

Sustainable Fleet Operations in the Postal Sector¹

Vanessa Chocteau, La Poste

David Drake, INSEAD

Paul Kleindorfer, INSEAD²

Renato J. Orsato, INSEAD

Alain Roset, La Poste

1. Introduction and Background

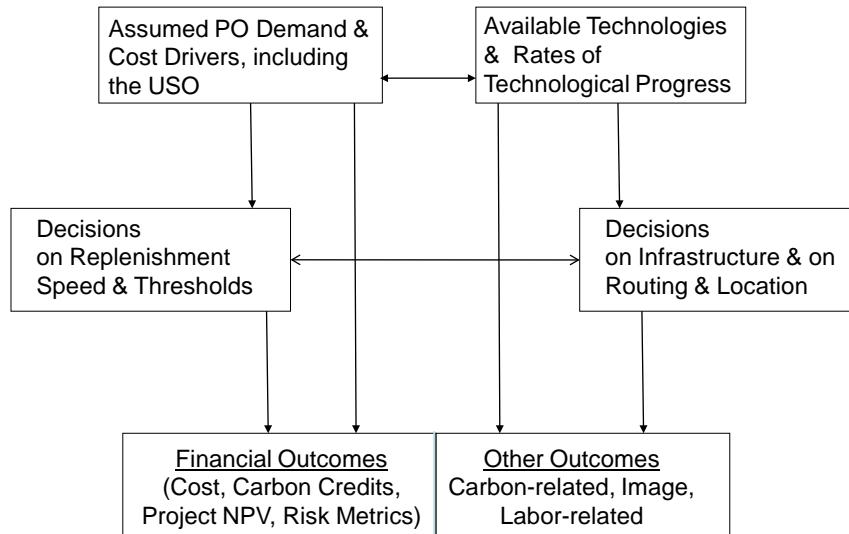
Fleet optimization for postal operators (POs) is an important effort towards sustainable transportation in several ways. First, of course, is its direct economic impact through investment, amortization and operating costs. Second, is its impact on the carbon footprint of the PO. While the evaluation of alternative fleet traction systems (e.g., fossil-fuel, hybrid and electric) is in many respects a relatively straightforward financial investment problem, there are additional complexities that make this problem an interesting research problem for sustainable energy. These include the uncertainties in market prices for various sources of energy, including emission credits for carbon leveraging of investments; the problem of infrastructure and support for new technologies; the intangible/reputation benefits of sustainable energy investments for POs; the problem of new technologies and learning effects and, finally; the nature of strategic partnerships and risk sharing that may be needed to achieve the requisite scale of operations to make low-carbon vehicles a feasible alternative for major fleet operators and for the automotive industry. Taking these features into account, this paper will describe a strategic framework for evaluating the possible transformation of postal fleet operations to hybrid or (pure) electric vehicles and present some initial results for this problem.

The basic objective of any analytical approach to this problem is to provide a multi-year comparison of a well-defined benchmark case with an alternative electric or hybrid vehicle replenishment scenario, accounting for both cost and carbon impacts. As shown in Figure 1, this framework would naturally encompass demand estimates, as fundamental drivers of fleet use, along with scenarios reflecting trends in components contributing to capital costs, operating costs, and carbon “revenues.” The focal decisions are the speed of transition to low-carbon vehicles by location and route type, and the roll-out plans and threshold values for various phases of the replenishment.

¹ Paper to be presented at 6th Conference: "Regulation, Competition and Universal Service in the Postal Sector" Toulouse, March 25-26, 2010. Views expressed in this paper are those of the authors and do necessarily reflect the position of participating institutions and organizations involved in this study.

² Corresponding author for the paper: paul.kleindorfer@insead.edu.

Figure 1: PO Fleet Replenishment Valuation



In the standard fleet replenishment problem, costs for infrastructure and maintenance are clear as are economic lives of vehicles and the relative efficiency of replacement vehicles. Under these conditions, a straightforward comparative analysis easily establishes when an incremental “new” vehicle should replace an “old” vehicle. In the present case, however, there are additional complexities: fundamental changes in the traction system – internal combustion engines (ICEs) to electric motors - and in supporting infrastructure need to be considered. In addition, carbon valuation and technological uncertainties on vehicle performance and price are present with EV traction systems (e.g., the initial and resale price of batteries for such vehicles). The nature of the PO’s universal service obligation (USO) going forward will also play a role in determining the intensity of vehicle use for collection and delivery operations. Moreover, all of this is tied up with underlying demand uncertainties on both letters and parcel products that are central to the future of the postal sector.

Concerning carbon valuation, this is an area of considerable uncertainty over the next decade, depending as it does on country and region-specific initiatives regarding carbon pricing. Valuing CO₂ and other greenhouse gas (GHG) emission reductions resulting from a shift to EVs could be important in determining appropriate levels of government support for an EV fleet transformation as well as in financing this shift in part through selling associated certified carbon offsets in carbon markets. In this paper, we will take the European Union institutions as the backdrop, including the existing cap and trade system in the EU.³ While this might

³ For details on carbon markets in general, and the EU in particular, see Mansanet-Bataller, M. and A. Pardo (2008). “What you need to know to trade in CO₂ markets.” Mission Climat de la Caisse des Dépôts, Paris. Available at <http://ssrn.com/abstract=1156973>.

dispel some of the uncertainty concerning future carbon prices, a great deal remains. This is partly the result of the still unresolved global approach to GHG reductions, following the Copenhagen Summit in December 2009, as well as the fact that the original Kyoto agreement itself comes up for reinstatement in 2012. The resulting caps, and the process of allocating allowances to various industries, remain very much a work in progress. So too is the treatment of the allowances from developing countries that will be allowed to reduce the burden of achieving Kyoto targets through domestic mitigation strategies alone.⁴ The result is that the future for carbon prices as this affects fleet transformation decisions until, say, 2020, even in the well organized EU market, is very uncertain.

On the cost side, there are likely to be minimum/optimal threshold values (in terms of introduction of EVs into the fleet) and these threshold values will intersect with infrastructure decisions (where to introduce these EVs first, in urban, semi-urban or rural areas). Financial risks and hedging/contracting on electric power prices (given the off-peak recharging possibilities inherent in postal fleet EVs) also make the problem interesting from the perspective of a large energy buyer. Other issues of potential interest concerning sustainability and brand image include public receptiveness toward this initiative and labor/employment and retraining issues to accommodate the fleet change. As a result, the fleet replenishment problem for a major PO can be considered, if not *sui generis*, then certainly a significantly different problem than that for which established research results can be readily applied. It is the aim of this paper to provide a strategic framework and some initial results for this problem.

The remainder of the paper proceeds as follows. In the next section, we examine the background of relevance to this problem for the postal sector and describe the basics of fleet planning for a major PO like La Poste. Section 3 describes the interdependencies among the three commercial stakeholders arising from the EV decision problem: (i) the PO, (ii) the electricity supplier, and (iii) the automotive manufacturer providing the EVs. Section 4 solves a simple version of the problem for a single new leasing decision, focusing on the three major commercial agents in the problem (the PO, electricity supplier and automotive manufacturer). The analysis in section 4 neglects risk-sharing issues among the stakeholders, which are considered in section 5, with other open research questions that need to be resolved.

⁴ For a discussion of the future valuation of Clean Development Mechanism (CDM) carbon credits, see Brinkman, M. (2010). "A New Look at Carbon Offsets." *McKinsey Quarterly (Climate Change Special Initiative)*, February. Brinkman makes the interesting point that the EU has capped total imports of CDM offsets through 2020 at 200 Million Tons of CO₂e. This means that cheaper projects for GHG reduction in the developing world will not be of much use in the EU unless this cap is changed.

2. Postal Operations, Sustainability and Fleet Planning

Any discussion of major new initiatives in the postal sector takes place against a complex backdrop of fundamental changes occurring in the sector worldwide. The driving force is undoubtedly the changes that have been occasioned by increased competition, first by the emergence of substantial private express companies in 1980s and second, and by the evolution of the Internet and related electronic services in the past decade. Electronic competition, in particular, means that POs are facing declining demand for the letter mail and transactions mail (e.g., from financial institutions and utilities) that not only provides higher margins than, for example, newspapers and advertising mail, but has traditionally been the *raison d'être* of national Postal Operators (POs). Declining letter mail volumes were becoming evident in the past few years in terms of slowing growth in letter mail volumes. But slow growth has turned into significant declines, for many European postal operators by as much as 10%, because of the financial crisis which began in 2007 and from which we are just now emerging.⁵ The most worrying aspect of this is that, rather than sporadic demand fluctuations, these declines are the result of new patterns of consumption, which may well continue into the future.

Around the world the story is the same: electronic substitution, the financial crisis, changing mailing and advertising patterns, and a continuing requirement and public expectation to provide universal services. To add to this list of challenges, POs in Europe face the prospect of full market opening under the Third European Postal Directive by the end of 2010. It is hard to imagine worse timing for any major policy change. However, competition in the communications markets is here to stay, so full market opening for mail is also a logical step in the process of fully liberalizing all communications markets. How this is to be done in the postal world, however, remains a complicated matter because of the complexities of allowing competition to proceed while imposing a continuing Universal Service Obligation on the national POs.

The transformation required under these rapidly changing conditions involves not only operational changes but also the transformation of POs into more commercial enterprises able to compete in the broader communications market.⁶ This three-way balancing between commercial flexibility, universal service, and fair competition has been a continuing theme in the postal reform area and will continue

⁵ These volume declines are in evidence in almost every postal operator worldwide and are not just in evidence in Europe. For example, the world's largest PO, the United States Postal Service (USPS), mail volume fell 12.4%, from 202.7 billion in 2008 to 177.1 billion mail pieces in fiscal year 2009. Over the same period, USPS operating revenues declined 9.1%, from \$74.9 billion to \$68.1 billion. The resulting operating losses in 2009 for USPS were \$3.8 billion.

⁶ One sign of this recognition of the need to commercialize activities is the privatization that has taken place in Germany, Netherlands and Austria over the past 20 years. In France, the recent change in statute of La Poste to a limited liability corporation (with a starting position of 100% of its capital owned by the French government), effective as of March 1, 2010, reflects this trend as well.

to be for the foreseeable future.⁷ Added to this volatile mixture of challenges for the postal sector has been the issue of growing expectations that POs will also operate as sustainable enterprises. In part, this is a natural derivative of the semi-public nature of the POs since their early history, acting as the backbone of the public communications infrastructure. In Europe, the expectation is very clear that POs, as very visible representatives of their respective countries, will set an example for leadership in the area of sustainability. Thus, it is not surprising that PostEurop, the organization representing postal operators in Europe, has identified sustainability as one of the central areas for cooperation across European POs.⁸ Against the dictates of cost and competitive pressures, however, it is clear that sustainability will have to be integrated with an overall strategy of achieving viable financial performance as well as viable environmental performance. This is the basic context that underlies the problem studied in this paper, namely the potential transformation of the sizeable postal delivery fleet to lower-carbon vehicles that are more consistent with the dictates of sustainability. Such a transformation must occur within the very tight constraints of commercial viability and the public USO mission imposed on POs.

Sustainability and Carbon Footprinting

Sustainability in a business enterprise is a broad topic (see Orsato, 2009), involving generally a credible concern for the social and environmental impacts of enterprise activities, even when these are not directly priced in the markets for a company's inputs or outputs. Given the focus of the present paper, we will be primarily concerned with energy and related greenhouse gas (GHG) emissions, as these are the central sustainability concerns of companies, like POs, with extended supply chains. In POs, GHG emissions and energy consumption result from the following activities: building and lighting energy consumption, energy for mail processing activities and transportation for collection, inter-regional transportation and ultimate delivery. The relative intensity of these differs across POs because of differences in mail volumes, delivery patterns and other aspects of the postal market in different countries. Table 1 (at the end of this paper) summarizes statistics for USPS and La Poste on the structure of transportation expenditures and fleet sizes for La Poste and USPS.

In terms of understanding the carbon emissions and energy consumption in a supply chain, the general approach taken has been carbon/energy blueprinting. Such an approach encompasses methodological challenges that are common to traditional life cycle assessment (LCA). First, in determining their carbon footprint, firms must identify the boundaries within which they are willing and able to exert

⁷ For a recent survey of major developments around the world in postal reform in balancing these issues, see Crew, Kleindorfer and Campbell (2008).

⁸ PostEurop and the IPC have both initiated programmes on the sustainability area in the postal sector, in recognition of the growing importance of these topics. See PostEurop (2010) and IPC (2009). To cite PostEurop (2010): "With approximately 1 million postal vehicles across Europe, we see great potential in working together to address a common solution in turning our fleets greener."

influence over carbon and energy consumption, identify GHG contributions from each activity and input within those bounds, and then convert those GHG emissions into CO₂e (CO₂ equivalent) emissions. Second, once a firm decides to include the emissions generated from its inputs, they must then decide how many upstream tiers should be incorporated into their footprint. As a general guideline, firms should consider in their footprint at least the emissions that they can influence. But this too leads to complexities when comparing footprints between firms, as such influence will certainly vary across and within industries. As an alternative, firms could take a “cradle to grave” approach, including all CO₂e emissions generated from initial raw material sourcing through product disposal. This, however, is obviously impractical simply because data is often not available, complicating the measurement task.

After setting system boundaries, firms must identify GHG contributions from each activity and input. This is not always a clear-cut process. Boots produced by Timberland, for example, require leather. The cows from which the leather is supplied emit substantial volumes of methane, and it is this methane, in fact, that drives the carbon footprint for many of Timberland’s boots. Timberland assigns 7% of a cow’s total estimated emissions to the leather it acquires, which is the percentage of a cow’s financial value generated by its leather. Leather producers, however, argue that the cow would be slaughtered for the meat that it supplies regardless of whether leather was also sold as a by-product (Ball, 2009). Whether emissions from such by-products are included within a firm’s carbon footprint can vary by industry. In cement, for example, substitute materials such as blast furnace slag and fly ash – by-products from pig iron production and coal-fired energy production, respectively – are counted as emission-free,⁹ contrasting Timberland’s treatment of its leather.

The final step in assessing a firm’s carbon footprint is to convert all GHG emissions to CO₂e (CO₂ equivalent emissions). This task is made simple by the many conversion tables and tools available, including a CO₂e calculator provided by the United States Environmental Protection Agency.¹⁰ Thus, a carbon footprint analysis reveals more than just a total CO₂e impact. It requires firms to consider how far their reach in controlling emissions might extend, and reveals which activities within the system are driving CO₂e emissions. Ultimately, the process can aid firms in determining where to focus their abatement efforts for maximum impact.

In the postal sector, a number of studies have started in this area. These include Buc (2010), Ravnitzky (2009) and USPS Inspector General (2009). These studies make a strong case for the importance of carbon footprinting and the potential contribution of EVs to lowering transportation costs and simultaneously to reducing carbon emissions from USPS operations.

Fleet Planning for Postal Operators

⁹ See Drake et al. (2010) for a discussion of carbon issues in the cement industry.

¹⁰ <http://www.epa.gov/RDEE/energy-resources/calculator.html>

Fleet planning and operations for POs is a continuing process of resolving the changing needs of operating managers for transportation support with available technologies. The basics of the process can be illustrated using the French La Poste as an example. Driven by the USO and its estimates of demand for its products, La Poste plans its needs for vehicles of different types by considering and optimizing route structures for collection and delivery. This gives rise to the definition and choice of vehicles, given available vehicles on the European market. Targets for these are continually updated but based on a rolling 6-year horizon planning. The same 6-year horizon is the current horizon for ownership and operation of purchased vehicles at La Poste.

La Poste self-finances the purchase of vehicles through a wholly owned subsidiary, which also has responsibility for insurance and for planned maintenance of the purchased vehicles. The subsidiary manages the financial end of these purchases, and provides these at an internal transfer price (rental fee) to operating managers of the organization. Various incentives are included in these contracts to assure that operating managers treat these transportation resources as fully internalized costs, with unusual wear and tear of the vehicles or unusual maintenance costs paid for from operating budgets. Vehicles are required to be returned at the end of their planned life (currently 6 years) in a condition appropriate for resale according to a set of specific standards. In this way, La Poste manages both the financial interface of fleet purchase and resale through its subsidiary, as well as providing incentives to its operating managers to use transportation resources provided in an efficient manner.

At present, given the variety of services supported by transportation, La Poste uses primarily 5 types of vehicles (totaling some 45,000), of which the very visible Renault Kangoo makes up about 60% of the fleet. As shown in Table 1, 10% of current total operating costs of the Mail Division of La Poste are currently spent on transportation. Some of the factors that can be expected to impact the number and type of vehicles required for transportation in the next decade include the following:

1. The increase in the number of delivery points (driven by population increases and decreases in the number of addressees per delivery point);
2. Changes in the product mix from small letters to parcels and flats;
3. Decreases in the number of delivery post offices with more delivery routes but balanced by redefined route structures to optimize the number of vehicles required;
4. Moves to reduce the number of mopeds by 4-wheel vehicles to reduce injury rates;

In summary, the demand by POs for vehicle support is driven by the underlying demands for its products, with strong interactions with USO-driven quality standards, post office locations and collection requirements, and with continuing pressures to optimize the costs of fleet operations.

Framing of the Sustainable Fleet Replenishment Problem in the Postal Sector

We note the following major elements of sustainable fleet operations for a PO like La Poste, operating with the continuing public mission as the national PO:

1. Sustainable Fleet Operations need to be understood as one key element of overall sustainability strategy in the context of a PO with a public mission, and the expectation by its external stakeholders and its employees that the PO will be exemplary in pursuing sustainable operations.
2. Any strategy that involves significant expenditures must be cost effective given the competitive context of POs. In other words, *sustainable* here means cost-effective, consistent with the commercial nature of a PO and the competitive environment POs now face. Although POs may obtain some reputational value out of low(er) impact operations, evidence from other industries suggests that consumers are not willing to pay price premiums for low carbon transportation. Hence, any additional costs incurred in the move towards low carbon have to be absorbed by POs.
3. Transportation is a centerpiece of any PO's operations, which must be coordinated with a host of other postal activities with which such transportation activities must find a smooth confluence.
4. For fleet replenishment activities, a number of actors beyond the PO itself are involved, and the problem of valuing GHG reductions and of designing appropriate approaches to achieving such reductions therefore extends to a broader system of developing partnerships in sustainable transportation.

3. Principal Stakeholders in Sustainable Fleet Operations

In this section, we consider the interests and constraints of the major stakeholders associated with the potential transformation in the composition of a PO's fleet from internal combustion, fossil-fuel fired (ICEs) to electricity powered or hybrid vehicles (EVs).¹¹ The essentials of the matter for the decision problem faced by the PO can be conveyed succinctly in the following equation for the net present value at period t of the *life-cycle cost* $LCC_v(t)$ of a vehicle leased at the beginning of period t under the normal multi-year leasing arrangements used by POs.

¹¹ For details on the background to automotive choices, see chapter 7 of Renato Orsato, *Sustainability Strategies*, London: Palgrave, 2009.

$$LCC_v(t) = P_{vt} - \delta^L R_{vt+L} - S_{vt} + \sum_{\tau=t+1}^{t+L} \delta^\tau [C_{v\tau} + M_{v\tau} - G_{v\tau}] \quad (1)$$

where

- v = vehicle type, = Internal Combustion Engine, EV = Electric or Hybrid
- δ = discount factor
- L = leasing period (typically 4-5 years), assumed to be the same for vehicles of either type $v \in \{EV, ICE\}$
- P_{vt} = initial leasing fee for vehicles of type $v \in \{EV, ICE\}$
- R_{vt} = resale or return fee at end of lease for $v \in \{EV, ICE\}$
- S_{vt} = government subsidy for $v \in \{EV, ICE\}$
- C_{vt} = operating cost for $v \in \{EV, ICE\}$
- M_{vt} = maintenance and other vehicle specific fixed costs for $v \in \{EV, ICE\}$
- G_{vt} = value of reduced GHG emissions for $v \in \{EV, ICE\}$

We can disaggregate C_{vt} and G_{vt} further as:

$$C_{vt} = P_{et} \square_{vt} d_t; \quad G_{vt} = P_{ct} \square_{vt} d_t \quad (2)$$

where, for each period t ,

- P_{et} = price per kWh for energy in period t
- P_{ct} = price per t-CO₂e credit in the carbon market
- \square_{vt} = energy intensity of $v \in \{EV, ICE\}$ in kWh per km
- \square_{vt} = carbon intensity of $v \in \{EV, ICE\}$ in t-CO₂e per km
- d_t = distance driven by the vehicle in service period t

Projections of underlying PO-specific variables (e.g., the distance driven) and of the stochastic processes governing each of the variables above would provide the basis for determining the expected value of $LCC_v(t)$ and other statistics relevant for risk management. A real options analysis of the choice could then provide a basis for choosing to replenish some or all of the PO's newly leased vehicles at time t with ICEs or EVs. We analyze a simple deterministic version of this problem in more detail in the next section. For the moment, let us note a few of the factors that will underlie the drivers of the above model of PO life-cycle vehicle costs. We consider these from the perspective of the different stakeholders involved.

Postal Operator (PO)

For the PO, there are a number of factors that favor the transformation to electric

or hybrid vehicles.¹² First and foremost, EVs are an appropriate technology for most postal collection and delivery purposes. For example, the average length of routes in France is 33 km, with the vast majority of daily usage of vehicles well below the 100 km range that is easily achievable with current technologies. Indeed, EVs were the preferred method for delivery in the early days of vehicular transport, both for the postal service as well as for other similar daily route services, such as dairy services in the UK. Such conditions favor the EV technology, with regenerative breaking power, and many stops.

Added to the appropriateness of the EV technology for PO operations are the savings in operating costs, maintenance costs and environmental impacts. Concerning these costs, Table 2 (at the end of this paper) shows a stylized comparison of typical usage patterns for EVs and ICEs in the postal context. The assumptions under the table are intended to be realistic but conservative. Let us consider the details.

The maintenance cost estimates in Table 2 for EVs are set at 70% of those for ICEs and are based on current engineering estimates¹³, but it should be noted that the long history of use of EVs by parcel delivery companies in the first half of the 20th century also supports these estimates.¹⁴ The underlying reason for this is the much greater simplicity of the EV drive train from that of an ICE. While there will be some variations across model types, the much lower operating and maintenance costs shown in Table 2 below is quite robust. Indeed, with a well built chassis, and replaceable batteries, there would be no reason why EVs would not have useful lives extending for decades. This has obvious favorable implications for EVs for the resale value (if leased) or for depreciation expenses if owned.

Concerning operating expenses, and again with an eye on Table 2, fuel/electricity cost per km can be expected to be significantly lower for EVs than for ICEs at current electricity and fuel prices. Given the volatility and expected increases in gasoline and diesel prices relative to electricity over the coming decades,¹⁵ this also bodes well for the adoption of EVs or Hybrids for postal operations.

Finally, concerning environmental benefits, Table 2 shows the reduction in CO2e emissions per km. These would, of course, depend on the mix of electricity generation used to recharge EV batteries. For France, for example, where nearly 80% of electric power produced is generated by nuclear power (some of which is exported to neighboring countries, the switch to EVs would bring very significant reductions in GHG emissions. As shown in Table 2, every 10,000 EVs substituted for ICEs would yield annual CO2e savings of 18,000 tons if used on the average La Poste

¹² These are based on the discussion in Ravnitzky (2009)..

¹³ The USPS-OIG (2009) report uses 50% as a representative figure.

¹⁴ See Ravnitzky (2009) for a detailed discussion of the early history of EV use by POs and other utilities.

¹⁵ As recorded, for example, in the International Energy Associations reports at <http://www.iea.org/>

vehicular route (of length 40 km/route). We return below to the potential value in reputational benefits and in current carbon markets of such CO₂e emission reductions to a PO or its national government. Reinforcing these absolute savings is the fact that the location of emissions from electric power plants would be remote from urban locations, while many of the ICE emissions would not be. Finally, NO_x (Nitrous Oxides) and Volatile Organic Compounds (VOCs), the latter the result of furtive emissions and evaporation of fossil fuels from ICEs, are the primary precursors of atmospheric ozone, which is a significant and dangerous pollutant in many urban areas. These pollutants would be essentially eliminated in EVs, with potentially significant associated health benefits.

Let us also note that current Lithium Ion batteries, the current frontrunner for battery technology EVs, face no real problems in obtaining raw materials for their manufacture, and in their ultimate disposal. Indeed, after they have past their useful economic life in powering EVs, currently after approximately 2000 full recharges,¹⁶ they would still be useful as reserve power banks for contingency and regulated power uses (discussed in more detail below).

Summarizing, EVs appear to present an excellent investment opportunity given the predictable, short and repetitive routes for collection and delivery of mail. Compared to their ICE counterparts, they provide significantly reduced operating and maintenance expenses, and environmental benefits, which may be monetized. Other benefits noted below include their potential contribution to integration of renewable into the electric power grid and to meeting national commitments to reduce GHGs under the Kyoto Protocol. However, these benefits come at the expense of additional upfront purchase or leasing costs and uncertainty on resale value based on technological progress in producing the necessary batteries to power these vehicles. The factors that underlie these latter costs and rates of progress are largely in the automotive sector, to which we now turn.

Automotive Manufacturer (AM)

Electric vehicles have long been considered a technological choice by automakers. Indeed, the early days of the automobile witnessed a short-lived dominance of the electric power train. In 1905 there were more EVs on the roads of New York than ICE cars (Yergin, 1992). But the lack of infrastructure for recharging EVs and the early association between the petroleum and car industries resulted in the gasoline car becoming the winner of the technological race of the 20th century, and attempts to bring EVs back to mainstream markets during the past 100 years have only dented consumer confidence in the technology. In this respect, if EVs were a viable option in the early days of the auto industry, we could then ask: why have EVs failed to reach mass commercialization? Why have carmakers not pursued such option?

¹⁶ See USPS-OIG (2009)..

Besides the lack of recharging infrastructure, price is a relatively simple answer. In order to reach ranges above 100 km per charge - which, by the way, is substantially inferior to the range achieved by petrol-powered cars - EVs need to be fitted with large, heavy and, consequently, expensive batteries. The result is obvious; private consumers and fleet operators have been reluctant to buy pricy vehicles that have inferior performance compared to ICEs. What is less clear though, is the enduring interest in electric power trains. If EVs are inferior to ICEs, what explains the long-term attention on such technology by both outsiders and players within the car industry?

One of the reasons for such interest is based on the assumption that EVs do not always require the equivalent performance of petrol-powered cars, and that current levels of performance make EVs suitable for specialized applications. Small (lightweight) electric vehicles can be used for short trips in the vicinities of households, or for applications requiring multiple stops within a short range - normally less than 50km. Indeed, niche markets for EVs have always existed and, because the volumes are in the order of a few thousand cars, they have been supplied by specialized manufacturers. Large automakers have mostly ignored such markets because their systems of production have been designed for break-even points at above 100,000 vehicles per year. As Nieuwenhuis and Wells (1997) pointed out, the technological choice associated with the all-steel car body and the internal combustion engine results in significant high break-even points for any model. Put simply, in order to make money, *volume* manufacturers need to sell cars in the order of hundreds of thousands a year. In this respect, current demand for EVs by fleet operators suggests the existence of an untapped market space for EV fleets above 10,000 vehicles and, at least in the early days, inferior to 100,000. Fleet operators such as postal services need a level of market presence and business longevity that small niche players are not able to guarantee. Satisfying this market demand in its early stages will require either the formation of customer consortia so the minimum of 100,000 vehicles/year is reached.

The uncertain potential of mass markets for EV can also explain the reluctance of volume manufacturers to invest in the EV technology. During the greater part of their history, car manufacturers have been busy commercializing high volumes of petrol-powered cars that (apparently) satisfied consumer preferences. It was only in the last quarter of the 20th century that they faced effective pressure to reduce the environmental impact of vehicles. After substantial improvements made in ICEs, the only alternative left seems to be the electric power train. The reason is simple: electric traction is far more efficient than traction based on fuel combustion. In terms of environmental performance, a lightweight electric vehicle outperforms a conventional automobile in almost every aspect. Electric motors present an average of 75% efficiency, against 20% of ICEs (rather than the overall efficiency of the ICE, it is the high-energy content of hydrocarbon-based fuels that is responsible for the advantage of traditional cars, when compared with EVs). In addition, because EVs have fewer running parts, they also require 50% less maintenance. Indeed, back in

1993, Whitelegg already pointed out that EVs have superior performance regarding the energy demand during production, use, and in the recyclability rates of car parts. In the late 2000s, the environmental advantages of EVs started to be seen as a potential source of competitive advantage for the next generation of cars. Carlos Ghosn, the CEO of both Renault (France) and Nissan (Japan), has been the most prominent advocate of this view, but he is not alone. Most carmakers have made public their intention to have several EVs in their vehicle portfolios within the next five years.

Executives in the car industry also justify investments on EVs on the basis of a potential breakthrough in battery technology. If this happens, it will not only solve the problem of automobile emissions but also help automakers reduce their dependency on oil – a recognized weakness for the long-term survival of the industry. Battery technology could represent a major *first mover advantage* for car companies. Indeed, in the past decades, battery performance and range have been on the rise, while costs have been decreasing¹⁷. But while the trend is promising, not everyone is confident about the potential of a battery breakthrough. Auto industrialists, experts and academics have different opinions regarding the limits of battery technology. Defenders of *hybrids* (i.e.: cars powered by ICEs, supported by electric motors) assert that cost reductions resulting from improved performance of batteries and their mass production may never bring the price of EVs close to that of petrol-powered cars. They see the hybrid technology as the only viable solution for the next generation of low-carbon vehicles. Such disputes, however, only indicate the centrality of the electric technology surrounding the car of the 21st century: All long-term alternatives for the ICE-car currently under consideration - EVs and hybrids - involve electric traction. The question is, therefore, about the place and the method electricity, which will power electric motors, will be generated and stored. There is no question in regard to whether electric motors will be used in power trains.

While battery technology evolves, as long as the full life-cycle costs of the vehicle are considered, current EVs are already cost-competitive. The relatively high initial purchase price of EVs can be mitigated along the full life-cycle of the vehicle. Start ups such as Better Place¹⁸, constitute indications that by decoupling the ownership of the vehicle body from the battery, EVs can be viable under current conditions. However, if EVs can already compete with traditional cars, the infrastructure problem remains. Although it should be obvious to us that an infrastructure for recharging must be available *before* EVs are sold, this is seldom recognized. People buy ICEs because they are certain that petrol stations are ubiquitous, and except for their own carelessness, they will not be left stranded

¹⁷ Deutsche Bank. Electric Cars: Plugged In. 9 June 2008.

¹⁸ Better Place is a new entrant in the mobility sector, which has been backed by venture capital - \$200 million in 2007 and \$350 million in 2009. The company is deploying recharging infrastructure and battery swap stations in Israel and Denmark (later to be extended to Australia, California and Hawaii), and will sell “mobility plans” associated with EVs. For more details, see Chapter 7 of Orsato (2009).

without gasoline. Unless sufficient infrastructure for recharging is available, neither private consumers nor fleet operators/POs will be willing to invest in EVs. For this reason, we need to evaluate whether electricity suppliers are willing to invest in infrastructure for recharging.¹⁹

Electricity Supplier (ES)

For the electricity supplier (ES), the electrification of major commercial fleets offers new sources of demand of a particularly favorable variety, namely off-peak demand. In addition, under vehicle-to-grid (V2G) operations, batteries connected for recharging can also provide backup power for a number of purposes, including contingent load (in the event of failure of a generating unit connected to the grid), regulation (fine tuning the necessary instantaneous balance between supply and demand on the grid), reactive power (providing local phase-angle corrections important in AC networks), and load-following reserves (necessary in particular to back up and absorb variations in power provided by renewable such as wind and solar).

Since the earliest days of major grids in the late 19th century, electricity has remained essentially a non-storable commodity. Some sources of power, such as hydro, can be varied within wide limits in response to changes in other sources of power connected to the grid. However, it is primarily gas turbines running as spinning reserve and not cheaper base-load plants such as nuclear and coal that provide the reserve energy for contingent power, regulation and reserves. The appeal of major commercial EV fleets in this regard is the possibility of using the batteries of such vehicles when they are not on the road as a source of reserve power and buffering for the grid. This entails some costs in connecting and controlling these batteries for bidirectional flows, and the challenges of doing so are non-trivial. However, given current objectives to introduce massive amounts of renewable energy into the grid, the economies of scope between providing both transportation services as well as battery reserves when EVs are not in use are very appealing and are under close scrutiny in several countries. They represent, in fact, a means of adding significant energy storage to the grid, thus alleviating some of the problems of peak loads that are otherwise associated with electric power.²⁰ At present, the only competition for regular hydro and natural gas as load-following generation is pumped storage. Pumped storage uses off-peak energy from base-load plants to pump water to a higher elevation and then release the water through a turbine during peak hours, using the stored potential energy as load-following generation. However, even given sizable differences in peak and off-peak generating costs, pumped storage is costly to install and only a small percentage of

¹⁹ As ADEME (2009) indicates, however, this is not likely to be a near term problem for France, as there is sufficient off-peak energy available to digest a large number of EVs through 2015 (though the infrastructure problem will become significant in France if the upper limit of 4 million vehicles materializes by 2020).

²⁰ Since the work of Gravelle (1976) and Nguyen (1976), it has been recognized that storage flattens peak prices and leads to significant efficiency benefits by helping to avoid the use of the highest variable cost plants during peak hours. The same economic argument applies to batteries.

EU energy comes from this “stored electricity”.²¹

Load leveling is especially important for a country like France with a lot of base load nuclear plants which are designed to provide reliable and steady power output at close to their rated capacity. What nuclear plants are not designed to do is to follow variable load. Reserve capacity for intermittent output renewables such as wind power and solar must be provided by other means than this base load. EVs provide two sources of potential reserve for the grid operator. First, is the use of EV batteries as energy storage and reserve power during the non-use periods of EV life. Second, after batteries have ceased to have the requisite power for effective EV use, they can still provide up to 40% of their rated power for several years thereafter, so that banks of used batteries can provide useful reserves beyond their economic life as the power source for EVs. We return to this point in section 5 below.

National Government (NG)

For national governments, the widespread use of EVs by local POs can be an important means of meeting Kyoto commitments. Encouraging these through taxes, regulation, and subsidies of green technologies have been an increasingly important element of the EU landscape. This has included “Cash for Clunker” programs that provide subsidies for new, more fuel efficient automobiles as well renewable Feed-in Tariffs and portfolio standards that require a certain percentage of electricity supply to be provided by renewable energy sources.²² Perhaps the most important aspect of this for the present discussion is the EU’s Climate Change Package, approved in April of 2008 and committing EU member states to achieve by 2020 an overall level of energy efficiency improvements of 20% together with increases of renewables as a percentage of the total energy supply to 20%. Accomplishing this will require, *inter alia*, integration of additional wind and solar power into the EU grid system.²³

²¹ See Deane et al. (2010) for a recent review of pumped storage in Europe.

²² It is not our purpose here to analyze the cost-effectiveness of any of these measures, but the issues of multiple and overlapping regulations leading to double payments of subsidies and mis-incentives for GHG reduction are now beginning to be analyzed by regulatory economists, e.g. Böhringer et al. (2008), Eichner and Pethig (2009). Suffice it to say that there are at least two phases to any regulatory program; first is setting up the infrastructure for the program and the second is fine tuning the program parameters to achieve cost-effective results (in the present case, a uniform and lowest cost per unit of GHG abatement). If the legislation launching a program is faulty, then the first phase could produce results that are very inefficient in the long run.

²³ In 2009, installed capacity of wind for the EU was 74.8 GW, with the capacity to meet nearly 5% of EU’s total energy demands. Growing capacity in wind generation is one of the primary reasons that the EU is optimistic that it will meet its ambitious goal of producing 20% of total energy consumed in 2020 from renewables (including hydro, solar and wind). Of course, rated or installed capacity for wind is not a reliable indicator of available capacity, as the wind capacity factor is highly variable and typically in the range of .2 to .35. This variability is the primary factor underlining the importance of finding additional sources of reserve and contingency power, such as EV battery storage under V2G operations, to allow the large-scale integration of additional wind and solar capacity into the grid.

From a public economics perspective, there are two operational concerns in the design of regulatory and tax/subsidy programs to implement GHG abatement. First, is meeting the requirements of the Kyoto Protocol in a cost-effective manner. Second is valuing the benefits of meeting other public policy objectives such as improved air quality related to reducing atmospheric ozone precursors, promoting better integration of renewables into the electricity grid, and providing a stimulus for achieving the necessary scale to allow economic manufacture of EVs for the broader commercial fleet and private vehicle markets. These issues are sufficiently interesting and complex to warrant separate studies, certainly beyond the ambitions of the present paper. On the matter of cost-effective implementation of Kyoto requirements, national governments of the EU-15 member states that were covered by the original Kyoto Protocol have committed themselves under the negotiated caps to achieve the EU-wide target to country specific targets. Failure to meet these means that the country involved has to purchase the necessary allowances through international offset markets (the CDM and JI markets).²⁴ Thus, even if the PO does not convert carbon savings into credits in the JI certificate market, there may be good reasons for the national government to provide incentives to the PO to move to EVs as part of the country's accounting for its GHG emissions under its national Kyoto Plan. We revisit this issue in Section 5 below.

4. Efficiency Analysis for EV Choices

The stakeholders analyzed in the previous section - the PO, Automotive Manufacturer (AM), Electricity Supplier (ES) and National Government (NG) - are all essential players/agents in the strategic game that may give rise to a solution that is a continuation of the status quo or, alternatively, to a switch of the PO's fleet to EVs. We will deal in this section with the simplest version of this problem, assuming risk-neutral preferences and ignoring the role of the Government and the associated public benefits of EVs. The central issues that are highlighted here are the economies of scale in automotive manufacturing and infrastructure costs for harvesting V2G benefits. We will note extensions of this formulation to capture efficient risk-sharing issues at the end of this section (risk-sharing is not relevant in the context of risk-neutral agents that do not face significant risks of financial distress or other transactions cost affecting their valuation of realized cash flows).

We imagine the following decision or choice context. The PO (and possibly other commercial fleet owners that may cooperate with the PO in placing orders for EVs) are about to make an irrevocable choice of vehicles on lease with AM for the next leasing period. The number of such vehicles to be replaced is dictated by a fixed

²⁴ The fact that projects at a national level could have implications at the margin for national budgets is not just academic. Indeed, it appears likely for the current Kyoto end date of 2012 that several EU countries (including Ireland, Italy, Portugal and Spain) will have to resort to offset markets to cover gaps between their country performance and the EU negotiated targets. The most egregious problem is, however, with Austria, which may miss its Kyoto target by as much as 100 million tons of CO2e (with a current market value on the ETS of upward of a billion Euros). See <http://www.reuters.com/article/idUSTRE5AB3WX20091112>.

requirement of K vehicles in total that must be replaced to meet operational needs.

We use the following notation.

- N = Set of commercial stakeholders = {PO, AM, ES}
- x = Number of required vehicles replaced with EVs, where $x \leq K$ and where the remaining $K - x$ are replaced with ICEs
- y = Number of the PO's EVs connected to the grid and providing V2G services, where $y \leq x$
- $R_i(x, y, P)$ = Reputational and revenue benefits for agent $i \in N$ from strategy (x, y) when prices are given by the vector of prices P (P is specified below)
- $C_i(x, y, P)$ = Cost of strategy x for agent $i \in N$ when prices are P

Let us now consider the costs and revenues for the agents N. For the PO, we can imagine various forms for reputation benefit and revenues from carbon markets resulting from the purchase of EVs. Reputation benefits would result to the extent that purchase of EVs is viewed as evidence of sustainable behavior by the PO and that such behavior is valued and rewarded by consumers or regulators.²⁵ Reputational benefits are likely to require a minimum sized investment in EVs to be visible (i.e. reputational benefits are likely to be convex in x until a minimum size is reached and then concave). For the present analysis we treat only revenues from carbon credits and from V2G services provided to ES by the PO, so that $R_{PO}(x)$ has the form:

$$R_{PO}(x, y) = P_C g_E \Delta x + P_{BE} y \quad (3)$$

where

- Δ = Total km's per vehicle driven over the lease period (assumed given)
- g_E = Carbon intensity in t-CO₂e/km of the EV relative to the benchmark ICE (and so represents the carbon credits obtainable from the EV in the JI-carbon market)
- P_C = Discounted carbon price over the period of the lease (so that $P_C g_E \Delta x$ represents the NPV of carbon credits over the life of the lease)
- P_{BE} = Discounted price paid to PO for battery reserves and contingent power connected to the grid (V2G services provided by the PO) for the y vehicles connected to the grid, where $y \leq x$

²⁵ The analysis of carbon footprinting and related sustainability value for public organizations is in its infancy. In the postal sector, work to date is summarized in Buc (2010). Orsato (2009) provides the basic framework valuing of sustainability strategy. A review of previous theoretical and empirical work across all fields, including marketing and reputation value, is provided in Durif and Julien (2009), who note that empirical research to date has not provided a very precise answer to the question of "how much is it worth to be green?" Nonetheless, current regulations and public pressure for carbon footprinting and other sustainability metrics are likely to make it costly for visible quasi-public organizations like POs to ignore the need for life-cycle assessments of the environmental impact of their products.

Costs for the PO are represented as:

$$C_{PO}(x) = (P_{AE}(x) - S_E + C_{ME} + C_{OE})x + (P_{AI}(K - x) - S_I + C_{MI} + C_{OI})(K - x) \quad (4)$$

where

$P_{Av}(z)$ = Lease price per vehicle for EVs ($v = E$) and ICEs ($v = I$) when z vehicles are leased

S_v = Present value at time of lease purchase of the salvage/resale value at the end of the lease period for $v \in \{E, I\}$

C_{Mv} = Present value of Maintenance and non-fuel operating cost at time of lease purchase for $v \in \{E, I\}$

$C_{Ov} = \Delta P_{Fv}$ = Present value (at time of lease purchase) of fuel/electricity cost per vehicle over the life for $v \in \{E, I\}$, where Δ is defined in (3) and P_{Fv} is the discounted average price of fuel/km over the life of the lease

For the Automotive Manufacturer (AM), we will assume that this is the same company that provides both EV and ICE replenishments for the PO. (This has the effect of making salient price and cannibalization effects for AM between providing EVs rather than competing alternative ICEs). Thus, AM's revenues are given by:

$$R_{AM}(x) = (P_{AE}(x) - S_E)x + (P_{AI}(K - x) - S_I)(K - x) \quad (5)$$

$$C_{AM}(x) = C_{AE}(D_{AE} + x) \cdot x + C_{AI} \cdot (K - x) \quad (6)$$

where D_{AE} represents EV sales by AM to buyers other than the PO. C_{AE} , respectively C_{AI} , represents AM's average cost of producing EVs, respectively ICEs. We assume that $C_{AE}(z)$ is decreasing in total output z and that total cost $C_{AE}(z)z$ is increasing and concave (in particular, marginal cost is always less than average cost for EVs), while C_{AI} is a constant (economies of scale have been exhausted for ICE production for the ICE-model in question).

For the Electricity Supplier (ES), we assume a negotiated price per MWh supplied, with a positive margin reflecting the fact that recharging energy for EVs will be provided in the postal context off-peak. Revenues for the ES are given by:

$$R_{ES}(x, y) = \Delta P_{FE}x + A_{BEY} \quad (7)$$

$$C_{ES}(x, y) = \Delta C_{FE}x + P_{BE}y + F_{BE}(y) \quad (8)$$

where

- P_{FE} = (Defined at (4) above) Discounted average price of electricity/km over the life of the lease
- A_{BE} = Discounted value of unit avoided cost resulting from battery reserves and contingent power provided to the grid by the PO for the y vehicles connected to the grid, where $y \leq x$
- C_{FE} = Discounted cost of electric power/km for EVs over the life of the lease
- P_{BE} = (Defined at (3) above) Discounted price paid to PO (for V2G services provided by the PO) for the y vehicles connected to the grid, where $y \leq x$
- $F_{BE}(y)$ = Cost to ES of connecting y PO vehicles to the grid, where $y \leq x$

Concerning (7)-(8), in the postal context it is natural to assume that the margin $P_{FE} - C_{FE}$ would reflect off-peak prices and costs. The fixed cost $F_{BE}(y)$ to connect PO vehicles to the grid for V2G backup and reserve services represents the cost of control devices for bidirectional use of EV batteries for reserves and contingent power. Besides the natural assumption that $F_{BE}(y)$ is increasing in its argument, given the largely dispersed character of PO vehicles, it is likely that these costs will be significant and convex (i.e. connecting a larger fraction of the PO's EVs to the grid will likely be increasingly expensive).²⁶

From the above, and given the existence of monetary transfers among all parties (through the prices the PO pays or receives), any Pareto-efficient solution to the problem of replacing the K vehicles at the present lease period requires the joint maximization of benefits across the three parties, with participation (or individual rationality) constraints determined by existing outside options. Thus, the Pareto-optimal or First-Best problem of choosing the best fleet composition for N can be stated as follows:

$$\text{Maximize } \left\{ \sum_{i \in N} B_i(x, y, P) \mid (x, y, P) \geq 0; y \leq x \leq K; B_i(x, y, P) \geq B_{i0}, i \in N \right\} \quad (9)$$

where B_{i0} represents the value of agent i 's alternative or default option²⁷ and

$$B_i(x, y, P) = R_i(x, y, P) - C_i(x, y, P); \quad i \in N \quad (10)$$

and the price vector P is given by²⁸

²⁶ See section 5 for a detailed discussion of the factors likely to drive the structure of ES connection and control costs for V2G operations.

²⁷ The reader will note that (8) is the standard Pareto condition associated with the Nash Bargaining problem (Nash, 1950) when side payments are possible. Under this condition, the only efficient choice is one that maximizes total net benefits, with the standard Nash solution then determined by choosing transfers among the agents to assure equal payments above their default options. We are not interested here in sorting out the effects of bargaining power and default options, so we will just concern ourselves with the standard Pareto solution.

$$P = (P_{FE}; P_{BE}; P_v = P_{Av}(z) - S_v, v \in \{E, I\}) \quad (11)$$

Concerning P , $P_{Av}(x) - S_v$ represents the NPV of net lease payments per vehicle to AM. Since any of the prices in (11) can be set independently of x and y in the optimization (9), this price vector merely acts to co-determine the total value of the leasing arrangements for $v \in \{E, I\}$ in assuring the satisfaction of the participation constraints in (10),

Rewriting the objective function in (9), using (3)-(8), we obtain:

$$\begin{aligned} \sum_{i \in N} B_i(x, y, P) = & P_C g_E \Delta x - (C_{ME} + C_{OE})x - (C_{MI} + C_{OI})(K - x) \\ & - C_{AE}(D_{AE} + x)x - C_{AI}(K - x) + \Delta(P_{FE} - C_{FE})x + A_{BE}y - F_{BE}(y) \end{aligned} \quad (12)$$

Using the definition $C_{Ov} = \Delta P_{Fv}$, $v \in \{E, I\}$, we can rewrite (12) further as:

$$\begin{aligned} B(x, y) \equiv \sum_{i \in N} B_i(x, y, P) = & P_C g_E \Delta x - (C_{ME} + \Delta C_{FE})x - (C_{MI} + \Delta P_{FI})(K - x) \\ & - C_{AE}(D_{AE} + x)x - C_{AI}(K - x) + A_{BE}y - F_{BE}(y) \end{aligned} \quad (13)$$

which (as noted above) is independent of the inter-agent transfer price vector P . To get a sense of the structure of the Pareto-optimal solution for N , we rewrite $B(x, y)$ as follows:

$$B(x, y) = \alpha x + \beta y + \gamma + f(x) + g(y) \quad (14)$$

where

$$\alpha = P_C g_E \Delta + [(C_{MI} + \Delta P_{FI}) - (C_{ME} + \Delta C_{FE})] + C_{AI} > 0$$

$$\beta = A_{BE} > 0$$

$$\gamma = -(C_{MI} + \Delta P_{FI} + C_{AI})K < 0$$

$$f(x) = -C_{AE}(D_{AE} + x)x$$

$$g(y) = -F_{BE}(y)$$

The fact that $\beta > 0$ follows from the presumed superiority of EVs relative to ICEs in terms of maintenance and operating cost (see section 3 above), so that the expression in $[\cdot]$ is positive. From our assumptions, $f(x)$ is a concave, decreasing function of x . The solution to (9) is found by maximizing (14), subject to the

²⁸ Finally, we assume that the (expected) price of carbon credits P_C and the avoided cost (e.g. of backup reserve power) from using EV battery supplied reserves A_{BE} are both known.

constraint $0 \leq y \leq x \leq K$, and then adjusting prices P to assure that individual rationality constraints are satisfied at the solution found. Of course, this can only be accomplished if the optimal solution (x^*, y^*) to (14) satisfies: $B(x^*, y^*) \geq \sum_{i \in N} B_{i0}$.

There are two regions of interest in the constrained optimization: either $y < x$ and a separable optimization results, given the structure of (14), or $x^* = y^*$. Since $f(x)$ in (14) is concave, and therefore the separable optimization of $f(x) + \alpha x$ over the interval $[0, K]$ occurs at the boundary, it is clear that the optimal solution satisfies the following:

$$\begin{aligned} [x^* > y^* \geq 0] &\square [x^* = K; y^* \square \arg \max_{y \in [0, K]} \{g(y) + \beta y\}] \\ [x^* = y^* \geq 0] &\square [x^* = y^* \square \arg \max_{x \in [0, K]} \{f(x) + g(x) + (\alpha + \beta)x\}] \end{aligned} \quad (15)$$

As an example, assume that the average cost function C_{AE} and the V2G cost function F_{BE} defining $f(x)$ and $g(y)$ above are of the form:

$$C_{AE}(z) = \begin{cases} \frac{F_{AE}}{z} + c_{AE} & \text{for } z > 0 \\ 0 & \text{for } z = 0 \end{cases}; \quad F_{BE}(z) = C_{BE}z \quad (16)$$

with $C_{BE} > 0$ a constant. Then $B(x, y)$ in (14) is concave in both arguments and a boundary solution results under either of the conditions in (15). The result is a bang-bang solution with the optimal solution being either $x^* = y^* = 0$; $y^* = 0 < x^* = K$; or $x^* = y^* = K$. Assuming (16), the optimal solution to (9) is therefore the following:

$$\begin{aligned} [(C_{BE} > A_{BE})] &\square [y^* = 0; x^* = K \chi(B(K, 0) - B(0, 0))] \\ [(C_{BE} \leq A_{BE})] &\square [x^* = y^* = K \chi(B(K, K) - B(0, 0))] \end{aligned} \quad (17)$$

where the indicator function χ is defined as $\chi(z) = 1$ if $z \geq 0$ and else $\chi(z) = 0$. From this, it is straightforward to show from (14) that x^* is increasing (i.e., more likely to be K rather than 0) whenever $\alpha + \beta$ increases or whenever D_{AE} increases or C_{BE} decreases. For example, consider the second of the cases in (18), where $C_{BE} \leq A_{BE}$, so that there are some potential benefits from V2G services. Then the indicated condition on whether $x^* = y^* = K$ (rather than 0) is:

$$[C_{AE}(D_{AE} + K) - C_{AI}] + [C_{BE} - A_{BE}] \leq P_C g_E \Delta + [(C_{MI} + \Delta P_{FI}) - (C_{ME} + \Delta C_{FE})] \quad (17)$$

which is a straightforward comparison of the per vehicle benefits of EVs, when $x^* = y^* = K$, compared to the alternative full replenishment of the K needed vehicles as ICEs. Note that the lhs of (18) is decreasing in D_{AE} , the base number of vehicles sold to operators other than the PO, implying that the constraint (18) will be easier to

satisfy as D_{AE} increases. A similar interpretation is readily apparent for the other terms in (18). All of this comports well with intuition.

In concluding this section, we note that we have not considered risk-related issues or the dynamics of these. Clearly, the actual choice problem faced by the PO and other stakeholders will be affected by the progress of the stochastic processes describing developments in the electricity and fuel markets and in the price of batteries. The appropriate framework for this decision problem is a real options approach. Such an approach can be expected to trigger replenishment of some or all of the PO's newly leased vehicles at each time period as a function of the state variables describing the current and expected evolution of key pricing and cost variables. There may also be additional risk sharing issues arising from concerns with resale prices and the transactions costs of potential losses from fleet operations for the PO. Thus, the problem confronted by a PO in the electrification of its fleet is a dynamic version of the multi-party risk-sharing problem originally analyzed by Karl Borch (1967) in the context of insurance markets.²⁹ While the cost issues analyzed in this section will be important, so too will demand, pricing and EV product design, as we now examine.

5. Discussion, Implications and Future Research

The analysis of section 4 only scratches the surface and indicates the necessity of in-depth modeling to get at the details of how battery price, economies of scale and the structure of EV demand will affect pricing and risk-sharing amongst the stakeholders to the EV fleet transformation problem. At this point, these issues can all be viewed as topics for future research. In this section, we discuss the principal open issues in terms of bilateral interactions and risk sharing between the PO and each of the other three major stakeholders (ES, AM and NG).

Electric Power Costs and Risks (PO and ES)

As noted earlier, the key value-added activities resulting from EVs for electricity supply reside in four general areas, generally listed in increasing order of the difficulty of harvesting these benefits from EV-V2G operations:

1. The ability to smooth daily load by using cheaper off-peak power sources for recharging. Such recharging options can accommodate some level of interruptible supply in the event the system operator needs to curtail aggregate system load. Smoothing load does not require V2G bidirectional flows and can be accomplished with modest additional controls and investments at the distribution level.

²⁹ Since Borch's original exposition in the context of insurance markets, the theory of risk sharing has become central to several fields, including decision analysis (Raiffa, 1967), capital asset pricing theory (Aase, 2002) and principal-agent theory (Laffont and Martimort, 2002).

2. The ability to provide frequency regulation for the grid operator. This does require V2G bidirectional flows and additional controls and investments at both the transmission/grid level and the distribution level. The magnitude and nature of these investments depend in part on the concentration of EVs (e.g., distributed with only a few EVs per charging location vs. larger concentrations of a few hundred EVs in a single aggregate facility such as a parking lot).
3. The ability to provide reserve power (often called “spinning reserve” to emphasize its nearly instantaneous readiness for service). Reserve power will be increasingly important in the future in integrating intermittent renewable energy supplies such as wind and solar power. The key differences between frequency regulation and reserve power are two-fold. Frequency regulation generation is quite small relative to dispatched generation (on the order of 1-2 % in terms of capacity for the regulation vs. dispatch). Reserve power, on the other hand, can be as much as 10% of average dispatched generation (and may grow beyond that in the future). The required reserves to assure system reliability is a problem of considerable complexity and depends on transmission constraints, the size of the largest generating units on line and on the degree of variability of the total intermittent power sources on line.
4. Finally, bidirectional V2G reserves can also provide voltage and reactive power at the local distribution level.

All of the above are possible sources of value from EVs. It can be noted, immediately, however, that assessing this value will be primarily in the hands of the electricity supplier (in particular, the grid operator and the local distribution company). To the extent that such services as generation, reserves, frequency and voltage support are provided in competitive electricity markets, and to the extent that suppliers to end-use customers are also competitive, one can imagine a reasonable price for these services materializing from the market. However, many of the investments required will naturally fall on parts of the electric power system (the transmission grid and local distribution wires and substations) that have natural monopoly characteristics and where services, appropriately, will continue to be organized under regulated monopoly franchises. It is therefore to be expected that it will be some time before regulation can establish the “proper price” for capital recovery for these investments.

Kempton et al. (2009) provide a review of existing literature on the equipment and preconditions necessary for connecting EVs to the grid for reserves and frequency regulation. They note that privately owned EVs, the vast majority of which are driven less than 2 hours a day, would have excellent prospects for providing all of the above value-added features. The situation is a slightly less propitious for PO fleets. First, this is so because contrary to privately owned EVs, PO vehicles would

be available for frequency regulation or reserves off peak (not in the much more valuable peak period). Second, as noted, reserve services will require fairly substantial numbers of EVs to be effective and so are not a likely prospect for the start-up period of EV sales. Thus, it seems likely that the only bidirectional V2G services likely to be important until significant sales of EVs materialize are frequency regulation. However, such services are typically purchased in 1 MW unit contracts, so even these services will require aggregating on the order of several hundred EVs to achieve the necessary capacity to provide frequency regulation services.³⁰ Aggregation will be possible only for a small percentage of a PO's fleet, since PO vehicles are typically located at or near the Post Offices or distribution points from which they pick up their mail for delivery. Of course, information technology can do wonders, so aggregating across distributed locations is also feasible (see Kempton et al., 2009). Nonetheless, the structure of the investment cost function for investments required to control such distributed sources of stored energy vs. more concentrated sources (e.g. larger parking facilities) is an open question. For the near term, it seems that the only sure short-term benefit from EVs for a PO will come from access to cheaper off-peak power. Other benefits could be significant in the medium and longer term, especially in the integration of intermittent renewable energy sources. However, the magnitude of these benefits remains certain and, in any case, will be colored by the control of key investment choices by monopoly suppliers.

EV Costs and Risks (PO and AM)

The central uncertainty associated with the relationship between the PO and AM in the purchase of EVs is focused on two issues:

1. Tooling and initial investment costs for EVs and dynamics of pricing the timing risks associated with reaching minimum optimum scale for annual production and sales;
2. Technological progress with respect to battery technology and pricing of the risks associated with the resale value of EVs at the end of their lease period.

Several approaches are available to unbundle and price these risks. Concerning the first risk, leaving aside the cost of the EV battery, initial investment costs for new vehicle models are well understood in the automobile industry, as are minimum scale requirements for annual production (on the order of 100,000 vehicles per year for a specific model). For sales to POs and other fleet operators (where additional infrastructure costs for recharging stations is not a major concern), the key issue for the AM in setting EV prices in the early years will be the expected sales of EVs for the model(s) in question. Total sales to all participants are a key determinant of efficiency in the analysis in section 4 and can be expected to be a central

³⁰ See Kempton et al. (2009) for a discussion. The calculations there show a reserve capacity, under bidirectional charging and discharging, of roughly 1 MW for every 100 EVs connected to the grid. As noted, taking advantage of batteries for either frequency regulation or reserves, would require additional investments in the distribution system.

determinant of price in meeting AM's threshold return levels. Fleet operators can be expected to cooperate in buying consortia to provide both increases in bargaining power on price as well as to provide AM additional assurance that it will reach minimum scale.³¹

Concerning batteries, there are several non-pricing issues for the question of risk sharing on technological approaches, and these are already in evidence in practice. The first is the unbundling of battery prices/sales/leasing from the chassis. Doing so makes more transparent the better understood costs of tooling and assembly line investments for EVs and leaves room for private companies like Better Place, who provide battery exchange service and infrastructure for both fleets and individual private owners, to compete with unbundled products.³² Synergies in terms of economies of scale with the private market are quite evidently a matter of great interest to companies in the auto sector currently bringing EVs to market (including BMW, Renault/Nissan, Toyota and VW).

Related to this unbundling of batteries and chassis, the AM could itself transfer some of the risk associated with technological change in battery design to the reinsurance or capital market, with a securitized instrument defined on an index of battery price or performance. Such securitized instruments, in the form of Asset Backed Securities, have been in use for some time to finance the initial sale of commercial fleets and to insure the resale value of such fleets.³³ The risks in the case of EV batteries are somewhat mitigated by the fact that even after their 7-8 year useful life in an EV, such batteries can continue to provide significant benefits in Battery to Grid applications, which would group large numbers of these batteries in some convenient location, charge them off-peak and use them for both frequency regulation and reserve power. This central concentration and use of such batteries would not suffer from the problems of distributed EV locations. Thus, the resale of batteries, even after their economic life as motive force for EVs, could be significant and would mitigate the consequences of technological uncertainty for EV batteries. To be sure, the details and value of such unbundled arrangements are yet to be

³¹ In France, this has been occurring through an initiative led by the CEO of La Poste, with the objective to obtain a minimum of 100,000 EVs commitments from public and large private fleet operators. Concerning pricing in the presence of scale effects, it is generally understood that such scale effects and associated learning by doing in technological progress functions will produce lower prices during product introduction to encourage cumulative sales and learning. However, strategic effects from competitive learning can affect this monotonicity, per Fudenberg and Tirole (1983). Furthermore, monotonicity may also not hold when the stochastic elements affect the rate of learning itself, per Mazzola and McCordle (1997). Nonetheless, in the present setting it seems likely that price discounts to encourage commercial fleet buyers to make early purchase commitments will be an important element of the problem.

³² This matter is currently actively being discussed in the context of the Nissan LEAF, one of the EVs for the general market. For details, see <http://earth2tech.com/2010/02/12/nissan-come-get-your-electric-car-in-april-batteries-included/>.

³³ See, e.g. http://www.rcibanque.com/en/grou_historique.html, which describes Renault's financial services offered by RCI Banque. Interesting problems emerge in such risk coverage, as for example the question of the Asset Backed Security underlying Toyota leased vehicles subject to recent recall (see <http://www2.standardandpoors.com/spf/pdf/events/SFArticle1Feb18.pdf>).

made clear in the market place.³⁴

Carbon Costs and Risks (PO and NG)

There are two related sources of value and risk related to carbon costs and sustainability. As an organization with a demanding public mission (the USO), POs worldwide have been subject to increasing pressures to measure the environmental impact of their operations. At La Poste, for example, a management framework and related metrics (e.g., its carbon footprint) for sustainability have been in place since 2006.³⁵ At USPS, Buc et al. (2010) describes current efforts to map the carbon footprint of US mail. These initiatives reflect the importance of sustainability as a central element of strategy for POs. This is arguably one of the pillars on which public trust in POs contributes as an intangible asset to the value of the post and the continuing demand for its products (both its traditional mail products as well as financial services in POs like La Poste that offer these). Thus, the question of EVs for POs must be understood against the background of improved value and image that sustainability initiatives may bring.

The same reputation and image value apply at the country level. In particular, meeting Kyoto objectives arguably contributes to the general perception of the world of a nation's commitment to international sustainability efforts. These are clearly important in Europe and elsewhere, with ministers and government portfolios directly concerned with sustainable development. Partly in support of the objectives for sustainable development, significant subsidies are available in the energy and transport sector to promote renewable energy sources and low-carbon vehicles. On the former issue, see Kleindorfer (2008). On the latter, subsidies per vehicle until 2012 in France are 5,000 Euros or 20% of the sale price, whichever is less, for EVs, a significant incentive for their early adoption.³⁶

Just considering the benefits of CO₂e reductions from EVs, the proper valuation from the NG's perspective of EV-related CO₂e reductions would be to value these at the international price of marginal CO₂e abatement, as determined by the CDM and Joint Implementation (JI) markets. For countries in deficit with respect to their Kyoto targets, except for possible savings in transaction costs, it should be a matter of indifference as to whether they paid the PO this amount as a subsidy and saved themselves the corresponding outlay in the CDM/JI market or allowed the PO to have the EV project certified under JI, with the PO collecting the value of the CO₂e reductions and the country taking credit for these in its national Kyoto Plan. For efficiency, the important thing is to ensure that the PO is paid an amount at the

³⁴ See the note above on the Nissan LEAF, which notes Nissan's interest in the unbundled arrangements for battery sales, motivated in part by the possible end-of-life use of such batteries in banks of reserve storage capacity.

³⁵ According to its published carbon footprint ("Bilan Carbone") La Poste operations in 2008 gave rise to some 470,000 tons of CO₂-e, made up of 266,000 tons from internal transportation and 206,000 from building energy emissions, with an additional 400,000 tons resulting from sub-contractors in trucking transportation.

³⁶ Note, however, that these incentives are also capped at a total number of EVs. Similar subsidies are available in the UK. Need references here on both France and the UK.

margin equal to the international abatement cost, and that no double counting (i.e., certification under JI as well as government subsidies) occurs. Of course, there may be other reasons (such as additional public health benefits of EV use) to provide governmental subsidies, but not for CO₂ abatement.

Accounting and payments for CO_{2e} reductions are considerably murkier in practice than the above simple logic might lead one to believe. First, the process of certifying CO_{2e} reductions (the magnitude of “additionality” offsets relative to business as usual) must be accomplished by a certified registrar. Second, selling these credits requires the services of JI-broker. Third, some countries (e.g., the UK) do not allow JI certificates to be used as offsets in meeting nationally imposed Kyoto targets in covered industries. Fourth, the regulatory landscape and targets beyond 2012 remains to be determined, as Kyoto must be reauthorized for the period 2012. Both countries and market participants who may be interested in using carbon credits to co-finance investments, such as conversion of fleets to EVs, therefore face considerable uncertainty in terms of what targets and standards they will be held to. In light of this, while image and brand value may play a role for both POs and NGOs, JI carbon credits are not likely to play a major role for the near future in the decision to switch to EVs. The key factors underlying this choice will be the initial start-up costs (tooling and assembly lines) for auto makers, the price of batteries, the projected resale values of EVs, and the price of competing energy sources between fossil fuels and electric power.

The picture emerging from this analysis is the need to provide a calibrated model, covering the risks noted above and with enough detail on the real options involved to provide a credible foundation for valuation and the timing of choice. Coupling this real-options approach with demand scenarios for the PO and with non-market drivers such as the subsidies for EVs and the institutional future of Kyoto and the JI process remains the central focus of current research by the authors on the question of EVs for the postal sector.

References

- Aase, K. K. (2002). Perspectives of Risk Sharing. *Scandinavian Actuarial Journal*. No. 2: 73–128.
- ADEME (Agence de l’Environnement et de la Maîtrise de l’Energie) (2009). “Les transports électriques en France: un développement nécessaire sous contraintes,” ADEME et Vous : Stratégie et Etudes, No. 21, Paris.
- Ball, J. (March 1, 2009). Six Products, Six Carbon Footprints. *The Wall Street Journal*.
- Böhringer, C., Koschel, H. and U. Moslener (2008), Efficiency losses from

overlapping economic instruments in European carbon emissions regulation, *Journal of Regulatory Economics*, 33(3), June, 299-317.

Borch, K. H. (1967). The Theory of Risk. *Journal of the Royal Statistical Society, Series B* 29, 432 –453.

Buc, L. C., P. A. Soyka and S. S. Glick (2010). “The Environmental Impacts of the US Mail: Initial Life-cycle Inventory Model and Analysis.” In M. A. Crew and P. R. Kleindorfer (eds), *Heightening Competition in the Postal and Delivery Sector*, Cheltenham, UK: Edward Elgar Publishers.

Crew, M. A., P. R. Kleindorfer and J. I. Campbell, Jr. (eds.), *Handbook of Worldwide Postal Reform*, Edward Elgar, Cheltenham, UK: 2008.

Deane, J. P., B. P. O’Gallachoir and E. J. McKeogh (2010). “Techno-economic review of existing and new pumped hydro energy storage plant”, *Renewable and Sustainable Energy Reviews*, 14(4), pp. 1293-1302.

Drake, D. F., P. R. Kleindorfer and L. N. Van Wassenhove. 2010. “HeidelbergCement: Technology Choice under Carbon Regulation.” INSEAD Case Study.

Durif, F. and C. Julien (2009). “What do we really know about green products? Summary and meta-analysis of 30 years of research”, *International Nonprofit and Social Marketing Conference 2009 – Proceedings*, Victoria University, available at: http://www.insmconference.vu.edu.au/documents/papers/Durif_Julien.pdf.

Eichner, T. and R. Pethig (2009). “CO₂ emissions control with national emissions taxes and an international emissions trading scheme,” *European Economic Review*, 53(6), August, 625-635.

EU (2003): Council Directive 96/61/EC, establishing a scheme for greenhouse gas emission allowance within the community and amending, European Commission, Brussels.

Fudenberg, D. and J. Tirole (1983). “Learning by Doing and Market Performance,” *Bell J. Economics*, Vol. 14, 522-530.

Gravelle, H. (1976). “The Peak Load Problem with Feasible Storage.” *Economic Journal*, 86 (June), 256-77.

IPC (International Post Corporation) (2009). *IPC Strategic Perspectives on Electrical Vehicles*. Brussels.

Kempton, W., V. Udo, K. Huber, K. Komara, S. Letendre, S. Baker, D. Brunner and N. Pearre (2009). "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System." Working Paper, University of Delaware, available at: <http://www.magicconsortium.org/Media/test-v2g-in-pjm-jan09.pdf>

Hogendorn, C. and P. R. Kleindorfer (2008). "The Economics of Renewable Resource Credits", in Morgan Bazilian and Fabien Roques (eds), *Analytical methods for Energy Diversity and Security*, Elsevier Ltd (UK).

Laffont, J-J. and D. Martimort (2002). *The Theory of Incentives: The Principal-Agent Model*, Princeton: Princeton University Press.

Mazzola, J. B. and K. F. McCardle (1997). "The Stochastic Learning Curve: Optimal Production in the Presence of Learning Curve Uncertainty." *Operations Research*, Vol. 45(3), 440-450.

Nash, J. F. Jr. (1950). The Bargaining Problem. *Econometrica*, Vol. 18, pp. 155-162.

Nguyen, D. T. (1976). "The Problems of Peak Loads and Inventories." *Bell Journal of Economics*, 7(1) (Spring), 232-41.

Nieuwenhuis, P., & Wells, P. (1997). *The Death of Motoring?*, Chichester: John Wiley and Sons.

Orsato, R. (2009). *Sustainability Strategies: When Does It Pay to Be Green?* London: Palgrave McMillan.

PostEurop (2010). PostEurop News (Feb, 2010). At: www.posteurop.org/index.jsp

Raiffa, H. (1968). *Decision Analysis: Introductory Lectures on Choices under Uncertainty*. Oxford: Addison-Wesley.

Ravnitzky, M. (2009). "Electric Drive Vehicles for Mail Delivery: Identifying Key Issues," Paper presented at the Rutgers University CRRI 28th Annual Eastern Conference, Skytop, PA, May.

USPS-OIG (United States Postal Service-Office of Inspector General) (2009). "Electrification of Delivery Vehicles." Washington, DC: USPS (August 28). Available at: http://www.uspsoig.gov/foia_files/DA-WP-09-001.pdf

Whitelegg, J. (1993). *Transport for a Sustainable Future: The Case for Europe*, London: Belhaven.

Yergin, D. (1992). *The Prize*, New York: Touchstone Books.

Table 1: PO Transportation Expenditures for 2008*

	La Poste	USPS
Total Number of Vehicles**	45,000	200,000
Number of Mail Collection & Delivery Vehicles that are candidates for switch to EVs**	30,000	142,000
Current Vehicle Expenses	Millions of Euros	Millions of Dollars
Capital and Depreciation	93.6	169.8
Maintenance/Operating Costs	132.9	777.7
Fuel Costs***	68.8	148.3
Total Vehicle Expense	295.3	1,095.8

* The US numbers here come from Ravnitzky (2009) and from the USPS Cost Segment Report for FY 2008, filed with the Postal Regulatory Commission (PRC) on July 1, 2009, with additional input from Dennis Stevens of USPS.

** The corresponding numbers for Deutsche Post AG are 43,400 vehicles in total, of which 30,000 to 35,000 are judged to be possible targets for EV replacement. Source: Michael Tauer, DP Fleet GmbH.

*** The total of maintenance and operating costs at USPS for FY 2008 was \$926.0 Million, which includes costs for all parts and supplies, including fuel.

Table 2: Illustrative Comparison of Electric (EV) and Internal Combustion (ICE) Vehicle Cost and Environmental Performance

	EV	ICE
Purchase Price (€)¹	25,000	10,000
Resale Value at End of Year 5 (€)²	5,000	2,000
Vehicle Expenses (€)³		
Annual Capital Cost	5,225	2,090
Annual Operating Cost	1,029	1,139
Annual Maintenance Cost	1,110	2,221
Total Annualized Vehicle Expense	7,364	5,450
CO2e Emissions (tons/year)⁴	0.0	1.8
Annual Value of CO2e Emission Reductions (€)⁵	54.00	0.0
Other Environmental Benefits	---	---
TOTAL ANNUAL COST/vehicle	7,418	5,450

1. For EVs, a \$40,000 cost per vehicle is used in the USPS-IG (2009). The current market costs are decreasing. The 10,000 Euro figure corresponds roughly to current La Poste conditions.
2. Including battery resale and replacement. This value will depend on the growth of secondary market for EVs and for batteries, both for EV use and for energy storage for V2G services.
3. Capital costs are calculated using straight-depreciation for a five-year period and a 7% cost of capital (as used in USPS-OIG (2009)).
4. The EV number is based on La Poste conditions in which electric power off-peak is essentially carbon free (provided primarily by nuclear). The entry of 1.8 tons/vehicle/year is calculated on the basis of 40 km/route, 6 days/week delivery, 150 g/CO2/km. In the US, where coal generates about 50% of total electric power, including base load power, the EV emissions number would be greater than 0.
5. This is calculated by considering the entire emissions profile of ICEs as avoidable when switching to EVs, with the emission reductions valued at 30 Euros/CO2-te, the expected price of CO2 credits in the 2013-2018 time frame.