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Sara Mehar, Sherali Zeadally, Guillaume Remy, Sidi Mohammed Senouci. Sustainable Transportation Management System for a Fleet of Electric Vehicles. IEEE Transactions on Intelligent Transportation Systems, 2015, 16 (3), pp.1401-1414. 10.1109/TITS.2014.2367099 . hal-02539881

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***Abstract*—In the last few years, significant efforts have been devoted to developing intelligent and sustainable transportation to address pollution problems and fuel shortages. Transportation agencies in various countries, along with several standardization organizations, have proposed different types of energy sources (such as hydrogen, biodiesel, electric, and hybrid technologies) as alternatives to fossil fuel to achieve a more ecofriendly and sustainable environment. However, to achieve this goal, there are significant challenges that still need to be addressed. We present a survey on sustainable transportation systems that aim to reduce pollution and greenhouse gas emissions. We describe the architectural components of a future sustainable means of transportation, and we review current solutions, projects, and standardization efforts related to green transportation with particular focus on electric vehicles. We also highlight the main issues that still need to be addressed to achieve a green transportation management system. To address these issues, we present an integrated architecture for sustainable transportation management systems.**

***Index Terms*—Electric vehicles (EVs), fleet management system, itinerary planning, power consumption optimization, smart grid, sustainable transportation.**

I. INTRODUCTION

THE industrial revolution in the 18th and 19th centuries led to the first engine and motor inventions for various types of transportation (air, maritime, and land). Technological advances in the transportation sector continue to enable people and goods to be transported worldwide. Air transportation is fast, but it has high costs; maritime means are cheaper but slow. Thus, land transportation is the most practical for daily commuting and travel between cities or countries. In the past, the efficiency and affordability of fuel along with the need for flexible, fast, and private means of transportation increased the need and the desire for people to own ground vehicles. In [1], the authors studied the relationship between vehicle ownership and per capital revenue; they estimated that 2.08 billion vehicles will be driving across the world's roads by 2030, while there were only 70 million cars after World War II and only 900 million today. This trend implies a huge increase in fuel demand. In fact, vehicular fuel consumption has jumped from 57 880 million gallons in 1960 (which cost about 40 800 million dollars) to 168 597 million gallons in 2011 (which cost 1 079 400 million dollars) [2], [3]. The widespread ownership of vehicles causes unwanted effects and problems such as road accidents, traffic jams, increased fuel consumption, and greenhouse gas emissions. The U.S. Department of Transportation [2] and the European Commissioner for Climate Action [4] reported that the average fleet emission is 158.7 g/km, and the U.S. Environmental Protection Agency reported that the annual greenhouse gas emissions per passenger vehicle is 4.8 tons of CO_2 per vehicle per year (based on average daily mileage in the U.S.) [5]. Fuel consumption increases the rate of hydrocarbons, carbon dioxide, and nitrogen oxides in the atmosphere and introduces toxic particles that make fresh air poisonous. Consequently, pollution of the atmosphere by greenhouse gas emissions [6] has generated significant environmental degradation and respiratory diseases.

In addition, the petrol production rate has reached a critical threshold, and it is expected to decrease over time as the world's crude oil dwindles [7]. In a few decades, we will very likely face serious shortages of almost all petrol and gas sources [7]–[10]. The lack of energy is a serious problem for transportation systems because it could freeze mobility in large urban areas and affect the economy and industrial activities of the world. For these reasons, sustainable mobility is now a real requirement rather than an option. Researchers have dedicated increasing attention to sustainable transportation [11] in an effort to improve long-term mobility by monitoring vehicle emissions, reducing gas consumption, and introducing new alternative energy resources. The U.S. Electric Power Research Institute, the Natural Resources Defense Council, the Electrochemical Energy Laboratory, and the European Commissioner for Climate Action studied the environmental impact of the manufacturing and deployment of large fleets of plug-in hybrid electric vehicles and found that they emit less greenhouse gas by using cleaner energy sources to produce energy and replacing pollutant and expensive raw materials during the cars' fabrication processes [4], [12].

Recently, several efforts have been focusing on leveraging Internet and communication technologies to access sensitive and important information that helps to manage transportation systems and power consumption efficiently. For example, real-time traffic information can reduce power consumption, while renewable energy can help us achieve energy independence and a green transportation system.

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The major contributions of this work include the following.

1) We present an overview of green transportation management systems with a focus on emerging alternative technologies. We focus on the basic components of a smart transportation management system, and these include the following: infrastructures, communication technologies, and electric vehicle (EV) integration into the smart grid.
2) We discuss recent related works that aim to address the problems of power consumption and pollution caused by road transportation technologies. We also highlight some of the limitations of previously proposed alternative transportation solutions.
3) Finally, we propose a complete sustainable transportation management system (STMS) integration framework that takes into consideration power consumption, smart grid load management, and EV fleet management.

The rest of this paper is organized as follows. In Section II, we present the background of alternative transportation. Then, in Section III, we describe the basic components of a smart transportation management system by focusing on the required infrastructures, communication technologies, and value chain of EV integration into the smart grid. In Section IV, we analyze various transportation management systems to classify them into three main categories: 1) fleet management system that optimally schedules the fleet to optimize the energy consumption; 2) itinerary planning that chooses the most economic route in terms of energy; and 3) grid to vehicle (G2V) and vehicle to grid (V2G) regulation solution that aims to balance the power utilization load. After that, in Sections V and VI, we present some standardization efforts and challenges in the area of green transportation systems that still need to be addressed in the future. We also propose our complete STMS integration framework. The latter considers all of the factors that impact power consumption, smart grid load management, and EV fleet management. Finally, we offer some concluding remarks.

II. BACKGROUND

Many solutions have been proposed to reduce transportation pollution (e.g., carplatooning, carsharing, carpooling, and electric rail transportation). Car platooning is a solution that involves a group of vehicles that follow a lead driver along the trip unless the platoon is dissolved. It aims to increase road capacity and reduce traffic congestion and pollution [13]. Carsharing and carpooling systems [14] are car rental models in which many clients share a car. These systems are used today in many countries such as the following: France (AutoLib carsharing), the U.S. (City Carshare), and the U.K. (City Car Club). Optimizing the cars' allocation reduces congestion and air pollution. Alternative means of transportation are attractive solutions that can decrease the level of harmful gas emissions. Nowadays, there are several types of vehicles (fuel-based, electric, and hybrid vehicles). In this section, we review the main characteristics (such as operating mode and power consumption) of fuel-based, electric, and hybrid cars.

A. *Fuel-Based Cars*

Fuel-based cars use an internal combustion engine to produce power. In a combustion chamber, air and fuel are mixed, compressed, and burned to produce forces that transform chemical energy into useful mechanical energy. This process suffers from high energy losses because only between 15% and 40% of the fuel power is transformed; more than 60% of the energy is lost [15]. The more efficient the engine, however, the more effectively it produces mechanical power and reduces CO_2 emission and fuel consumption. CO_2 emission depends on the quantity of energy that is used to produce the required roll forces, the type of fuel, and the driving cycle mode [15]. Electric and hybrid cars are more energy efficient than fuel-based cars. We note that hydrogen cars produce energy either by burning hydrogen in an internal combustion engine or by reacting hydrogen with oxygen in a fuel cell to run electric motors [16], [17]. However, it does not produce CO_2. In this section, we refer to fuel-based vehicles that do not use hydrogen.

B. *EVs*

Electric cars have a small electric motor rather than a combustion engine. Electric cars can reach an energy efficiency around 90% [18], [19] and have many benefits for both the economy and the environment. They enable energy independence by using locally generated electricity rather than relying on imported fossil resources. In addition, electricity is cheaper than fuel and can be generated using various natural and renewable resources. Multiple studies have shown that renewable energy has the potential to meet the vast majority of our energy needs and to minimize air pollution. The first electric car called "La Jamais Contente (The Never Satisfied)" was invented in 1899 [20]. It was able to achieve a speed of about 100 km/h. However, due to some batteries' limitations and low fuel costs, electric motors were used only in rail transportation and small bicycles. In fact, batteries have limited the progress of EVs. The distance that electric cars can cover is limited; EVs (e.g., Tesla electric cars) can travel at most 450 km with a fully charged battery [21]. Moreover, the electric battery needs a long time to charge depending on the charging type. There are three types of charging for EVs [22], [23]: 1) Slow charge requires between 4 and 8 h; 2) normal charge requires around 2–4 h; and 3) fast charge requires at least 30 min.

C. *Hybrid Vehicles*

Hybrid vehicles are a compromise between gasoline and EVs. Baker and Woods introduced hybrid vehicles in 1916 in the U.S. [17]. Since the creation of the first commercial gasoline-electric engine, several hybrid models, from small cars to sport utility vehicles, have been made. A hybrid car combines an internal combustion engine with an electric battery. The vehicle starts working on battery power, and it switches the power source to the internal combustion engine as the speed of the car increases. The electric battery is also used when the car needs more power to climb a hill or to move at a higher speed.

TABLE I
FUEL CARS VERSUS ELECTRIC CARS VERSUS HYBRID CARS

	Fuel cars	**Electric cars**	**Hybrid cars**
Gas Emission	25 kg/100km	0 kg/100km	12-21 kg/100km
Power consumption	<40 MPGe =7.1 L/100km	<50 MPGe = 5.6 L/100km	Between 47-76 MPGe =3.7-6 L/100km
Maximum distance	>320km	Between 160-480km	Between 320-800 km
Charge duration	Fuel: <5 min	Electricity: 30 min to 8 hours	NA
Energy price	5-6.25 $/100km	0.62-1.25 $/100km	NA
Car price	>9.500$	>35.000	>25.000$

The advantage of hybrid cars is the fact that they have two power sources, which means that they can use the appropriate power source when needed. Additionally, hybrid cars have very low emissions and high fuel efficiency. However, some of the disadvantages of hybrid vehicles include their price, the environmental hazards associated with recycling their batteries, and the CO_2 emission. There are many different types of hybrid vehicles detailed in [17], [22], and [23], but only the gasoline-electric hybrid is currently commercially available.

D. Comparison of Fuel, Electric, and Hybrid Cars

In Table I,[1] we summarize the features of the three types of cars [15], [24]. As we can see from the table, there is a compromise between using cheap fuel cars and expensive clean electric and hybrid vehicles. As EVs are still in the development phase, we can assume that the prices are likely to fall in future years.

III. BASIC COMPONENTS OF AN STMS

Today, new communication technologies, high-speed information access, and large storage capacities all enable the design of new and complex systems such as the following: smart buildings, smart cities, smart grids, smart transportation systems, smart clients, and many others. To enable long-term smart, safe, and sustainable mobility, it is important to guarantee a balance between energy, environment, and transportation, which leads to a smart STMS. An STMS is a combination of several smart entities such as smart vehicles, sensors, road side units (RSUs), charging stations, and traffic lights, all of which are usually connected via a communication network to each other and to centralized or distributed control centers. The term “smart” here is used because the devices are managed in order to collect, analyze, and process information to provide various transportation services such as traffic light management, fleet management, and others. The term “sustainable” is related to the use of renewable sources of energy to make transportation green and cleaner.

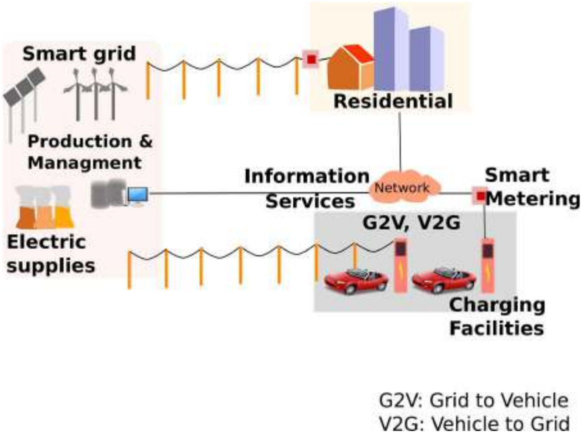

Fig. 1. Basic components of a smart STMS.

Fig. 1 depicts the main system entities of STMSs (such as customers, smart grid, facilities, decision-making system, data, and network) and the relationship between them. The smart grid acts as the power provider and power manager. The customers (vehicles) and facilities (charging stations and RSUs) collect information (energy load and road traffic). The network is the backbone of the system and ensures communication and interoperability among all STMS’ entities. Operation centers analyze and process information and make decisions based on various factors and criteria (e.g., energy cost and greenhouse gas emission). Thus, the role of an STMS is to provide a required set of flexible components to collect information, communicate requests, organize resources, and integrate services effectively. However, until today, traffic information is not fully considered by existing transportation management systems. Additionally, existing solutions and projects view the smart grid and transportation management system as two independent systems. That is why we present a fully integrated solution to achieve a real STMS in Section VI-F.

In this section, we introduce the basic required infrastructures (power generation facilities, EV supplies, and smart meters) and communication technologies (wired and wireless). Then, we explain the value chain of EVs and supplies markets. In fact, an early phase in any management system is to take into account the financial considerations.

A. Infrastructure and Basic Required Facilities

In this paper, we focus on electrical vehicles. Fuel-based vehicles are not considered in this work because our goal is to promote alternative and clean transportation. Electric motors consume a large amount of electrical energy and require mainly basic resources and hardware such as electricity factories and utility, charging stations, sensors, and metering devices. Electricity generation and supplies together with energy management utilities constitute the smart grid, which uses communication technologies to collect and analyze the state of electric grids in order to monitor the production and the consumption of electricity. It defines how energy is transmitted, distributed, and measured efficiently. In addition, smart grid technologies

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[1] Miles per gallon gasoline equivalent (MPGe) in Table I is used to measure the distance traveled per unit of energy consumed for fuel and EVs. Here, each gallon is equivalent to 33.7 kW.

TABLE II
RECHARGING TYPES

	Charging Voltage and Current	Charging Power	Charging Time Required
Slow charge	220V, 13A*	2.9 kW	6-7 hours
Normal charge	220V, 16A*	3.5 kW	4-5 hours
	220V, 32A*	7.0 kW	2-3 hours
Fast charge	DC Quick Charging 400 A	50 kW	$\simeq$ 30 min

aim to keep grid load balanced and promote the utilization of renewable grid resources. The smart grid produces energy from several resources (wind, solar, water, nuclear, bioenergy, coal, and fuel), carries electricity, and delivers it to consumers by using transmission and distribution units. When consumption is lower than production, the additional energy is stored in storage units. The smart grid uses metering units (also known as smart meters) to record electricity consumption and evaluate the usage of electric energy. Communication units integrated into the smart grid facilitate remote control by communicating information to all other units. Finally, the smart grid uses security units to prevent and control damage.

Electric cars come with a new type of charging station or EV supply equipment (EVSE) to charge the cars' batteries. Indeed, an important element of charging stations is the chargers' efficiency. EVs can be recharged from a domestic wall socket or external charging station. Other solutions, such as mobile charging stations and battery replacement stations, have been introduced recently to the charging market. IEC 61851 [22] is the international standard of the EV charging system. This standard describes all circuit and protective device requirements. As mentioned previously, there are three types of recharging, which are summarized in Table II.

We note that the charging voltage and current for an EV depend on the design and setting of the onboard charger of the EV manufacturer, which may cause the charging time to vary [22]. A higher charging current shortens the charging time. Sheneider electric provides a full list of commercial charging station facilities designed for North American commercial and residential end-users [25].

Many research programs and industrial projects focus their efforts on optimally deploying electric utilities, especially charging stations, to balance the load of the smart grid so that EVs do not overload the electric grid. The first deployment solution for charging stations used fuel charging stations at specific parking locations. Next, people began installing charging stations in their homes. These home charging stations can potentially cause instability in the electric grid. To optimize the deployment of charging stations and balance the energy consumption and production loads, many studies were proposed. They take into account the energy load in the roads and financial cost of building electric utilities and charging stations [26]–[28]. In addition, the Electrical and Mechanical Services Department has specified and revised technical regulations in order to satisfy the requirements needed to deploy electric charging facilities [22]. Charging infrastructures can be categorized as follows:

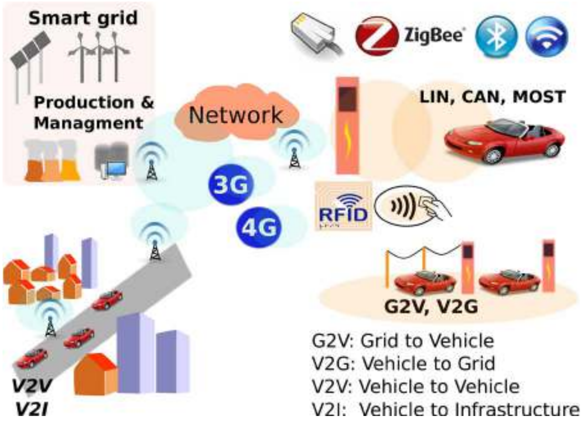


Fig. 2. Communication technologies.

1) public charging station (e.g., in public parking, outlet, and commercial area);
2) private charging station (e.g., home and company's parking);
3) private-shared charging station (e.g., shared electric taxi).

Smart grid infrastructures and facilities are summarized in [29] and [30].

B. Communication Technologies

Smart networks open up many possibilities to make an electric power transmission system smart. Many technologies cooperate to ensure real-time communication to transmit crucial data (demand load, road traffic information, client location, and charging duration information) and to provide various transport applications and services (charging station reservation request and reply, safety control information, battery state, path planning, and authentication).

As shown in Fig. 2, several wired and wireless communication technologies could be used.

1) Wired Medium: Communication is possible over power lines, telephone lines, coaxial cables, and unshielded twisted pair or optic fibers. These technologies are used to communicate between fixed facilities, and they offer reliable data transmission to the energy management system.

Wired networks are also used to communicate among components (microcontrollers, sensors, and devices) inside the vehicle. Common examples include Local Interconnect Network [31], Ethernet [32], FlexRay [33], Controller Area Network (CAN) [34], Media Oriented Systems Transport [35], and Domestic Digital data Bus [36].

Wired installation is expensive and does not support mobile communication between vehicles and infrastructures; wireless technologies, in contrast, are more flexible and cheaper to use.

2) Wireless Medium: The smart transport management systems also use many wireless technologies depending on the services being supported. For example, to achieve low-power monitoring, they utilize radiofrequency identification to authenticate the car for parking or charging. Bluetooth is used to monitor charging remotely, and Zigbee (802.15.4) is used to send information about the battery state to the charging

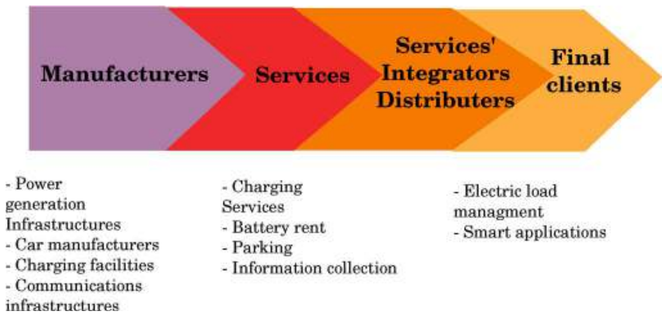


Fig. 3. Simplified value chain of EVs and supplies market.

station. To enable higher flexibility, larger coverage, and higher bandwidth, an STMS employs Wifi (802.11.a, b, n), WAVE (802.11p), and WiMAX (802.16) technologies to communicate with cars or to transmit the collected data about road traffic conditions. In addition, 3G and 4G/Long-Term Evolution (LTE) technologies are used for high performance, to ensure rapid communication in case of vehicular network disconnection, or to deliver the highest quality of service for time-sensitive applications. Moreover, mesh networks are also used in the smart grid to communicate information about electricity load and remote metering.

C. Facilities Value Chain (Business Model of EVs and Supplies Market)

Depending on the infrastructure deployment model and the provided services, the total cost of deployment includes one or all of the investments and service costs shown in Fig. 3. The total cost covers the following: 1) the deployment of infrastructure, which includes electric utility deployment and generation as well as the cost of metering devices that enable power management; 2) the fee for the charging process and the fee for renting the battery. Given that the battery is more expensive than a car today, car vendors rent a battery, and clients pay a monthly bill; 3) the network infrastructure and maintenance costs; and 4) management service costs, which include power grid management and charging operation management. These fees depend on government policies in place during the construction of the charging infrastructure. The government could finance the projects, or funding could be sought from private companies.

Europe has created a high-speed electric rail network that joins almost all of its countries together. Other EV projects are currently under progress. EURELECTRIC [37] is the European electricity industry association that has 32 European countries as members. Its mission is to cover issues affecting the electricity industry, energy policy, renewable power, and environment. Reference [38] presents two models to deploy charging infrastructures to be used for EVs and to organize the electric market (E-Market). Two possible charging station models have been proposed: 1) In *the independent e-mobility market model*, the infrastructure investment is recovered only by the electric-mobility (e-mobility) customers. This model is currently being implemented in Germany, France, Spain, and Denmark. When customers want to use a charging station operated by a different e-mobility service provider, access can be granted via a roaming agreement. 2) In *the integrated infrastructure market model*, the infrastructure investment is included in the grid fees. Thus, all grid clients pay for the construction of the charging stations and a multivendor platform with competitive offers among e-mobility service providers and continue to have access to the public charging infrastructures. This market model is already being implemented in Italy, Ireland, and Luxembourg.

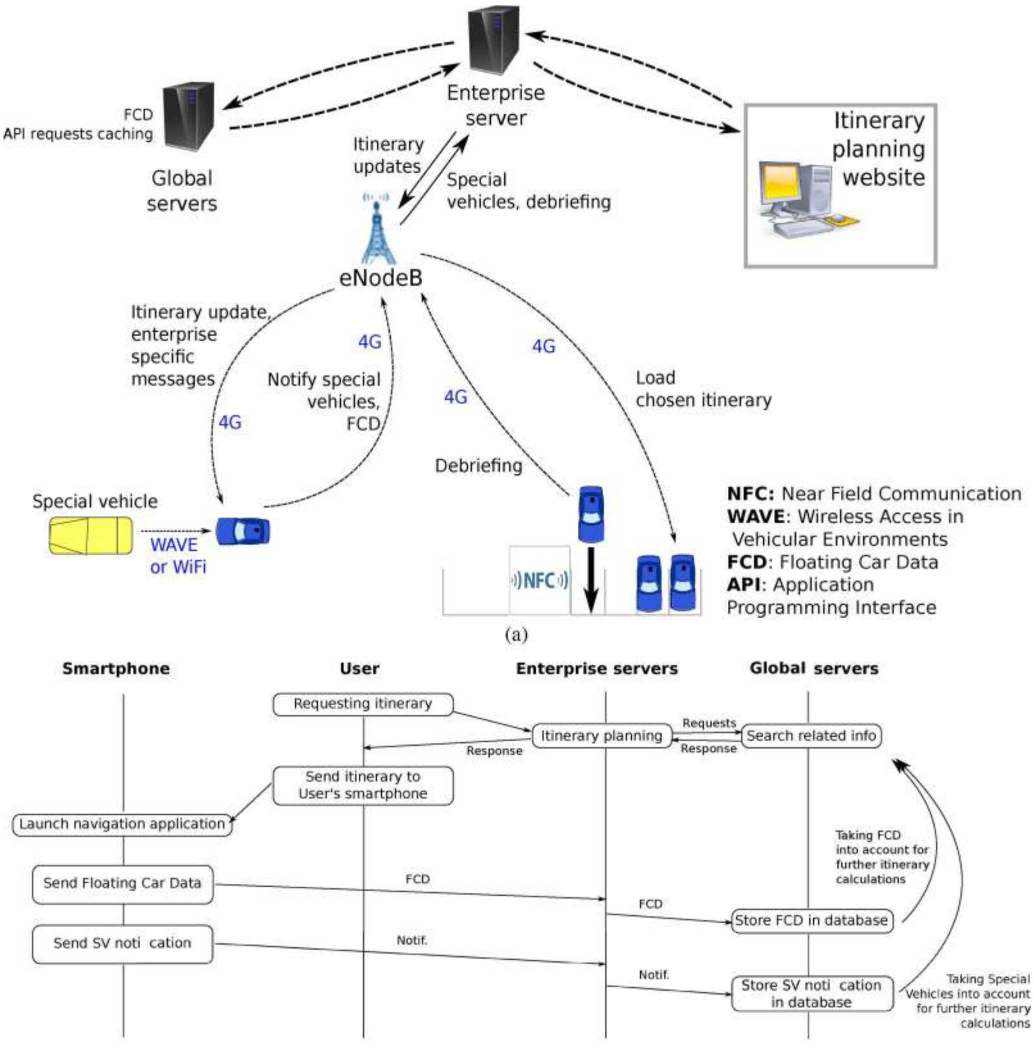
IV. SUSTAINABLE TRANSPORTATION MANAGEMENT ARCHITECTURES AND APPLICATIONS

Smart vehicles are now equipped with a set of sensors to monitor engine performance, braking, and passenger safety and with a communication antenna to collect and broadcast traffic information. Collecting and processing information that affects energy consumption help manufacturers and drivers to cope with some of the EVs' limitations (such as short battery autonomy). By using such information, we can achieve, for example, most efficient itineraries. In this section, we first review some recent research efforts and projects on transportation management systems, focusing on data acquisition and processing. Then, we describe three types of applications: 1) fleet management systems; 2) itinerary planning applications; and 3) G2V and V2G management systems and charging stations' reservation solutions.

A. Fleet Management System

Fleet management systems and architectures are designed mainly to collect useful information and to support several services. Those systems aim to improve driving efficiency, perform smart resource allocations, and reduce traffic jams. The provided services decrease pollution and the amount of consumed energy. Several research efforts cover the fleet management system [39]–[42].

Thong *et al.* [39] implemented a fleet management system that collects data such as mileage, fuel consumption, and driving speed via general packet radio service (GPRS) and short message service (SMS). The information collected is used to obtain more accurate location information while tracking the fleet. The tracking system receives real-time vehicle positions by combining two technologies such as a Global Positioning System (GPS) and Global System for Mobile Communications (GSM) and by using a Kalman filter to improve the location accuracy. To be able to perform autonomous decisions (e.g., avoid congested roads and decelerate if an obstacle blocks the road), cars are equipped with front-end intelligent technology, which makes them less dependent on remote backend servers that are usually used to calculate the cars' positions and send them back to the cars' GPS (e.g., a Tomtom GPS device receives positioning information from a remote server). In addition to vehicle tracking, this solution provides other features such as driver assignment and maintenance alerts. Grantner *et al.* [40] developed a health management system for military vehicles. To verify a vehicle's state, the architecture collects data using the engine's internal sensor and axle measurements and sends them via Zigbee to a central computer. The latter



(a)

(b)

Fig. 4. EcoDrive green fleet management system [44]. (a) EcoDrive architecture. (b) EcoDrive: communication sequence diagram.

uses a fuzzy model developed on expert knowledge and a linear damage model in order to obtain accurate vehicle diagnostic information and to locate axle fatigue damage. Srinivasan *et al.* [41] designed a multiagent traffic management system. Each agent in this system collects real-time traffic information and sends it to a centralized controller. The centralized controller retrieves optimum green light duration information in order to reduce traffic jams by using the traffic information and a genetic optimization algorithm. Stojanovic *et al.* [42], [43] proposed a Web information system for fleet management and transport telematics. The architecture collects information using GPRS, Wireless Application Protocol, and SMS. This information is used to provide several services in addition to vehicle tracking, fleet management, itinerary generation, and vehicle rerouting.

B. Green Itinerary Planning

Green itinerary planning is a type of route planning based on energy consumption. Unfortunately, green itinerary planning is an underexplored area of research. Remy *et al.* described a green fleet management architecture called EcoDrive in [44]. EcoDrive provides a route planning service and supplies a wide range of real-time services based on the information collected from the road traffic and high-precision fuel consumption. As depicted in Fig. 4(a), EcoDrive consists of a global server (a server from the company Orange in this work), the company's server, and a vehicular network. The client books a car on a company server that sends the request to the global server. This server then computes the best itinerary using the following: 1) road cartography information based on information such as elevation and speed limits; 2) the vehicle's feature, including its weight and engine efficiency; and 3) weather conditions, including wind speed, and temperature. During the trip, the floating car data (FCD) and "special vehicle" notifications are sent and stored on the global server database for further use. Fig. 4(b) summarizes the communication steps between the different system components. At the end of the process, the economic itineraries are sent to the company fleet, and the best one is uploaded into the GPS device or into the smartphone of the driver. However, this solution considers fuel vehicles only.

For EV itinerary planning work, one solution is to use the Dijkstra algorithm. It uses a weighted directed graph to determine the shortest path between the source and the destination node [45]. However, the Dijkstra algorithm does not solve a

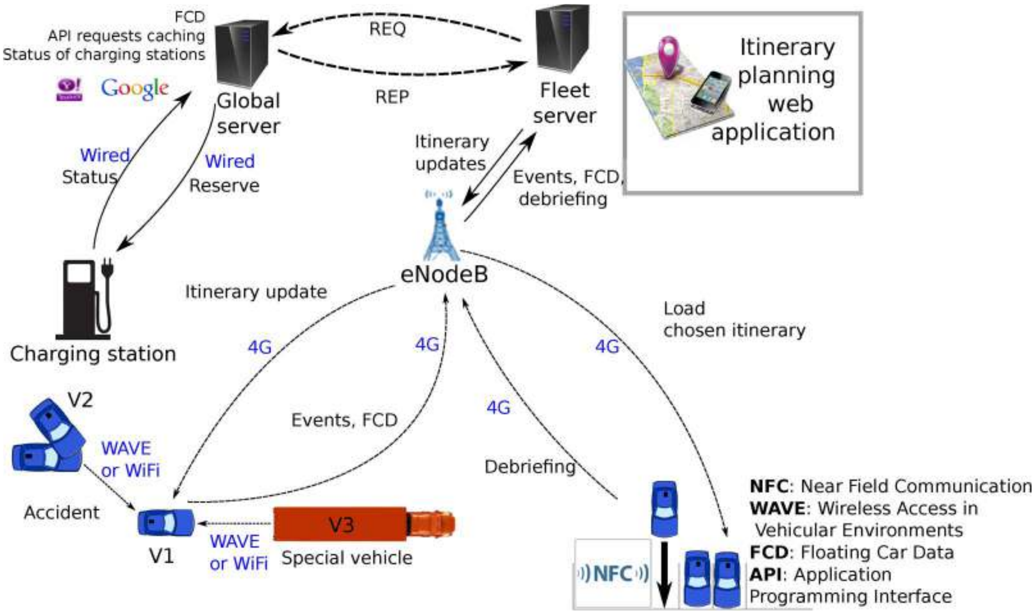


Fig. 5. EV-Planning: green fleet management system for EVs.

graph with negative edges; for EVs, some path costs are negative because EVs regenerate the energy when they decelerate (e.g., along the way down). To address the issue of negative path cost, Fakcharoenphol *et al.* in [46] calculated the shortest path by using the Johnson algorithm or an adaptation of the Bellman Ford algorithm [47]. In addition, the vehicle's weight, air friction, and road elevation were considered while computing the most efficient path. The green navigation solution [48], [49] extended the shortest path algorithm as follows: 1) Energy consumption and recharge were formalized as a particular case of the constrained shortest path problem; 2) an adaptation of the four shortest path algorithms (i.e., Dijkstra, first in first out, expand, and expand-distance) was proposed to evaluate the negative path cost in the case of charging or regeneration of the power; and 3) a prototype software system for energy efficient routing was implemented based on open source libraries, including OpenStreetMap and NASA Shuttle Radar Topographic Mission. Other solutions were proposed to provide the positions of charging stations. For example, CarStations [50] is a Web application that shows the positions of the charging stations on a map. This application does not provide itinerary or power consumption computation. The EV charging station location application [51] displays the shortest itinerary based on distance and the number of charging stations on the road, but it provides no alternative route if the shortest path does not have any close charging station. Almost all previous studies calculate the most economic itinerary. However, they neglect to consider that drivers may not follow the planned route to find a charging station when the battery power level drops.

Mehar *et al.* proposed EV-Planning [52], which is an extension of the green fleet management system (EcoDrive) [44] to consider EVs. EV-Planning computes the most economic itinerary based on electric power consumption, battery autonomy limitations, and electric charging stations' positions. EV-Planning provides many services, such as electric fleet booking and management, and also economic itinerary planning. In addition, EV-Planning supplies accurate information about charging stations (positions and availability). This enables the inclusion of the battery charge in itinerary planning. Furthermore, EV-Planning considers several factors that affect the energy consumption: 1) internal car features, such as the EV's weight, battery type, and engine map effectiveness, and 2) external factors, such as air friction, wind, temperature, road elevation, traffic congestions, unexpected events, and driver habits. As shown in Fig. 5, to book a car, the client requests an available car through the Web application of the fleet company's server, and he/she provides the final destination information. This request and the selected car characteristics are sent to the global server, which calculates the itineraries to reach the final destination based on the following information: car features (weight and battery charging efficiency), road traffic information and stored FCD, and road information (elevation, speed limits, and weather condition) requested from two application programming interfaces (APIs), the Google map API and Yahoo weather API. First, the global server calculates a possible set of initial routes with the Google map API, and then, it divides each route into several subsegment and computes the power consumption by combining all collected and stored information and subtracting the sum from the initial battery capacity. If the state of the battery is lower than a given threshold, the global server stores the already calculated subpath (i.e., where the energy is sufficient). Then, it requests the available charging stations nearest to the draining vehicle and calculates the new subpath separating the draining position and the final destination. Finally, it computes the power consumption over the new subpath and adds it to the stored subpath. This process is repeated for each alternative route. The results of all possible paths (the combination of the subpaths before the battery draining and the subpaths that pass through the nearest charging station) are then sent back to the fleet company's server, which displays it on the map and sends a copy to the client's smartphone or uploads it directly into the car GPS device. Duchrow *et al.* described in [53] a framework that collects data (position, speed, state of charge, and weather), transmits them via GPRS to a central server, and performs the following analyses on electric fleet vehicles: 1) road utilization statistics to calculate road usage in order to locate charging points optimally; 2) trip statistics to report information about battery state-of-charge (SOC) and the trip duration; and 3) determination of charging intervals used to define charging intervals and durations.

C. Fleet Model for Charging Regulation and Scheduling

The regulation service monitors electricity consumption in order to ensure the smart grid's stability even during peak hours. For example, by reducing the power price at night, customers are encouraged to modify their charging habits and pushes them to choose the off-peak periods for charging. Vehicle to grid (V2G) is a regulation solution that encourages individuals to sell electricity stored in the vehicle to the smart grid rather than buying from it. This solution helps to support the smart grid in peak load hours. It requires to recover a large quantity of energy from many charged cars that are parked for a long time. However, the disadvantage of frequent charging and discharging is to damage the battery and reduce its lifetime. In [54], Hill *et al.* studied the financial impact of battery degradation. To avoid the case in which the V2G gain is lower than the investment cost, the fleet company forecasts the V2G revenue and studies the impact of parameters such as battery cycle life and regulation requests (request to generate more or less power). In addition, the authors considered a fleet of trucks instead of private cars because the fleet company can manage the truck fleet efficiently and pay for the battery recycling costs. The results show that the battery life duration is one of the critical parameters in the V2G financial model; therefore, to make such a model profitable, it needs to be supported with higher energy rates (higher renewable-energy penetration). Singh *et al.* in [55] proposed a multicharging station. A multicharging station is a set of charging stations that are connected to the same electric distribution node in residential, office, and commercial areas. The idea is to monitor a large fleet of EVs using a fuzzy logic model in order to balance the electric charging load and to keep the smart grid stable. Thus, it manages EV charge/discharge decisions depending on time, the client's charge/discharge preferences, and the studied area type (residential, market, and office). Simulation results show that this model is easy to implement and that it can give the available power in the charging stations, the charging demands, and the total unused energy in cars in each area. The unused energy could be used to supply the smart grid and balance the load in the charging points.

Recent efforts described in [56]–[61] aim to reduce energy cost and usage and to increase the stability of the local power system by managing the charging and discharging operations of EVs. Brandl *et al.* [56] implemented a hardware-based three-layered architecture for a battery management system (BMS). The BMS estimates the battery charging status and helps to extend battery life by including a fully integrated active charge equalizer. The charge equalizer balances the voltage between the battery cells during the charge/discharge periods and ensures the full charge of all cells while charging and the full discharge of all cells while discharging. In [57], Xie *et al.* studied the characteristics of charging station loads. To forecast daily EVs' charging load, they proposed three models: the back-propagation neural network model, radial basis function neural network model, and grey model. Rezgui *et al.* proposed the Reliable Broadcast for EV Charging Assignment (REBECA) in [58]. REBECA aims to determine the number of EVs that can be served efficiently using queuing theory (M/M/1) and statistical analysis to keep the latency and the probability of EVSE overloads as low as possible. In [59], Qin *et al.* analytically modeled the waiting time in charging station queues. They proposed a distributed solution to charging station scheduling in order to minimize the waiting time in the charging queue and to balance the power utilization among several stations. To do so, each EV sends a reservation request to the nearest charging stations. The charging stations exchange reservation information via the Internet and 3G. This information helps to estimate the current waiting time at each charging station. The results of this estimation are sent to the clients who later choose the best station for the next charging process to reduce the waiting time and to minimize air pollution at the same time. In the following, we cite examples of ongoing projects regarding electric transportation.

D. Ongoing Projects on Electric Transportation

ECOtality, a leader in clean electric transportation technologies, has deployed chargers in major cities across the U.S. as a part of its EV project [62], [63]. ECOtality has three charging station solutions: 1) Blink for consumers and businesses; 2) Minit Charger for industrial applications; and 3) ETEC LABS for research testing to improve battery technology and the use of EVs. Through the Blink membership program and free charge rewards, the ECOtality EV project obtains information from EV drivers and charging stations about the consumption patterns of EVs in any weather condition. This collected information is analyzed in order to evaluate the effectiveness of charging facilities, the evolution of the green transportation system, and the commercialization of EVs. The Electric Drive Transportation Association (EDTA) is a U.S. industry association working on hybrid and EVs and transportation technologies. The EDTA works with policymakers to promote electric drive transportation [64]. The Edison Electric Institute (EEI; a member of EDTA) focuses on increasing the awareness, acceptance, and adoption of electric transportation by enhancing the management of the power grid, promoting electric power generation, and providing strategic business information. To optimize the energy use, the company Southern California Edison [65] provides useful guidelines for safe and reliable EV charging installations. The company proposes equipment upgrades to achieve energy savings in current facilities, and it organizes workshops and classes to teach how to manage the power usage.

European countries, such as Spain, Ireland, France, and Italy, have also started to use renewable energy through many projects. For example, the ENDESA company started the SmartCity project in Malaga, Spain. This project is the largest ecoefficient city initiative in Europe. It relies on a renewable-energy generation and management system, a charging infrastructure, the smart meters, and an advanced communication to optimize the energy distribution for the charging of EVs. The project also allows clients to monitor their energy consumption habits online [66]. In the city of Saitama, Japan, Honda launched the smart home system in collaboration with other companies. As an efficient home energy management system, the smart home system manages the urban use of EVs. The project manages the urban use of EVs. It aims to reduce CO_2 emissions and to optimize the generation and consumption of power through electric car sharing, commercial use of electric cars, strategic implementation of electric supplies in Saitama, and infrastructure and car maintenance to ensure compatibility and long life cycles [67].

V. STANDARDIZATION EFFORTS FOR SMART AND SUSTAINABLE TRANSPORTATION

STMS is a green intelligent transportation system that aims to address economic and ecological issues. However, STMS is composed of many complex subsystems (smart grid for power generation, distribution and metering, fleet management systems, communication network) and is the result of the integration of efforts from many different countries, companies, and research institutes (Section IV-D). Thus, it is important that we get a set of standards to follow in the next decades to ensure interoperability and growth.

A. STMS Standardization Requirements

A successful STMS design and deployment needs to satisfy the following requirements.

1) Guarantee the interoperability and integration between heterogeneous subsystems (smart grid, fleet management system, charging reservation, and authentication and payment systems).
2) Unify the framework and schemes to fabricate compatible universal devices (cars, batteries, and charging stations).
3) Define guidelines to develop the required electric and network equipment (inlet, connector, plug and socket-outlets, and wired or wireless devices to connect the cars to the charging stations).
4) Design user-friendly interfaces to simplify the utilization of new equipment and technologies related to green transportation.
5) Ensure safety of all electric installations (define the maximum current and voltage to use in domestic or commercial charging stations).
6) Introduce a set of rules and best practices for many situations and conditions (e.g., advice for electric battery maintenance and safety caution after a collision when driving an EV).
7) Define economic models for the electric-transportation market in which standard organizations define how to deploy publicly accessible charging infrastructures, and organize electric cars and electric charging station investment in order to ensure balance between reducing costs and getting a profitable gain.
8) Define priority actions to ensure the long-term system utilization and upgrade (e.g., recycling the battery instead of throwing it away).

TABLE III
SAE, ISO/IEC STANDARDS

Type	SAE Standard	ISO/IEC Standard
Connector, inlet & EVSE	**J1772TM:** PEV conductive charge coupler, **J2954:** PEV wireless charge, **J2894:** Power quality requirements for plug-in electric vehicle chargers, **J2894:** 1) Requirements, 2) Test methods, **J2990:** Design preferences identification, systems and components descriptions, testing procedures definition.	**IEC62196:** 1) Industrial plugs and socket-outlets, 2) Plug types, 3) DC fast charging (draft standards), **IEC61980-1:** Inductive charging safety coupler supply equipment.
Communication	**J2836TM:** General information (use cases), **J2836/1TM**: 1) Utility programs, 2) Off-board charger communications, 3) Reverse energy flow, 4) Diagnostics, 5) Customer and Home Area Network (HAN), 6) Wireless charging, discharging, **J1939** Vehicle's internal communication components.	**ISO, IEC15118:** 1) Vehicle to grid communication interface, general information and use-case definition, 2) Network and application protocols requirements for V2G communication interface, 3) Physical and data-link layers requirements for V2G communication interface.
Safety	**J2344:** Electric, HEV and Plug-in, Vehicle Safety, **J1766:** Crash integrity testing.	**ISO6469:** EV safety. **IEC61851:** Operating conditions and safety requirements.

B. STMS Standards

Automotive and power generation companies proposed a wide variety of products and solutions to meet the highly diverse needs of green transportation trends. The standardization of those solutions presents a growing need in the transportation sector. International standard organizations such as SAE, ISO/IEC, and IEEE have started to create a set of standards for electric and hybrid vehicles and charging utilities to avoid incompatibility among products, to simplify the production of various components, and to ensure safety as high voltage is used in ESVE to feed electric and hybrid vehicles [68]–[73]. As shown in Table III, we can classify these standards into three categories: 1) electric component connectors, inlet standards, and EVSE standards, which specify connectors (inlet, connectors, and plug and socket-outlets) and the different charging modes and describe general design requirements for electric and hybrid vehicles; 2) communication standards, which describe the communication between vehicles' internal components (CAN bus and sensors), communication between EVs

TABLE IV
BENEFITS AND DRAWBACKS OF GREEN TRANSPORTATION

Advantages	Drawbacks
- Highly efficient vehicles that reduce the power consumption, - Clean vehicles with low CO_2 emission, - Uses renewable energy sources such as solar, water, wind, etc, - Allow sustainable mobility.	- Electric and hybrid cars are still expensive, - Electric vehicles are not useful for long trips and limited to daily driving profile, - Battery charging takes a long time, - Initial deployment is still expensive and needs a deep financial study to organize it.

and the EVSE, network and application protocol requirements for V2G communication interface, and physical and data-link layers requirements for V2G communication interfaces; and 3) safety standards, which specify safety features to cover all life cycle phases (design requirements, test units, and recycling programs). These features help to prevent hardware and software failures in the automotive system, estimate potential system hazards, and specify installation protection for electric telecommunication facilities for electric supply locations.

In addition to electric and hybrid standards, there is another standard for renewable energy called the Renewable Portfolio Standard, which specifies the required rules to increase renewable-energy production by power companies [74].

VI. CHALLENGES AND ISSUES

The increasing shortage of fuel expected in the future is motivating researchers, designers, car manufacturers, and transportation agencies to seek alternative sources of power, such as electric power, for vehicles. In Table IV, we present some of the benefits of green transportation and the main drawbacks that can delay a large-scale deployment of this kind of transportation. Then, we discuss some of the issues and challenges associated with the deployment and management of EVs:

A. Cost

The raw materials needed to manufacture electric batteries are scarce and costly. In addition, the battery state degrades quickly with poor or inconsistent charging habits or in case of frequent fast charging. Thus, many additional maintenance fees are needed to keep EVs operational. Moreover, new innovative engineering solutions are needed to improve the efficiency of EVs, to increase the amount of battery charge, and to reduce the charging duration to increase maximum driving distances. Furthermore, the smart grid and fleet management systems require more funds to maintain and manage the currently deployed infrastructures for EVs.

B. Standards

Another challenge is the lack of universal standards and regulations for electric facilities and EV markets. Indeed, many vehicle manufacturers, renewable-power producers, researchers, and governments simultaneously started many initiatives and projects to improve the electric cars' efficiency and to deploy them to ensure cleaner transportation. This led to the development of many different types of electric motors, charging stations, electric plugs, communication technologies, and pricing models. Thus, the electric car has many charging modes (see Table II), and most of the time, an electric car bought from one manufacturer cannot be charged automatically in any charging station except the one designed for its model (Section V-B) [75]. In addition, most of the solutions presented in earlier sections assume that EVs and charging stations share the same characteristics (same plug type, charging mode, and capacities). As a result, a common standard must be specified to support a variety of devices as well as battery types (lead-acid, nickel metal hydride, and Zebra lithium ion), chargers (fast, slow, and normal), traction motors (induction motor, interior permanent magnet synchronous motor, and spoke-type interior permanent magnet synchronous motor), power converters, and vehicle types (small car, truck, or bicycle), each of which has its own constraints and charging preferences. Moreover, standardization will play a paramount role in the future of EVs. It motivates manufacturers to produce EVs and encourage drivers to buy them. In fact, standards help to open up competition and reduce the manufacturing and deployment costs. Additional work is still needed in the standardization area to address the following emerging issues: updating the current standards to include the electric distribution network of electric cars, developing energy efficiency measurement capabilities for onboard chargers, and standardizing voltage levels in all types of EVs in addition to the standardization established for industrial vehicles (personnel and burden carriers, and scrubbers and sweepers). The development of a future standard will require closer collaboration between the standardization organizations (SAE, IEC, and ECE), researchers, and manufacturers.

C. Power Generation and Smart Grid

Given that EVs consume a large amount of electric energy, the smart grid faces a considerable challenge in that it must ensure the generation and management of the required energy. Currently, we face two issues: limited power production if we use only renewable resources (such as wind and solar) and environment pollution if fuel is transformed to produce electricity. In addition, power transmission is limited to the capacity of the distribution grid (transmission lines). Consequently, it is difficult to build a distribution grid to address the need of charging on a large scale due to substantial costs and high load safety considerations [76]. Unlike fuel-based cars, electric cars are mainly designed to drive over short distances. To get the required charge for daily driving profiles, they could use only the home plug to charge. However, home charging capacities are limited to one or two cars at most, which can become an issue for customers and for the smart grid if many cars need to be charged simultaneously everyday.

Additionally, although EVs owners are able to sell back the power stored in the electric battery, as we pointed out earlier (Section IV-C), the battery has a low quantity of power, and we need many cars to feed and support the smart grid during peak usage periods. Furthermore, retrieving the power stored

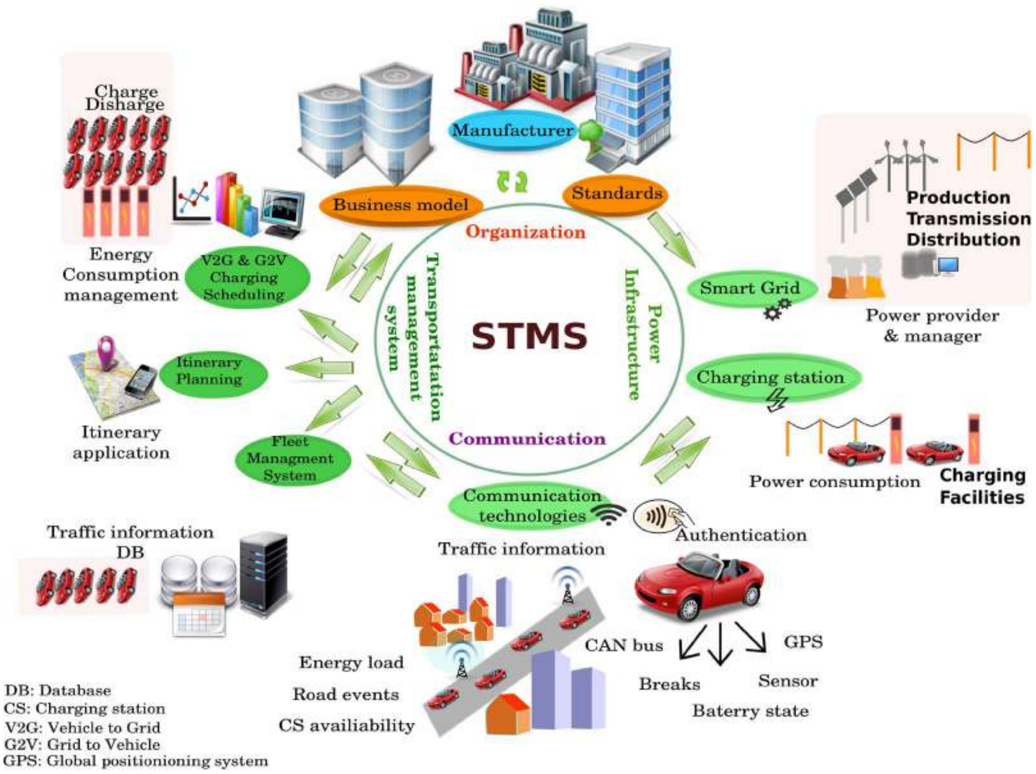


Fig. 6. Toward a smart STMS.

in the battery may harm the battery and reduce its life cycle. However, the power recovery depends on the preferences of the car's owner and requires metering and discharging terminals that heavily increase the investment costs. Thus, no guarantee is provided to obtain the required energy from cars, and we risk exceeding the power lines' capacities if the power retrieval pulls from too many cars in a limited area [76].

D. Incentive Efforts

The high costs of EVs, charging stations, and associated infrastructure remain a challenge because the market penetration of electric cars is still not very high. To fund future transportation projects, cooperation is needed between the electric car industry, the electricity companies, and the government. Several previously proposed initiatives have attempted to promote the manufacturing, marketing, and sale of EVs. Many governments have proposed customer incentives to increase EV sales. These governments reimburse a part of the EV's purchase price. EV manufacturers rent electric batteries to costumers rather than including the battery cost in the final price of the car, thereby decreasing the cost of electric cars. Finally, electric companies propose lower electricity prices in off-peak times to encourage clients not to charge their EVs during peak periods in order to ensure the stability of the smart grid and to minimize the charging cost of cars.

E. Communication Security

The smart grid and fleet management systems exchange a large quantity of information, such as charging station load, EV battery states, traffic information, and unexpected events and accidents in the smart grid, in real time. Most of the available solutions neglect the security of data transmission when communicating information to and from the smart grid, electric cars, and charging stations. Any security attack may affect the operation of the smart grid, the charging stations, and the electric cars. For example, falsification and alteration of voltage or current level information may burn the electronic components in both EVs and charging stations. Likewise, the transmission of unencrypted information about customers' personal and location information threatens the customers' privacy [77], and middle man attacks can change information in order to control billing information. More effort is required to ensure secure and reliable data transmissions among the various entities of the management system.

F. Integration Framework

As shown in previous sections, the major barriers for EV consumers include both the high prices of the vehicles and the lack of infrastructure to support them. For green transportation to become reality, we cannot focus on one specific aspect of transportation and ignore other factors that can affect energy management. A fully integrated framework where all entities are energy-aware is required to enable sustainable transportation. A complete smart transportation management system is illustrated in Fig. 6. The STMS integration is not possible without the cooperation and collaboration of car manufacturers, scientists, electricity companies, governments, and standardization organizations. We depict the STMS integration in layers in Fig. 7. We summarize the interaction between the different layers as follows: First, collaborative organizers studied the actual deployment state of EVs and supplies, considered all

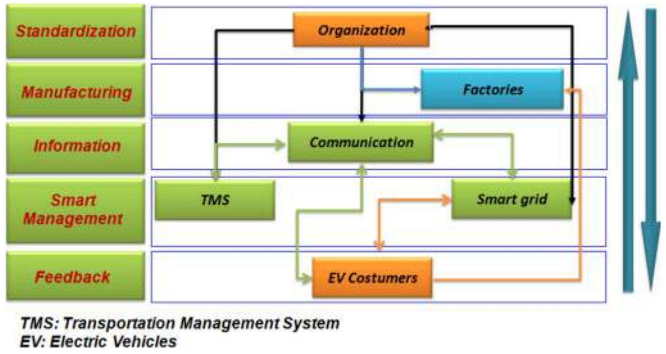


Fig. 7. STMS: layers' interaction.

previous experiments and leakages, and then suggested universal standards and policies. After that, the manufacturers should product the required components, such as electric batteries, charging stations, and plugs, by following the organizers' specifications. At the same time, the electric power industry should build the required power infrastructure to support the EVs' charging load. The next step is the most important. The cycle of power production and consumption should ensure the following: 1) real-time communication that has a crucial role in delivering and exchanging sensitive information (such as energy load from advanced metering interfaces, vehicle's battery state, and also charging requests and replies) between electric utility companies and customers; 2) load balancing and optimized energy management (production, distribution, and consumption) that scale with the new transportation market's energy demands; 3) efficient fleet management (fleet assignment and itinerary planning); and 4) charging station management that schedules EVs' reservations and charging. Finally, each layer sends feedback regarding its functionality (e.g., charging station efficiency, energy production, and consumption information) to the upper layers to improve the STMS.

VII. CONCLUSION

In the past few years, interest in green transportation technologies has increased. The emergence of technologies such as the smart grid and EVs promises to pave the way toward green transportation management systems. We have presented the various architectural components that need to be designed, implemented, and deployed to make a green transportation system a reality. We have reviewed recent standardization efforts in regard to various issues related to electric transportation. We have discussed some of the challenges and issues that still need be addressed in the future to have a fully functional and cost-effective green transportation system. Finally, we have presented an integration framework that takes into account the major fundamental components and factors impacting the life cycle of EVs. This framework aims to ensure full integration of EVs into the smart grid through communication, standards, and efficient management.

ACKNOWLEDGMENT

The authors would like to thank the Council of Bourgogne, Burgundy, France for their research grant support; A. Dewitt for her help and useful comments during the revision of this paper; the anonymous reviewers for their valuable feedback and suggestions, which help us improve the quality and presentation of this work; and S. Berte for her kind encouragement and support.

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