functionalities.

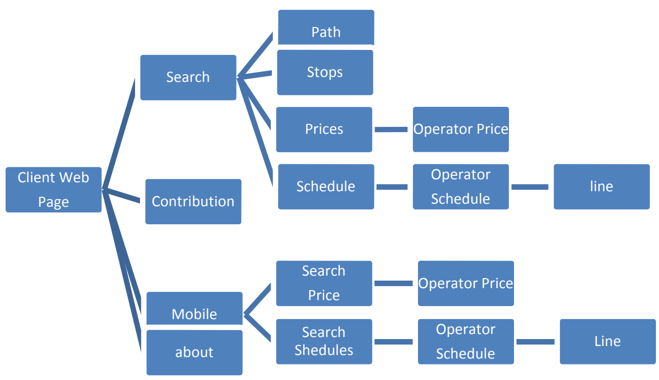


Figure 6-33: SITP - Web Client Application Menu

The developed application has the basic structure of a Master Page with an application menu. The menu implemented allows navigation of the site as intended, with Multi-Language support and a link to access mobile devices (see Figure 6-34 and Figure 6-35).

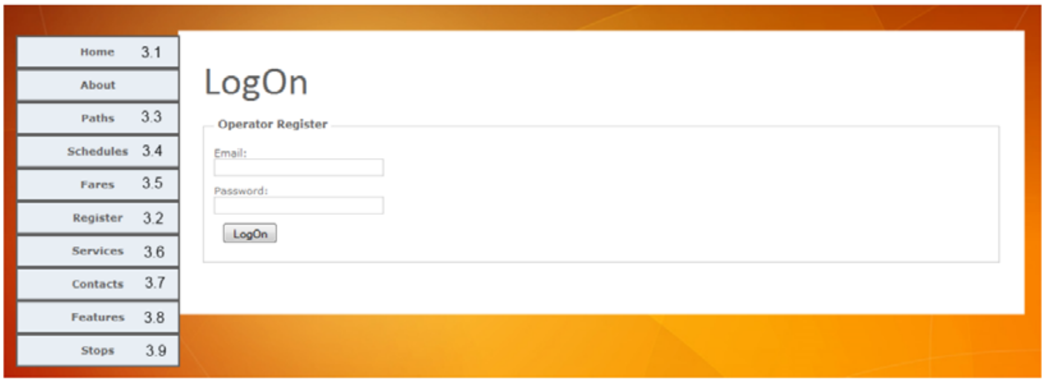


Figure 6-34: SITP - available menu for users

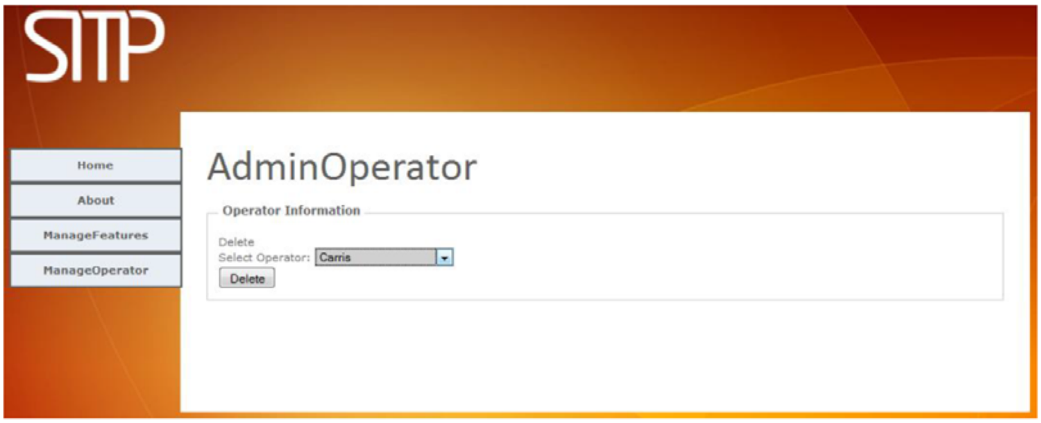


Figure 6-35: SITP - available menu for public transportation operators

6.5.1. SITP Cases of Usage

In this Section are described several cases of usage of SITP application.

Case one: search for near public transportation (stops), using a pre-defined radius from current user position (see Figure 6-36). Taking into account current time the SIPT indicates also close public transportation to arrive on selected stops.

Figure 6-36: Search result of a user query for a PT stop in a radius of 50m from his current position in Lisbon (Cais do Sodré)

Case two: getting public transportation prices for the desired journey. In Figure 6-37 is showed the price for the Portuguese company CP (a railway company).

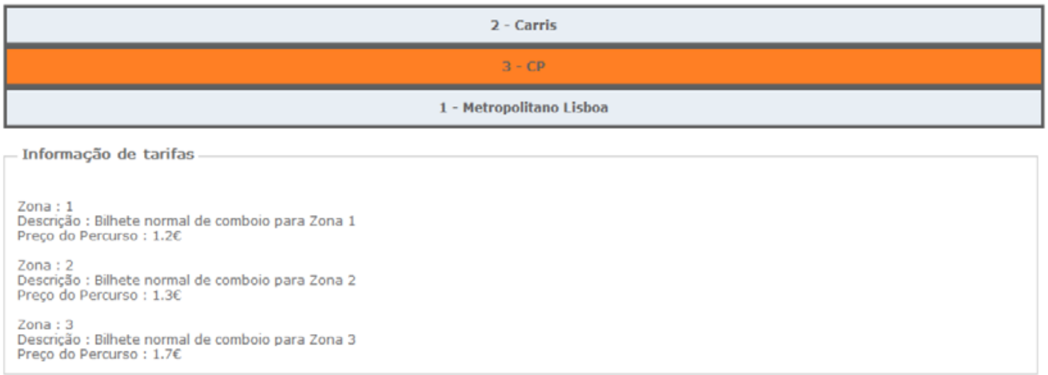


Figure 6-37: Search result of a user price query for CP public transportation operator (description in Portuguese Language)

In Figure 6-38 is showed the SITP application on a mobile device.

Figure 6-38: SITP mobile device interface

In Figure 6-39 is showed the menu for a public transportation operator that introduces a stop on SITP system.

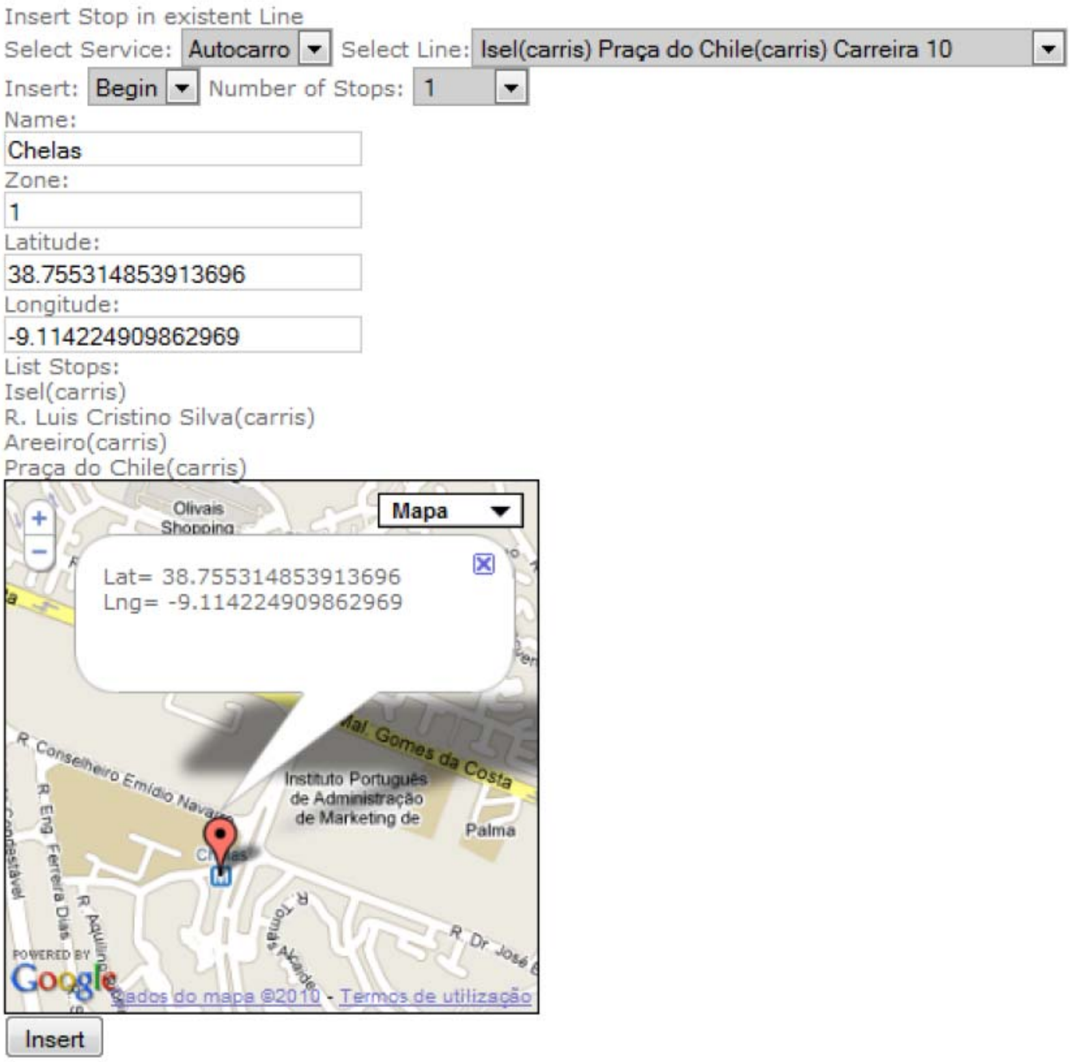


Figure 6-39: Menu for public transportation operator that introduces a stop on SITP system

6.6. Conclusion

More tests and pilots should still be performed, but in this upcoming reality is difficult to find working situations to take in order to use their data. Simulation performs an important role to give data for the used case studies. Two main applications were developed for two main mobile operation systems, Android and Windows Mobile, and for two Web applications, V2G Smart System and SITP. User acceptance of this mobile application should come from questionnaires feedback after drivers' usage.

7. CONCLUSION

Mobi-System develops a solution that supports the driver with the appropriate and relevant information to decide and plan his journey using an EV (Electric Vehicle), reducing the constraints related with the vehicle autonomy and allowing the driver to perform his journey with reduced anxiety about vehicle range. This system is in the intersection of EV integration problems (e.g., new charging infrastructures are being prepared, and several problems have been raised due to limited range autonomy and the long time of the charging process) with the new paradigm of smart cities, where a cooperative approach is established among different transportation sources. ICT (Information and Communication Technologies), with mobile communications and mobile information systems, play an important role in this process, in the integration and real time information access. The results bring new and increasing information needs for the drivers, because information forms a key part of the driver decision process. The success of EV penetration in the market will be in part due to this information availability at the drivers' side.

The main goal of this work was to bring ICT and Information System to an upcoming growing area of sustainable mobility process in smart cities, to help the EV driver on the charging process, and to minimize the range anxiety problem. To increase EV attractiveness electricity market participation is assisted through the creation and maintenance of EV community and an integration of local renewable energy resources. Figure 7-1 shows the main work research goals and the accomplished areas of work. The main result of this work is the development of driver relevant information on a mobile device, giving an integrated view of several areas as: charging process (at home and public station) in a EV, dealing with the driver range anxiety problem, creating a community of EVs for energy market participation, integration of local renewable resource and for a diversity of options towards mobility processes in smart cites: integration of bike and car sharing systems, car pooling, public transportation information integration, and best route taking into account a diversity of transportation and environmental policy options.

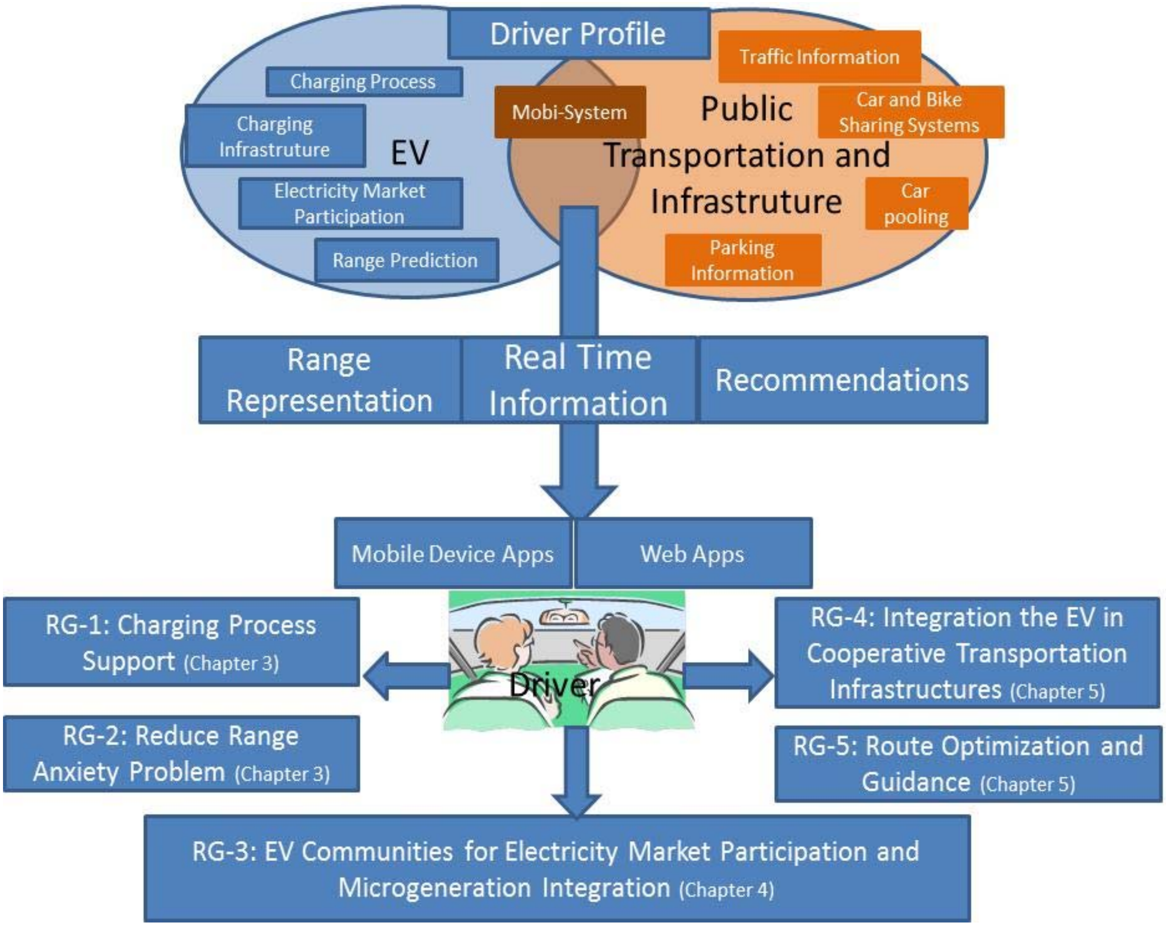


Figure 7-1: Mobi-System related areas and the achieved research goals

Figure 7.2 shows developed functions and systems for:

- EV charging or discharging operation: a management system was proposed with a smart charging strategy taking into account distribution and consumers power limitation. Since there is no real environment for testing purposes, an agent-based simulation tool was developed. Based on this tool and taking into consideration real world information (from user questionnaire's inputs and information taken from tracking systems), a home consumption analysis was performed based on agents and using a stochastic process. Taking into account the limitations of the distribution network and the user's power contracts, a smart charging strategy was identified (basically this is an indication of the maximum power through time that the charging process can use). In the author's opinion more complexity could be introduced on this tool, such as microgeneration and discharging process (when EV batteries send part of the stored energy back to the electrical grid). The geo-reference in a graph, the electrical distribution network and a visualization tool were also proposed, which can help the planning of new distribution infrastructures and the identification of regions of power constrains.

- Electricity Market participation: our main contribution was the definition of a conceptual system to create and manage the EV community. This is an innovative credit-based system that also involves a collaborative broker for DER (Distributed Energy Resources). Using this credit-base system, together with rankings, the users can profit from an open and healthy competitive environment. Also, in the future, to increase the market share of EVs, there will be a need of these types of systems to explore the energy market potential of these types of vehicles. Also, renewable energy sources integration and microgeneration can benefit from a community coordination action, where users can capture renewable energy produced in excess on local generation, at lower prices, avoiding electrical energy transportation loses.

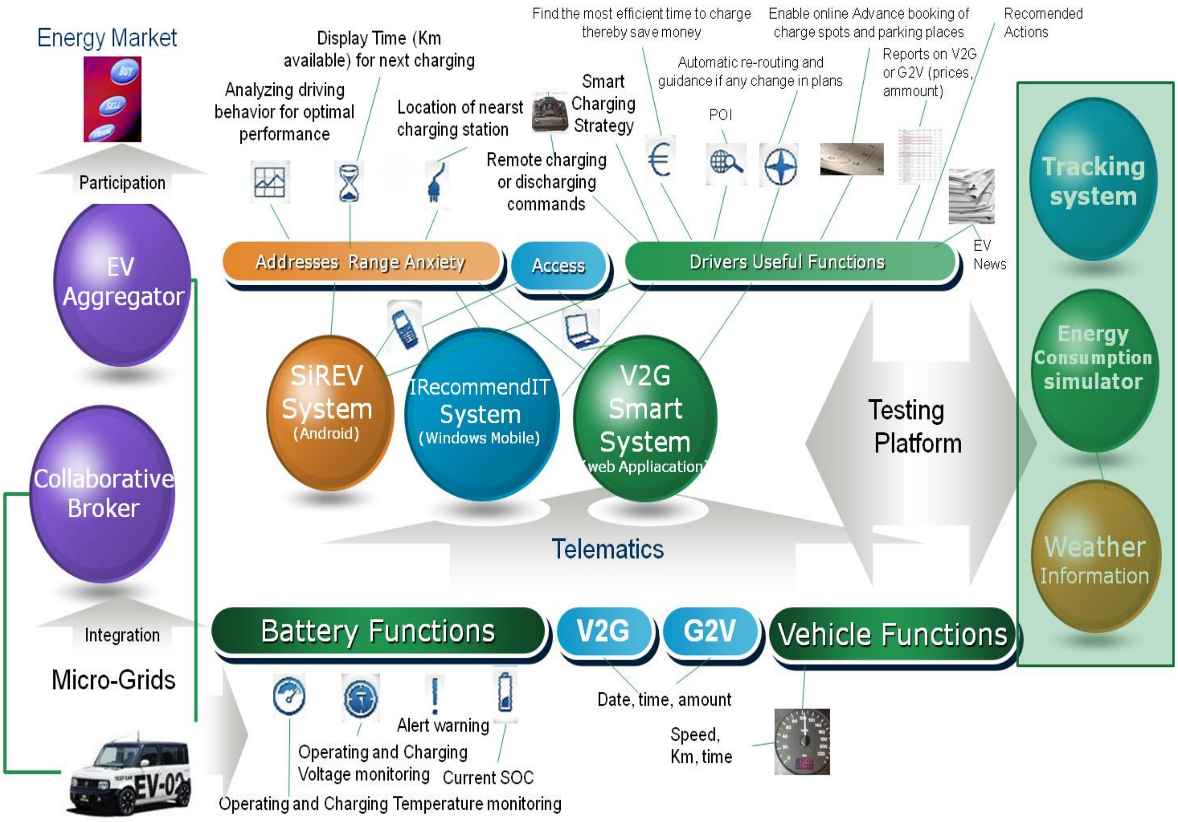


Figure 7-2: Developed Functions and System for Mobi-System for EV related and electricity market related functions

In this work it was proposed the integration of information from various areas that will for sure participate in the successful implementation of a mobility model for drivers of Electric Vehicles. However it was extremely difficult to find projects and technologies mature enough for the actual operating environment. There are prototypes from several players, mostly from universities or government projects. There are also some projects of companies starting in this market business, but most of them are in the process of prototyping or market testing phase. Additionally, it is very difficult to find specifications and standards to be globally used and accepted for exchange of information, particularly with the smart grid systems, public transport systems, control systems for charging batteries, and the electricity market. The data exchange from a technical standpoint it was chosen to submit asynchronous communication modes based on open specifications (e.g., XML files). It was also necessary to ensure that the integration model is sufficiently generic and flexible to be adapted to different systems, having a low impact on the implementation of Mobi-System. The simulation platform could have a great impact on this startup phase, since there are few real cases to test.

In transportation a diversity of systems to reduce usage of own vehicles was created, reusing pieces of software code and approaches created for charging process and electricity market participation (credit mechanisms, charging spots reservation). The main contribution is the Public Transportation data integration and the diversity of systems (car sharing, bike sharing, car pooling) on a user single interface combined with the best path or decision to go from point A to point B. This integrated view is important for end-users, but also for government or public operators, because it gives a transparent overview, where it is easy to identify lack of services in certain areas. It is also is important for areas where public offer is well dimensioned to introduce more severe penalties for the usage of own car. Besides, Green Router Planers can be adapted for local policies, where the arc cost between two nodes can be adjusted to local preferences or policies.

This work benefits from author’s background in Computer Science, from his automobile work experience, and also from his position as Professor at ISEL, where during the last three years he has supervised four master projects and nine final year projects in the Informatics Department.

7.1. Future Work

Electric Vehicles (EV) will open new business opportunities, because this type of vehicles needs more user interactions and systems to support its operating processes. OEMs (Original Equipment Manufacturers) will need to open access to vehicle information and a standardization process will play an important role. In this sense Telematics and Communications are good businesses opportunities. Traditional and new EV OEMs are betting heavy on Telematics: Renault Nissan, PSA, REVA, Th!nk, GM, and Ford, among others, are all gearing up with value-added Telematics features. This reality, added to Electricity Market participation, and Sustainable Mobility policies towards $C0_2$ emissions reductions, will raise this tendency and opens new opportunities, especially in giving right and important information to drivers through mobile devices.

To finalize, the author is aware that an alternative to the use of a mobile device (development option in this work) is the use of the navigation system device of the own Electric Vehicle, but the sustainable mobility function (described in Chapter 5) will always benefit from a mobile device option, because a mobile device can go with the user to everywhere, becoming the user's communication device. One future possibility is that these mobile devices could be mirrored in the Electric Vehicle (in the navigation system or in other equivalent device).

7.2. Expected Impacts of Current Work

Mobi-System provides to the drivers relevant information about public transportation, parking, car sharing system and charging stations. The creation of communities also provides conditions for electrical market participation, and consequently may provide the means to use the available spare power capacity (also allowing renewable energy integration) in each parked vehicle, avoiding the need of maintaining the excess of conventional electricity generation capacity currently required to provide regulation, spinning reserves and power peaks.

V2G model may have the potential to transform both energy and transport systems in profound ways, by promoting the deployment of alternative vehicle technologies, reducing inefficient investment in conventional generation, and supporting the installation of renewable electrical energy sources, including microgeneration.

Part of this work was submitted to the recent FCT call [FCT, 2010] with the project here described:

- Proposal Title: EV-Cockpit: Personal Mobile System for Electric Vehicle Control (PTDC/SEN-TRA/118302/2010).
- Abstract: *Project will create a mobile device application to assist EV drivers, receiving EV related information and created a diversity useful EV related information. Main project purpose is to get expertise from different group areas, such as information systems, mobile devices, communications, telematics and power electronics area to create a new product application: Mobile application with EV related information. Regarding the current problem (e.g. Drivers access EV related information) three main approaches could come out: (1) integrated system on EV, developed by OEM; (2) web application on desktop; and (3) mobile application. This problem could be similar to orientation devices (GPS) for vehicles, where there is two main consumers approaches: (1) taking solutions from OEM, full integrated in the vehicle; and (2) external devices for vehicle integration. This second solution is most chosen by the drivers because the price, most of the times are ten to twenty times cheaper. So we think that in future the EV mobile application will be a growing market with the possibility of drivers integrated several vehicles in the same mobile.*

Part of this work in collaboration with INTELI was submitted to a tender call to FP7 in May 2011 [Tender 2011]: *SMART 2011/0065 "The impact of ICT R&D in the large scale deployment of the electric vehicle"*, where an impact study will be focus on relevant problems and drivers of the ICT R&D in the large-scale deployment of the electric vehicle. This proposal identifies the present course of action of the UE for EV smart system and infrastructures and identifies its path dependence.

Also current work was the basis for a Portuguese FP7 project submission under the call GC-ICT-2011.6.8f - Integration of the FEV in the Cooperative Transport Infrastructure:

- Proposal Title: Electro-Mobility Cockpit Systems and Applications for FEV Range Optimisation and Seamless Integration in the Cooperative Transport Infrastructure (MOBI.Cockpit).
- Abstract: *Full electric vehicles (FEV) are being introduced in the market, but batteries reduced energy storage capacity and the lack of a high density charging infrastructure limit their autonomy range. In order to overcome this limitation, we propose developing a new solution enabling drivers to drive longer distances. This will be achieved by integrating some components of the cooperative transport infrastructure (charging system, public transport system and the vehicle), thus increasing driving autonomy through energy consumption reduction and driving efficiency. Integration with the charging infrastructure allows the driver to plan his journey considering charging points position, booking a charging point for a time period to perform battery charging, increasing the distance he can drive comfortably without fearing running-out the battery. Integration of FEV with public transport system allows extension of driving autonomy beyond the storing capacity of vehicle's battery. Supplying information on availability, schedule and price of public transport allows the driver to plan the journey using FEV and public transportation in a complementary way, using functions as car parking booking (and charging) and ticket buying. Energy consumption reduction on-board is the third approach to be addressed as one of the main ways to increase the autonomy of the vehicle. The adoption of new driving patterns and the possibility of automation of some of vehicle functions such as air-conditioning and speed limit, brings less energy consumption and increase autonomy. The outcome of this Project is the MOBI.Cockpit System (MCS) that includes three users' interfaces: mobile device application, infotainment and web application, supporting users in taking efficient decisions. MCS has the mission of supporting EV drivers on range optimization using intelligent route planning (taking into account public transportation information), charging management and energy efficiency, fostering electric vehicles adoption.*

Also, this work is part of the current participation of ISEL in the "Seamless Travel across the Atlantic Regions using sustainable Transport" (START) project. This PhD research contributes for the START project with best path algorithm, a proposal for public transportation information integration and an ontology for public transportation.

Annex

A.1 Ontology for Public Transportation (OPT)

OPT is built on top of Resource Description Framework (RDF), thus it inherits its concepts: resource, propriety, datatype and class. Figure 5-23 shows the hierarchy of OPT concepts: (1) Resource is one of the bases of RDF. It represents all things described and is the root construction. It is an instance of MOF classes. (2) Property defines the relation between subjects and object resources, and is used to represent relationships between concepts. Ontology class attributes or associations are represented through proprieties. (3) Ontology is a concept that aggregates other concepts (classes, properties, etc). It groups instances of other concepts that represent similar or related knowledge. (4) Classifier is the base class of concepts that are used for classification and is divided in: (i) datatype, a mechanism for grouping primitive data; (ii) abstract class; and (5) Instance that is the base class and is divided in individuals and data values.

Property: is a relation between a subject resource and an object resource. There are two types of properties: (1) object property, that may additionally be: transitive, symmetric, functional and inverse functional; (2) datatype. Users can relate properties by using two types of axioms: (1) property subsumptions, which specify the extension of a property and are subset of the related property; (2) property equivalence, which defines extensional equivalence.

Classifier: class that represents a concept for grouping resources with similar characteristics. It is similar to the concept of classes defined in Unified Modeling Language (UML) but with an orientation to object programming languages, and they are set theoretic. Classdescription is defined as a subclass of class to solve the problem of dynamic classifier. The class can be defined in the following four ways: (1) AllDifferent states that all of its instances have different identity; (2) restriction; (3) enumeration of individuals that form the instance of a class; (4) logical class of all individuals that could have the following attributes: (i) union; (ii) complement; (iii) intersection.

This is a work developed at ISEL under a Final Year Project integrated in the START project (for more details see [Domingues, 2010]). From several public transportation data base of consortium partners and standard specification, such as SIRI (Service Interface for Real Time Information) [www.siri.org.uk] and IFOPT (Identification of Fixed Objects in Public Transport) [www.ifopt.org.uk], as well as information provided by public transport operators, a procedure to design the ontology schema was created. Figure A-1 shows the main entities of the domain model. OPT is built on top of RDF using OWL (Ontology Web Language).

Also in Figure A-1 is represented the relationship between the entities Operator, Service and Contact. Public transport operators are represented by the entity Operator. This entity is associated with the entity that represents the Service(s) provided by a particular operator. For example, indicates the case that the operator Carris offers two services: bus and tram. The relationship with the entity Contact is due to the need that exists to represent the contacts provided by operators of public transport.

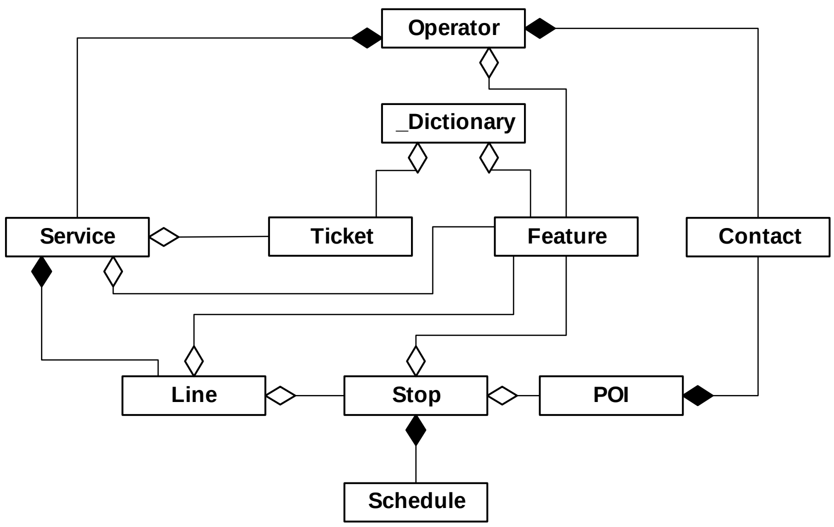


Figure A-1: Entities in the main domain model

The Contracting Service, Figure A-2, represents the services provided by an operator of public transport that can be, e.g., rail, road, air or water (sea, river or lake). Each service is linked to a type, represented by the entity Type, which represents the categories within each mode, e.g., rail, bus, plane or ship. Within these types may still exist variants: Variant entity.

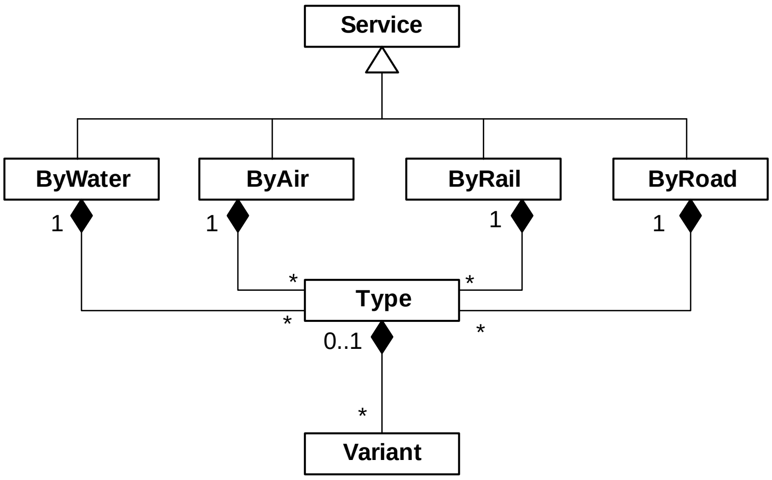


Figure A-2: Transportation service hierarchy

The Contact entity, Figure A-3, represents the contact types, such as: electronic mail (e-mail), telephone, address and website. This authority is shared by all entities, Operator and POI (Points of Interest), because both the transport operator and POI have similar types of contact. POI entity are divided into categories that highlight, for example, Academic (Academic), Rest (Restoration), Monument (Museums), and others.

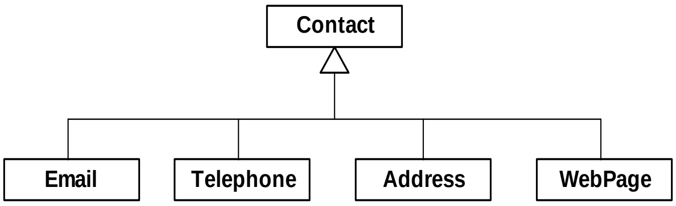


Figure A-3: Contact hierarchy

Also Figure A-4 illustrates the relationship between the entities Schedule, Stop, POI, Interface and Contact. Stop entity include the attributes: name of the stop, geographical coordinates (Latitude, Longitude) zone (taking the subway, as an example, it verifies the existence of two areas, one inside the city limits and another in the vicinity).

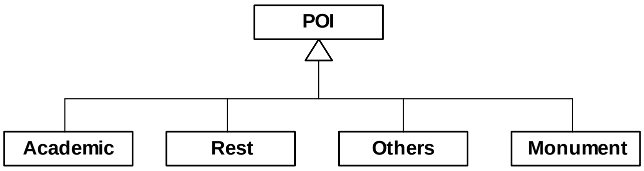


Figure A-4: POI hierarchy

The relationship between Stop and Schedule is justified with the representation of a schedule (see Figure A-5). A detailed description can be found at [Domingues, 2010].

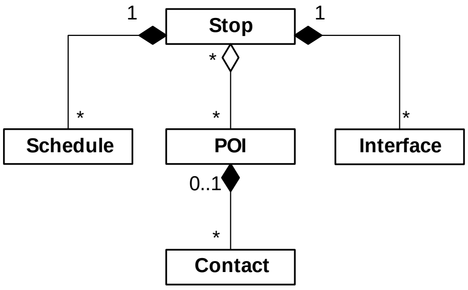


Figure A-5: Stop Hierarchy

A.2 Search Public Transportation Routes

To search for Public Transportation routes were considered several criteria's: The first is based on the selection of operators connected with the research. The second considers the number of transfers and price of the desired trip; and the last based on the trip duration using best path algorithm. In Figure A-6 is described in a sequence diagram the search process. The first's steps are the operator registration, where it receives an ID and publish the DB schema.

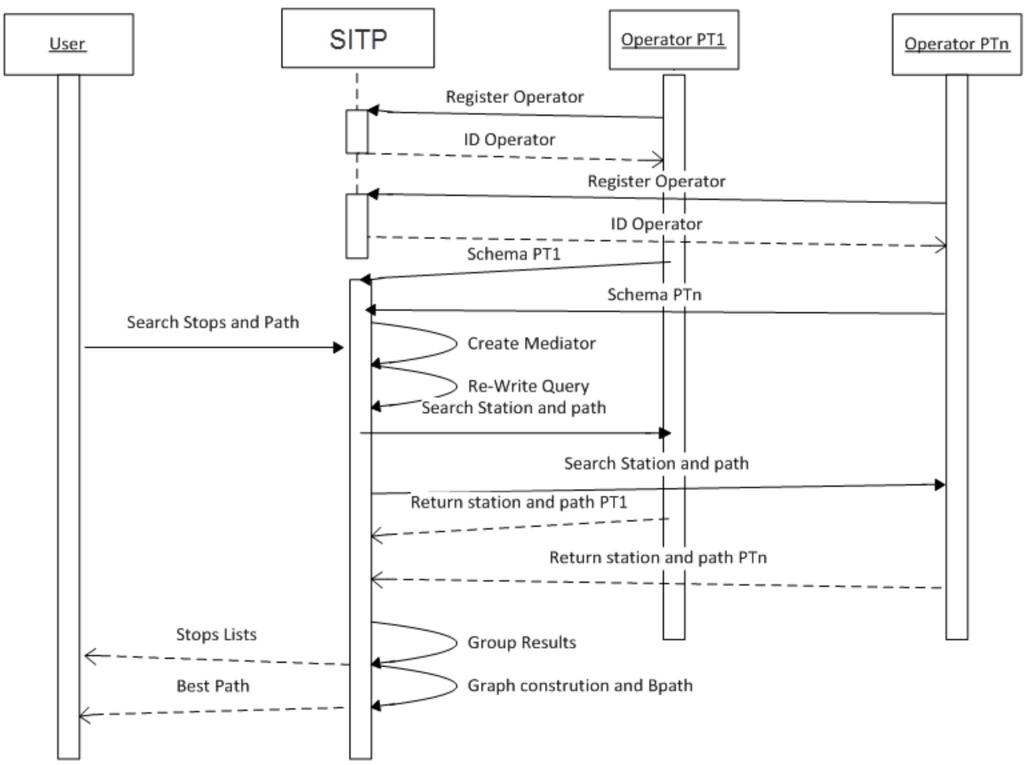


Figure A-6: Sequence Diagram of user search of Public Transportation stops and best path in different operators

A.3 Best Path Implementation

To calculate the paths it was considered two phases. At first it is checked whether the stations of departure and arrival belong to the same line. So when the departure and arrival stations belong to the same line *IsSameLine* the field is marked as true, otherwise it is marked as false. Where *IsSameLine* be true is executed the first phase of the research journey thus obtaining the data required to design the course. These data highlight the coordinates of the stations, the price of the trip, points of interest that are near the station of arrival and other information such as schedules and features. If *IsSameLine* is false then runs the second phase. In the second phase, the stations of departure and arrival are not on the same line. It is therefore necessary to find a path or paths considering the available interfaces on the lines corresponding to the stations of departure and arrival. This research takes advantage of the method *getAllInterfacesBetween*. This method was implemented in a recursive manner to allow the taking of all possible paths between two stations. To obtain the pathways analysis was carried out taking into account the interfaces of the line of the station that is being verified. In each interface is checked if the line matches the line of the arrival station guarding the path and if so, otherwise, it uses recursion repeating the analysis to find a route. A sample calculation (s) route (s) is illustrated in Figure A-7. Figure A-7 shows the paths generated between the starting point Odivelas (metro line) and the arrival point for Oriente (metro line). The first route uses only one interface (Saldanha (interface metro line)) to reach the destination while the second route uses two interfaces (Campo Grande (interface metro line) and Alameda (interface metro line)) to reach the same destination. In the case of route X as there is no interface that the route reaches the destination is not valid.

The method *getAllInterfacesBetween* to be implemented recursively have to take care to avoid cycles. To prevent cycling was implemented *VerifyCicleInPath* method that checks if the route has passed or not by a given interface. If so this path is excluded. The route shows to the user by taking advantage of Google Maps API. Information relating to the route is via steps with possibility to download the route to a text file.

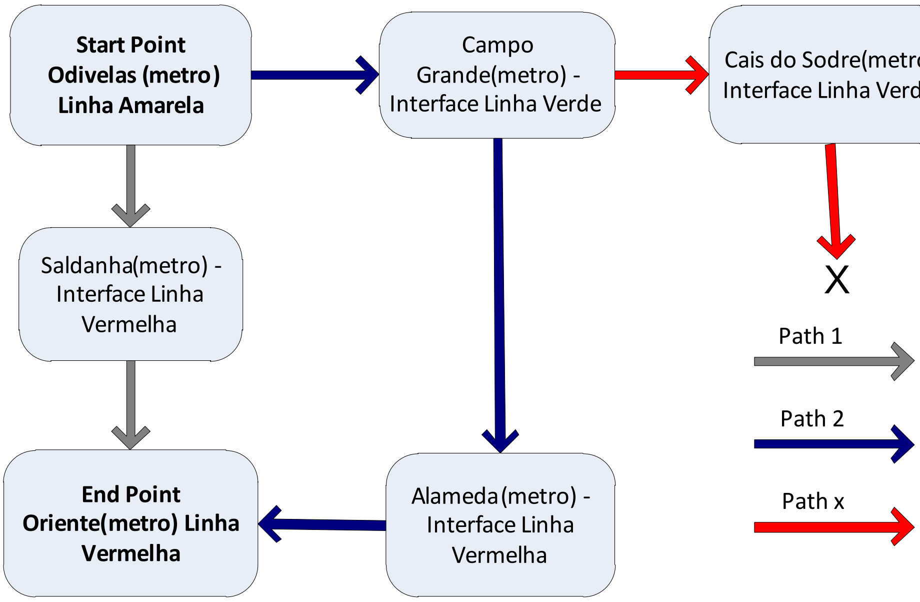


Figure A-7: Path Search using interfaces

A.4 Calculate the Price of the Trip

To calculate the price of the trip was defined *InfoServiceZone* the class containing the service identifier and zone. This class is used in the method *ObtainArrayTickets* to get a list of services and areas used on a trip, or a list in which each position corresponds to an instance of *InfoServiceZone*. This represents an instance of *InfoServiceZone* stage of the journey. After obtaining the list of stages of the method is invoked *CalcPrice*. This method evaluates the list of steps in order to return the price of the journey. Analysis of the list of steps highlight the fact that the next step is to compare with the previous order to ascertain whether there was an exchange zone or service. This comparison can then calculate the price given the exchange area or service over the route.

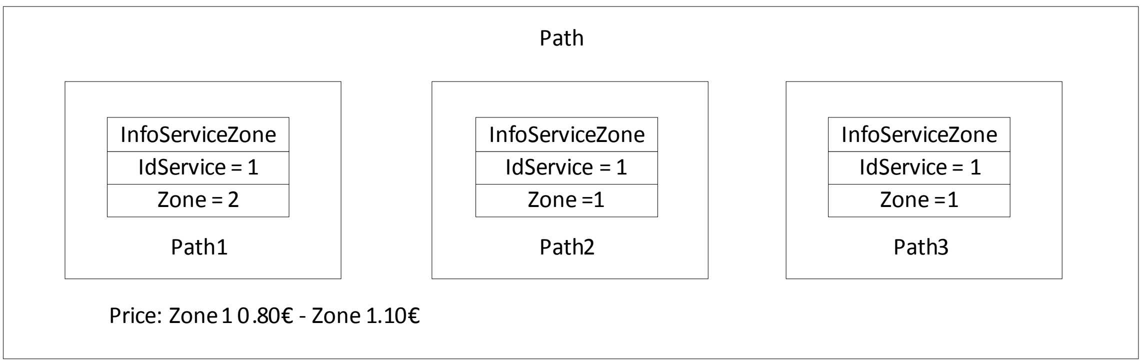


Figure A-8: Representação das etapas de um percurso para cálculo do preço

As mentioned before a route is divided into stages. Figure A-8 shows that the route is only done by a service (IdService = 1), so the price calculation takes into account the zones (Zone) of the steps. Once the trail starts in Area 2 the price to be added is € 1.10. When you perform the initial exchange of steps, from Step 1 to Step 2, it is verified that the area is below the Step 2 from Step 1. The fact that this happens will not affect the current price. If the area of Phase 2 was superior to that of Step 1 then the price would be the sum of the pricing zone subtracted from Step 2 to the pricing of the zone in Step 1. In return for the second stage, from Step 2 to Step 3 is to be noted that the pricing is the same zone is not changed. Please note that these calculations are made for services where the services allow transfers in your network. If the services do not allow transfers in calculating the price is the sum of the prices of each step. Assuming that the service (IdService = 1) does not provide the transfer on your network with a single ticket is the price of 2.70 € (1.10 € + 0.80 € + 0.80 €). The search page provides the user stops the ability to search stops in a certain radius. To implement this research used the Google Maps API, where the user can select a point on the map to determine if there are stops and a certain radius around that point. The radius is chosen by the user through a DropDown available for this purpose. If there are stations within the radius desired markers are placed with the operator logo on the coordinates where they are. The user can view station information by interacting with the markers. The information provided is related to service characteristics with the characteristics of the station, as well as information on upcoming departures of service. It is also available to the user the possibility to observe the line where the station is located. This was implemented in AJAX with ActionResult Controllers, for details see [Domingues, 2010]. Thus, whenever a request is made, the Controller responsible for the care of returns information about the form of a StringJson which is treated in the Client (JavaScript). Client-side (JavaScript) is methods that deal with the response and put the information available to the user. To determine the stations that lie within the perimeter defined by the user, the method *GetAllStopsInArea*. To find the two stations are set intervals by adding and subtracting the radius of latitude and longitude of the point chosen. Once these intervals a search is performed to determine the geographic coordinates of the stations that lie within these.

Regarding the Rates page is provided information on the tickets of a particular operator such as area, price and description. This information is represented whereas the seasons, although the same line, may belong to different zones with different price lists. Thus, the user gets the price depending on the area from where or where it goes. As an example, the journey from Campo Grande station (metro line) station Odivelas (metro line). In this case, the patient away from a station belonging to a zone must purchase a ticket for zone 2 since it moves to a station that belongs to zone 2. The same happens in reverse.

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