# Costs and Benefits of Electric Vehicles
# - A 2010 Perspective


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**Abstract**

This paper undertakes a social cost-benefit analysis regarding an increase in the number of electric vehicles in the Swedish transport sector by year 2010. Battery cars are generally found to be socially unprofitable, even though their private life-cycle costs and external costs are lower than those of petrol cars. One important reason for this is that electric vehicles are heavily 'subsidised' by having, in comparison with taxes on fossil fuel, a very low electricity tax. 'Hybrid' cars are more likely to be socially profitable, especially for city-based delivery trucks, which may be both privately and socially profitable without subsidies.



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## 1. Introduction

Despite their environmental advantages, Electric Vehicles (EVs) are still quite rare, and various ways of supporting them financially are often proposed in public debate. One argument is that even though EVs may not be socially beneficial today, they probably will be tomorrow and that the introduction of EVs is a long process that must start today. The main purpose of this paper is to find out whether it is likely that EVs will be privately and socially profitable in the foreseeable future, and hence indirectly to provide relevant information for policy decisions today. Therefore, we undertake a social cost-benefit analysis (CBA) of different kinds of electric vehicles, including hybrid vehicles and fuel-cell vehicles, in Sweden for the year 2010. Such a project involves large uncertainties, and many simplified assumptions. Nevertheless, we believe that order-of-magnitude estimates, along with a detailed presentation of the assumptions, are valuable from a policy-making perspective.

Considering the role of EVs in public debate about transport and the environment, it is somewhat surprising that, until recently, so few systematic CBAs of EVs have been undertaken. Kazimi (1997a,b), using a micro-simulation model, estimated the environmental benefits of introducing battery-driven electric cars (BCs) in the US. The cost-side was not analysed, but based on her results she judged that large price-reductions of alternative-fuel vehicles would not be socially beneficial. Funk and Rabl (1999) found that the life cycle costs for BCs in Greater Paris (France) were higher than the corresponding costs for gasoline cars, but were lower than the costs for diesel cars. Hahn (1995) discussed the cost-effectiveness of various measures to improve environmental quality in the transport sector. His main conclusion was that tighter air pollution standards and improved fuel qualities were more cost-efficient than, for example, an introduction of BCs. Similarly, Wang (1997) in a survey of American cost-effectiveness studies concluded that zero-emission vehicles were among the least cost-effective alternatives. More recently, Lipman et al. (2000) and Ogden et al. (2001) have presented detailed social-cost estimates of fuel-cell and hybrid vehicles, whereas Delucchi and Lipman (2001), based on damage costs from Delucchi (2000), provides detailed and comprehensive life-cycle cost estimates for BCs, and concluded that battery performance must improve and costs be reduced substantially if BCs were to become competitive.[1]

This study presents less detailed information on the manufacturing and maintenance costs, trying instead to capture reasonable order-of-magnitude estimates of all relevant cost elements while simultaneously highlighting the general-equilibrium-effects of changed tax revenues. This is particularly important in countries with high fuel taxes, as is the case in most European countries. A fairly common view seems to be that although BCs are not *privately* profitable, they are, or will be, *socially* profitable when the external costs are taken into account. However, as will be demonstrated, it may actually be the opposite, i.e. that BCs may become privately profitable (in certain market segments) but socially unprofitable when tax-revenue effects are taken into account, despite the fact that BCs are environmentally superior.

The remainder of this paper is organized as follows: In section 2, the theoretical CBA model is outlined in a stylized general equilibrium model, followed by a presentation and discussion of the large number of assumptions made in section 3. In section 4 the results of the CBA are presented, while Section 5 provides concluding remarks.

## 2. The Cost-Benefit Model

We use a standard cost-benefit model where we are primarily interested in consumer welfare, or utility. Although the standard CB model has been used in numerous applications in the transport sector, some features of the model remain unclear (at least in the Swedish policy debate): (i) How should the correction for changed tax revenues be made and, in particular, should one include value-added taxes (VAT) that are based on other taxes (such as energy taxes or environmental taxes)?[2] (ii) Should one correct for excess-burden effects, and if so how? To deal with these issues we apply a simple representative-individual[3] model with the following utility function:

$$U = u(l, x, c, e, D) \tag{1}$$

[1] Delucchi (2001) is another source of detailed life-cycle cost estimates.
[2] Energy taxes and environmentally related fuel taxes are currently part of the VAT tax base in Sweden.
[3] Hence, we do not deal with distributional aspects explicitly. We believe such effects are relatively minor in this context, but we believe the overall effects of subsidizing private EVs are regressive, since new cars are primarily bought by relatively wealthy people.

where $l$ is leisure, $x$ is a composite good or, put simply, money spent on everything except road transport, $c$ and $e$ are the consumption of conventional and electric-vehicle based road transport, respectively, and $D$ is environmental damage, and where $D = D(C, E)$, $C = \sum_{i=1}^{n} c^i = nc$ and $E = \sum_{i=1}^{n} e^i = ne$. We assume that $u_x > 0, u_c > 0, u_c > 0, u_D < 0,$ where subscripts denote partial derivatives, so that utility increases with increasing consumption of goods and transportation services, and decreases with increasing environmental damage, and that $u$ is strictly quasi-concave in the choice variables to ensure a unique equilibrium. Further, we assume that $D_C > 0, D_E > 0, D_C > D_E$, so that environmental damage increases more per unit of conventional car transport compared to EV transport. For simplicity, we assume that total transport is constant, so that $dC = -dE$. Using this and totally differentiating (1) we can express the overall utility change from marginal changes of $l$, $x$ and $e$.

$$dU = u_l dl + u_x dx + \left(u_e + nu_D D_E - u_c - nu_D D_C\right)de \tag{2}$$

On the production side we assume a linear technology so that $w(\tau - l) = x + q^c c + q^e e$, where $w$ is individual productivity and (exogenous) wage level, $\tau$ is total available time, and $q^c$ and $q^e$ are the production prices of conventional and EV transport respectively. Without loss of generality, the production price of good $x$ is normalized to one. By totally differentiating this function and rearranging, we get

$$dx = -(q^e - q^c)de - w\,dl \tag{3}$$

The individual maximizes utility subject to a budget constraint with consumer prices including taxes, implying the optimal conditions:

$$u_l = w\mu\,;\ u_x = (1 + t^x)\mu\,;\ u_c = (q^c + t^c)\mu\,;\ u_e = (q^e + t^e)\mu \tag{4}$$

where $t^x$, $t^c$ and $t^e$ are the consumption taxes on the respective good, and where $\mu$ is the marginal utility of (net) income. Inserting (3) and (4) into (2), we can write the social Marginal Net Benefit (*MNB*) of replacing conventional cars with EVs as

$$MNB \equiv \frac{dU/de}{\mu} = \left(MD^c - MD^e\right) - \left((t^c - q^c t^x) - (t^e - q^e t^x)\right) - w\frac{dl}{de}(1 + t^x) \tag{5}$$

where $MD^c - MD^e \equiv -\frac{n}{\mu} u_D \left(D_C - D_E\right)$ is the difference in marginal external costs between conventional and electric vehicles, and where we can interpret $t^x$ to be a general consumption tax, or a VAT. Hence, the social net benefit per unit of additional *e*, i.e. electric vehicle based road transport, equals the difference in marginal external cost between conventional cars and electric vehicles, minus the tax-difference net of VAT on the producer price, minus a term related to possible labor-supply changes.

The last term of (5) relates to excess-burden effects, i.e. in addition to direct resource costs, there is an additional cost of raising public revenues since tax increases in an imperfect second-best world causes distortions in the economy. From individual utility maximization we have

$$p^x \frac{\partial u}{\partial l} = w \frac{\partial u}{\partial x} \tag{6}$$

Totally differentiating this for fixed prices implies

$$p^x\left(u_{ll}dl + u_{lx}dx + u_{lc}dc + u_{le}de + u_{lD}dD\right) = w\left(u_{xl}dl + u_{xx}dx + u_{xc}dc + u_{xe}de + u_{xD}dD\right) \tag{7}$$

This can be re-written, applying the same conditions as previously, to obtain

$$\frac{dl}{de} = -\frac{\left(wu_{xx} - p^x u_{lx}\right)\left(q^e - q^c\right) + \left(p^x u_{le} - wu_{xe}\right) + \left(wu_{xc} - p^x u_{lc}\right) + \left(p^x\, u_{lD} - w\, u_{xD}\right)n\frac{\partial D}{\partial E} + \left(w\, u_{xD} - p^x\, u_{lD}\right)n\frac{\partial D}{\partial C}}{p^x u_{ll} + p^x w - wu_{xl} - w^2} \tag{8}$$

If utility is separable in the externality, so that the utility function may be written $U = u(f(l,x,c,e),D)$, we have $p^x\, u_{lD} - w\, u_{xD} = w\, u_{xD} - p^x\, u_{lD} = 0$. Furthermore, if leisure is weakly separable from the consumption goods as follows $U = u(l, g(x,c,e), D)$, then we have $wu_{xx} - p^x u_{lx} = p^x u_{le} - wu_{xe} = wu_{xc} - p^x u_{lc} = 0$. In the special case when utility can be written as $U = u(f(l, g(x,c,e)), D)$, both kinds of separability are fulfilled simultaneously. Substituting both associated conditions into (8) implies that $\frac{dl}{de} = 0$, so that we can disregard excess-burden effects altogether. The separability assumptions imply that environmental damage does not affect consumer choice, and an exogenous change in leisure does not affect the choice between transportation goods and other goods. This is of course restrictive, but it provides a natural benchmark case when dealing with public subsidies. Similar assumptions are often made in the literature (e.g. Bovenberg and DeMooij 1994). It should also be emphasized that the separability assumption does not imply that excess-burden considerations can be neglected generally. Given the assumption it is straightforward to show that an optimal externality-correcting tax (net of indirect taxes) is smaller (larger) than a standard Pigouvian tax if the uncompensated labor-supply elasticity with respect to a proportional income tax is smaller (larger) than zero; see Bovenberg and DeMoiij (1994). Similarly, an optimal investment to decrease environmental damage *D* directly is smaller (or larger) than the one corresponding to the Samuelson (1954) efficiency rule if the uncompensated labour-supply elasticity with respect to a proportional income tax is smaller (larger) than zero; see Atkinson and Stern (1974).

To see the intuition behind the result, consider the (unrealistic) case where a tax increase is used to subsidize *all* goods by a certain percentage. Assuming no transaction costs, this would clearly imply the same relative costs for all goods and leisure as was the case before the change; hence, there should be no correction for excess burden. If only one good is subsidized one would of course not expect to find the same results, since that good may, for example, be more complementary with leisure than other goods. However, it still appears reasonable to take the case of no excess burden as a natural benchmark if one has no other specific information.[4] Consequently, in this study we assume that the public subsidy of electric vehicles does not increase the excess burden. Furthermore, we recommend generally, as a benchmark case, that public subsidies should not be corrected for excess burden. This is contrary to the current practice in Sweden, where a factor equal to 1.3 (denoted "tax-factor 2" in Swedish transport planning) is used to reflect the marginal cost of raising public funds, as well as the marginal cost of public subsidies.

The social marginal net benefit of an increase in the number of electric vehicles can then be written as:

$$MNB = \left(MD^c - MD^e\right) - \left((t^c - q^c t^x) - (t^e - q^e t^x)\right) \equiv \Delta MD - \Delta R \tag{9}$$

[4] Furthermore, in a setting with many non-identical consumers and an optimal non-linear income tax, the work by Christiansen (1981), Boadway and Keen (1993) and Kaplow (1996) implies that correcting for marginal excess burden in public investments can be questioned more generally.

where $\Delta MD$ is the decrease in marginal damage, or external costs, from replacing one conventional vehicle with an EV, and $\Delta R$ is the associated decrease in tax revenues. In other words, the social net benefit of replacing one conventional vehicle with an EV is the difference between the benefit in terms of decreased external costs, and the cost in terms of reduced taxation. The reason differences in private (e.g. vehicle) costs do not enter this expression is that these costs are already taken into account by a rational utility-maximizing consumer.

In the special case where we are in a first-best world, with optimal Pigouvian taxes equal to the marginal damage for both types of vehicles, we find that the social value of such a shift is zero. It follows that changes in tax revenues should include VAT based on specific taxes, but not the "general" VAT based on the production price (or the value added). Once again, this is contrary to the current practice in Sweden. As we will see, changes in tax revenues will constitute a substantial element in the final CBA.

## 3. Assumptions

### *3.1 General Assumptions and Vehicles Analyzed*

The time perspective of this study is the year 2010, for which we analyse the introduction of various EVs. We assume that gasoline and diesel prices, as well as fuel and vehicle taxes, are similar to those of today. These assumptions provide a natural benchmark case, since it is not clear whether it is more or less likely that prices and taxes will increase rather than decrease.

This paper will, contrary to a number of recent studies in this sub-field, rely on conventional CBA methodology and *not* use life-cycle analysis; thus, we do not, for example, take environmental effects in vehicle production into account. This is for three reasons: First, our analysis focuses on the differences between various types of vehicle and since they are quite similar in most respects it is reasonable to expect that the associated environmental differences are fairly limited. Second, even if this is not so, it is still not clear that life-cycle costs theoretically should be taken into account. If these externalities are already internalized through the authorities in the producing country, then taking the same external costs into account again will lead to inefficiencies; this parallels the conclusions from the “small-number” externality case within a country (cf. Coase, 1960). Moreover, even if welfare-improving internalization is not implemented, the responsibility for this can hardly be given to another country. Third, there are huge practical difficulties when obtaining vehicle-type specific emission-estimates, since these vary largely between different countries and regions. Furthermore, it appears likely that emission differences arising from different legal rules *between* countries are much larger than the ones resulting from manufacturing different types of vehicles *within* a country.

For battery cars (BCs), we focus exclusively on small-sized cars, such as the Renault Clio / VW Polo, since the specific features of BCs make larger cars less realistic and attractive (Sperling and Lipman 2000). In order to limit the infrastructure investments needed for these cars, and since the health costs of local emissions are much larger in cities, we assume that all of these BCs are sold in the three major cities in Sweden: Stockholm, Göteborg and Malmö.

There are many types of hybrid vehicles, but they can be divided into two broad categories (i) vehicles using gasoline as their “primary” source of energy and are hence independent of central electricity production, and (ii) vehicles operating as battery vehicles most of the time and therefore use centrally produced electricity as their primary source of energy but also have a combustion engine as an auxiliary engine in order to increase performance and driving distance capacity. In this paper we focus on the former alternative for hybrid passenger cars (HCs), since it appears more likely that they will become socially beneficial. Cars such as Toyota Prius and Honda Insight that are already in the market are indications of this, but there is a fair amount of other evidence as well; see e.g. Harrop and Harrop (1999) and Sperling and Lipman (2000). We discuss two types of HCs: one "mild" and one "advanced" hybrid, where the mild hybrid is a less advanced type which is usually driven by a gasoline engine, and the advanced hybrid (e.g. Toyota Prius or Honda Insight) has a somewhat larger battery and can be driven as a pure BC for shorter distances at a low speed, e.g. in traffic queues. We assume that half of the HCs are sold within the three major cities in Sweden and the other half are sold throughout the rest of the country. In addition, we analyse an introduction of methanol-driven fuel-cell cars (FCCs).

For heavy vehicles, we focus on city-based delivery trucks, which are used in the cities, but not in the countryside. We analyze two types of hybrid diesel trucks (HTs): (i) Trucks using diesel as the "primary" source of energy, and (ii) trucks that can be charged with electricity from the national grid and can be used as a pure battery truck for shorter distances. We assume that both FCCs and HTs are only sold in the three main cities in Sweden.

For each EV introduced, the sale of conventional vehicles is reduced by one unit; implying that the overall size of the car stock does not change with the number of EVs introduced. Further, we assume the same average driving distance for the EVs as the conventional cars they replace. Both of these assumptions simplify the analysis drastically, since we do not have to estimate all external cost elements associated with road traffic, rather only those that differ between vehicle types. For example, we do not have to estimate the external costs of congestion, road wear and tear,[5] barrier effects or accidents, nor the consumer surplus change associated with a changed driving distance.

Even so, it is possible that overall car sales would increase. For example, some previous one-car households might diversify their car holding due to the different characteristics of EVs, and BCs in particular, that make them more attractive for some kinds of trip. Nevertheless, since the costs of such diversification are substantial, and the characteristics of the EVs are not that different from conventional vehicles of a comparable size, we suspect that the overall effect on total sale would be limited.

It is also possible that the average driving distance would be lower than that of the replaced conventional cars. If so, this would tend to bias the environmental benefits upwards. It is not possible to say in which direction this assumption would bias the overall CBA, however, since this depends on factors such as whether the taxes on car traffic today are higher or lower than the socially optimal level. To determine this, we need to value all external costs as well as estimate the spatial distribution of the change in traffic volume.

[5] However, as pointed out by a referee, road wear and tear is a function of the axle weight, which may be higher for EVs. Still, the associated costs are small for passenger cars, and for trucks the increased weight may be partly offset by changed design and construction, e.g. through more axles or a more even weight distribution between the axles (since the relationship between axle weight and damage is highly non-linear, it is mainly the highest axle weight of the vehicle that matters.)

### *3.2 Production and Maintenance Costs*

In a background report to Carlsson and Johansson-Stenman (2000a), Duleep (2000) estimated the costs of the different EVs for 2010. For BCs, characteristics and incremental price are presented in Table 1, where the baseline is a small gasoline car such as a Renault Clio. The comparison is done for two different battery capacities, both of the Nickel-Metal Hydride (NiMH) type. Most analysts seem to believe in this type of battery, considering both performance and manufacturing costs, although the uncertainties are large and possible alternatives include lithium polymer and lithium-ion batteries; see e.g. Lipman (1999) and Sperling and Lipman (2000). We assume that the batteries will last for the lifetime of the car, since the battery technology is expected to improve greatly by 2010 (Duleep 2001, personal communication). Still, that may be somewhat optimistic, in particular for BCs, and the cost of replacing a battery, if needed, is very large (Delucchi and Lipman 2001). We see that both the car's weight and its price increase drastically with battery capacity, and hence with driving range and performance. We therefore concentrate on the low-range vehicle in our economic analysis. For BCs and FCCs, Duleep (2000) assumes that worldwide sales for each model are relatively small, and production is set at 20,000 units per year per model.

(**Table 1** about here)

For HCs and FCCs the baseline for the comparisons presented in Table 2 is a Volvo V70. Controlling for differences in fuel economy and emission characteristics (and possibly reliability and service costs), the market value can be assumed to be about the same, since the cars are assumed to have largely similar characteristics. Duleep (2000) assumes that HCs will be sold worldwide in a significant volume by 2010, and that each hybrid make/model is produced at about 100,000 units per year. Hydrogen-based FCCs are shown only for comparison; we do no believe that they will be a realistic option by 2010.

(**Table 2** about here)

Repair and maintenance costs for EVs are of course difficult to estimate, but careful and detailed estimates are provided by Delucchi and Lipman (2001). They also report cost estimates to enable charging the vehicles at home. From their results one can conclude that the sum of the present value of the estimated repair and maintenance costs, insurance costs, and the costs associated with home charging[6] are quite similar for BCs as for conventional vehicles. Although these estimates are for an American context, it is hard to see why it would be very different in western European countries. It is also difficult to see why there would be any big differences for other kinds of EV; cf. Lave and MacLean (2002). For these reasons, and in order to keep the analysis as simple as possible, we will refrain from explicitly including these cost elements in the CBA.

Table 3 presents the characteristics and prices of hybrid diesel trucks (HTs) and compares them to conventional diesel trucks in 2010. A mild HT refers to a type of truck that is never charged with electricity from the national grid, whereas an advanced HT could be charged from the national grid and be used as a pure battery truck for shorter distances.

(**Table 3** about here)

### *3.3 Central Infrastructure*

The need for investments in infrastructure for BCs has been analysed in a background report to Carlsson and Johansson-Stenman (2000a) by Brännström (2000). According to this report, the introduction of BCs will most likely *not* require investments in the general electricity net (although investments are needed to enable charging of the vehicles, as mentioned). In addition to conventional charging at home, centrally distributed rapid charging stations would largely increase the flexibility and service level, e.g. since the risks associated with a sudden electricity shortage would decrease. Despite the name, rapid charging is still rather slow compared to fuelling a conventional gasoline car, however, and may require almost half an hour (assuming that there is no need to wait in a queue). Brännström (2000) assumed one station per 40 cars,

[6] How large these costs are naturally depends on the specific equipment that is considered necessary. Brännström (2000), for example, presents somewhat higher cost estimates.

distributed in the center of the city, and found the annual cost (including city land rental) to be as high as 855 USD per vehicle per year.[7]

Östman (2000), in another background report, analysed the additional infrastructure costs for methanol, to be used by the FCCs, relative to the corresponding costs for gasoline. The additional distribution costs are largely due to the lower scale compared to gasoline, but also due to the lower energy density of methanol (almost a factor 2 compared to gasoline). He concluded that an additional cost of about 0.12 USD/litre of gasoline-equivalent methanol (or about 0.06 USD/litre of methanol) is a reasonable estimate for the additional costs.

### *3.4 Emission Factors*

The environmental costs associated with different types of vehicle constitute an important part of our analysis. There are two important components: (i) the emissions associated with different vehicles, and (ii) the valuation of these emissions. For gasoline and diesel vehicles we use the estimates of emission factors in Ahlvik et al. (1996). These are estimated average emission factors throughout the lifetime of a car of a certain age based on many sources including decided and planned future emission standards within the EU.

In comparison with conventional vehicles there is little systematic empirical evidence on present or future emission factors for different kinds of hybrid vehicle. Furthermore, what evidence there is, is often based on information from car manufacturers for specific car models (see e.g. Lave and MacLean, 2002). Even so, most seem to agree that hybrid vehicles do have a potential for non-negligible emission reductions. Based on order-of-magnitude discussions with various experts we make the admittedly crude assumptions that the emission factors (except for $CO_2$) of mild and advanced HCs to be 50% and 25%, respectively, compared to the emission factors for gasoline cars. Similarly, we assume the emission factors from mild and advanced HTs to be 50% and 25%,[8] respectively, compared to the emission factors for diesel trucks.

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[7] The exchange rate of 1 USD = 10 SEK is used throughout the paper.

[8] The lower emission factors for advanced HCs and HTs should be seen as "effective" reductions, given that vehicles can be used as pure battery vehicles for shorter distances, where the emissions are particularly damaging. The advanced HT can in addition be grid-charged, for which we assume no local emissions.

$CO_2$ emissions from all vehicles are directly proportional to the fossil content of the fuel used,[9] and the emission factors used in the calculations are presented in Table 4.

(**Table 4** about here)

### *3.5 Emissions from Electricity Production*

In terms of emissions, what consequences will arise from an additional kWh of electricity? Within the kind of international deregulated electricity market that has developed in the northern part of Europe, marginal electricity production comes from fossil , whereas production from hydropower and nuclear power plants is fixed.[10] Furthermore, environmental effects are independent of where the $CO_2$ emissions occur. If the governmental objective is to reduce the impact of $CO_2$ emissions globally, rather than to reduce $CO_2$ emissions from Sweden, it follows that the external costs of $CO_2$ emissions should be based on electricity production from fossil fuels.[11] We assume, maybe somewhat optimistically, that marginal electricity production by 2010 will be based on natural gas, rather than coal or oil.

However, one could also argue that the main objective of the Swedish policy on greenhouse gases is not to reduce $CO_2$ emissions worldwide, but rather to reduce such emissions in Sweden, since Sweden, along with other countries, has signed international reduction agreements that it would like to comply with for the lowest possible cost. If this is the social objective, no $CO_2$ costs from imported electricity production should be included. Since the "true" underlying objective is difficult to obtain we present the results for both cases. Perhaps the most realistic assumption, however, is that the Swedish government does care about global emissions, but cares even more about emissions in Sweden, implying an intermediate case between the two cases presented. We ignore emissions from imported electricity for the same reasons because we do not perform life-cycle analysis of vehicle production.

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[9] The fossil fuel content per energy unit differs, however, among the fuels as follows: Gasoline, 260 g/kWh; Diesel (or oil), 271 g/kWh; Coal, 326 g/kWh; and Natural gas, 202 g/kWh.

[10] They are fixed annually, hence they are independent of whether electricity demand increases or decreases by 5%, for example. However, they will vary greatly during the year, mainly due to the seasonal characteristics of hydropower.

[11] To base the costs on some kind of average electricity production, as is often proposed, would clearly be incorrect.

### *3.6 Energy Efficiency, Prices and Taxes*

Table 5 reports our assumptions regarding energy use for different types of vehicle, again largely in accordance with Duleep (2000). In order to facilitate comparisons, we report fuel consumption in different units. The electricity consumption per km for a BC is highly uncertain, but we rely on the assumptions made in Duleep (2000). For HCs, gasoline is always used as their primary source of energy. Since the gasoline engine can be utilized more efficiently in a hybrid vehicle, e.g. since it can be optimized for a smaller range in terms of RPM, energy consumption is lower than in conventional gasoline cars. For conventional diesel and hybrid trucks we use the estimates in Duleep (2000), and we assume that the advanced HT uses diesel as its primary source of energy for 85% of the driving distance and electricity for the remaining 15%.

(**Table 5** about here)

We assume that fixed real fuel prices per litre are equal to 0.9 USD (including VAT) for gasoline, 0.96 USD (including VAT) for methanol, and 0.5 USD (excluding VAT) for diesel.[12] The fuel-tax levels, including VAT, for the year 2000 are 0.55375 USD/litre of gasoline, and 0.3325 USD per litre of diesel. The Electricity tax, including VAT, is 0.019 USD/kWh.

### *3.7 Environmental Shadow Prices*

We use the official values for transport infrastructure investments in Sweden, as recommended by SIKA (2000), to evaluate local and regional environmental effects. This is presented in Table 6 below. [13]

(**Table 6** about here)

The values recommended by SIKA are, like virtually all environmental shadow values, highly uncertain. However, many international estimates of local environmental costs are of the same order of magnitude; see e.g. Carlsson and Johansson-Stenman (2000b),

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[12] This is lower than the regular price at fuel stations, since all users of heavy vehicles have large rebates.

[13] There is no reported shadow value for $SO_x$, presumably due to the fact that almost all diesel sold in Sweden is of a high quality, with a very low sulfur content (<10 ppm).

Greene et al. (1997), Maddison et al. (1996), Mayeres et al. (1996), and Small and Kazimi (1993). A recent comprehensive study on health effects by McCubbin and Delucchi (1999) estimates local environmental costs of different types of emission. The SIKA values for VOC and particles are larger than these values, but the US values for $NO_X$ are generally higher.

The damage cost of $CO_2$ emissions is even more uncertain, and scientifically reported cost estimates include values from about 10 USD/ton of C (Nordhaus, 1994) up to 600 USD/ton C (Azar and Sterner, 1996), where the latter study used the same underlying scientific assumption but different assumptions on distributional consequences and (in particular) discount rates. In addition, there is great uncertainty about the underlying meteorological mechanisms, and the associated impacts on human welfare, both now and in the future. At the same time, Sweden, along with other countries, is spending its limited resources on combating $CO_2$ emissions in order to fulfil international agreements, and possibly for other reasons too. A good proxy for the associated shadow price is the household tax level, which is about 200 USD/ton of C (0.53 SEK/kg $CO_2$). Given that the tax level is set optimally, based on the governmental objectives (whatever they are), then this number reflects the social value per unit of $CO_2$ reduction. Therefore we use the tax level as an estimate of the external costs of $CO_2$ emissions in this study. It is also often used in other applications as a shadow price of $CO_2$ emissions in Sweden, despite the fact that it is not directly based on any $CO_2$ damage-cost estimates. It should be noted though that the value used is higher than most damage-cost estimates, and it is also higher than the 100 USD/ton of C estimate used by Ogden et al. (2001), which was based on the cost of achieving “deep reductions” in $CO_2$ emissions at coal power plants.

We follow the standard assumption of the literature regarding linear dose-response functions. This assumption may imply an overestimation of marginal environmental costs at concentration levels lower than today’s levels if the "true" marginal environmental costs are increasing slightly with the concentration levels, or if threshold levels exist. On the other hand, it is possible that other associated environmental and health risks will be identified in the future, which will correspondingly imply higher future environmental shadow values.

There are few available estimates of the marginal external cost of noise for different vehicles, but we know that most EVs are less noisy than gasoline and diesel vehicles. In order to have a simple measure of the marginal external cost of noise per passenger per kilometre we take the results for Sweden given by SIKA (2000) as a point of departure. They present crude marginal cost estimates of 0.07 USD/10 km for conventional cars and 0.47 USD/10 km for heavy trucks in cities. These estimates are of the same order of magnitude as the "high-cost case" presented in Delucchi and Hsu (1998), but are substantially higher than their "base case" and "low-cost case." For obvious reasons, even less is known about the external cost of noise from non-conventional vehicles. Still, based on the above numbers, we make the assumptions presented in Table 7. In addition, we take into account the fact that tyre-noise dominates engine-noise at higher speeds, implying that the percentage reductions are larger in city traffic. Further, the values reflect that we assume that BCs are driven only in the larger cities, whereas we assume that HTs are driven in different kinds of city, but not in the countryside.

Occasionally it has been argued that there is a negative side effect of quieter vehicles in terms of decreased safety, since silent vehicles are more difficult to detect. On the other hand, one can argue that noise makes it more difficult to concentrate and to communicate with other people, such as children, and hence that safety could improve by lowering the general noise levels. In the lack of clear evidence regarding this point we assume that the net effect is zero, i.e. we do not include any possible indirect effects on safety.

## 4. Cost-Benefit Analysis

### *4.1 External Costs per Distance Unit*

Given our assumptions, we calculate the environmental cost per distance unit for each vehicle type, and the results are reported in Table 7. We present the results only for the biggest city (Stockholm) and for the average of the rest of Sweden, although different values for a number of cities are used in the final CBA. In the case where marginal electricity production is assumed not to produce any external costs, the environmental costs for EVs are zero. BCs generally have the lowest environmental costs, as expected. We see that the external environmental costs for gasoline passenger cars are quite small for those made in 2010, which is a reflection of the expected rapid reduction of emissions; see Table 4. Even though BCs, HCs and FCCs produce even lower local and regional emissions, the cost difference in absolute terms is relatively small.

(**Table 7** about here)

Diesel truck emissions do not decrease as drastically by 2010 as gasoline passenger car emissions. The local environmental costs, particularly in larger cities, are substantial, largely due to particulate emissions, but also due to noise pollution.

### *4.2 CBA Results*

One of the most difficult components in producing a CBA on EVs is the road-users' valuation of the EV *per se*. For example, apart from the effects on their personal budget, do most car-buyers prefer hybrid vehicles or gasoline vehicles? Theoretically, an individual will choose an EV rather than a gasoline car when $WTP + \Delta PV > 0$, where *WTP* is the additional willingness to pay for having an EV instead of a conventional car, given an equal financial budget between the two. $\Delta PV$ is the present value of the additional cost of having an EV; that is, the present value of the EV price differential (including private infrastructure costs) minus fuel cost savings. To avoid having to calculate the *WTP*, we will calculate backwards the critical level of *WTP* at which the EV becomes privately profitable. From a social perspective, the most important issue is whether or not EVs should be subsidized, and if so, by how much. Below we calculate the socially optimal EV subsidy for each vehicle type. By doing this we do not intend to argue in favour of subsidies as a suitable policy instrument. Rather, we believe that there are other, more suitable, policy instruments, such as differentiated road-pricing (Johansson-Stenman 1999), especially in a long-term perspective. Even so, the values give an indication of the degree to which it is socially profitable to subsidize such vehicles.

(**Table 8** about here)

Table 8 shows that BCs are actually financially profitable, in the sense that the expected lifetime cost of a BC is lower than that of a corresponding gasoline car. This does not imply that many passenger car buyers will find BCs attractive, however, since many crucial characteristics differ, such as acceleration and engine power, driving range and battery charging time. Indeed, the recent literature on the choice among different types of vehicle indicates that BCs must be substantially cheaper than gasoline cars in order to obtain a non-negligible market share (Brownstone et al. 2000, Brownstone and Train 1999, and Ewing and Sarigöllü 1998).[14] However these are American studies, and it is difficult to use them in a Swedish setting since, for example, the Swedish and the American fuel-prices differ dramatically. Nevertheless, it appears reasonable that most buyers of a small new car in Sweden would also prefer a conventional car, despite the additional financial life-cycle costs. Still, the financial analysis indicates that specific niches might exist where BCs will be considered attractive.

In either case, private profitability may differ substantially from social profitability. Since the external costs associated with BCs are lower than those of gasoline vehicles, one would perhaps expect that their social profitability would be better than their private profitability. However, it turns out that this is not the case. This is because governmental tax revenues over the life cycle of a vehicle decrease greatly when replacing a conventional car with a BC. This reflects the fact that, compared with conventional vehicles, electric vehicles are already heavily "subsidized" through the relatively low electricity tax (as compared with fuel taxes). This is a social cost element that is often overlooked in the current discussions on policy. In addition, the difference in external costs is typically much smaller than the difference in taxes. Indeed, according to the results, every switch from a conventional car to a BC will imply a net present value cost to the rest of society equal to almost 4,000 USD. Despite this we have continued to use the questionable assumption that electricity production causes no external costs. The possibility of publicly provided rapid charging would further amplify the social costs of BCs. This would imply a social cost per car of about 10,000 USD.[15] Consequently, we can conclude that it appears very unlikely that an introduction of BCs through public subsidies would be socially profitable.

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[14] These studies are based on stated-preference data, except Brownstone et al. (2000) which use both stated and revealed preference data.
[15] Presumably, the *WTP* for a BC would increase due to such possibilities, but hardly of this order of magnitude.

Mild and advanced HCs are more promising from a social point of view, although the calculations show that there is no motivation for subsidising here either. Whether or not these vehicles are privately profitable depends on the willingness to pay for driving alternative fuel vehicles, which would be at least 900 and 1,500 USD for the mild and advanced HCs respectively. Since these vehicles have characteristics similar to those of conventional gasoline cars, the additional *WTP* for an HC reflects a *WTP* for a more environmentally friendly car. It is possible that a non-negligible fraction of new car buyers, including companies, would be willing to pay an environmental premium of this size in order to signal environmental awareness or social responsibility, for example.

Neither FCC seems to be privately profitable. In addition, since methanol cannot be expected to be supplied outside large cities, at least not in a consumer friendly way, the private *WTP* in favour of a conventional vehicle may be large, implying that a sizeable subsidy may be needed to sell FCCs in significant quantities. Furthermore, there is no reason to subsidise FCCs either. However, in a longer time perspective, hydro-powered FCCs with greater energy efficiency will be possible. The vehicle cost will then also be lower since no transformer will be needed.

Despite worse environmental performance with respect to local and regional pollutants, the less advanced HT is socially more profitable than the advanced HT.[16] Interestingly, this type of truck is more profitable than conventional diesel trucks. The present value of the social net cost of replacing one diesel truck is 21,850 USD. It should be noted that an important part of social profitability is the reduction in external noise cost. To a large extent this is due to our assumption that HTs are mainly driven in city centres. The less advanced type of truck is also profitable for the consumer, while the more advanced HT is only privately profitable if the associated *WTP* is sufficiently high.

## 5. Discussion and Conclusions

One purpose of this paper was to shed light on the question of whether governments should financially promote the introduction of EVs by, for example, subsidizing them. The conclusion is negative for most types of passenger car, at least on a large scale. One

[16] Note that we only report the results for marginal electricity production from fossil fuels, since the difference between the two cases is very small.

reason is the, often substantial, loss in tax revenue that the government would face if a consumer switches to an EV.

The perspective is different for city-based hybrid delivery trucks, which appear socially profitable by 2010, even though this conclusion is sensitive to the assumptions made. Since these trucks use diesel as their primary fuel, there are no large social "transition costs" of adapting HTs, and there is no particular infrastructure needed.

Further, these HTs are also likely to be privately profitable, due to improved fuel economy, implying that no (or only small) social subsidies would be needed. We focused our analysis of heavy vehicles on city-based delivery trucks, rather than on city buses, since the latter may need additional climate control equipment.[17] Nevertheless, much of the analysis is valid for city buses as well.

The results rest generally on a large number of crucial assumptions, some of which are rather uncertain. For example, future emission levels of passenger cars as well as of trucks are of course uncertain, as is technological development in general. If there were an unforeseen breakthrough in battery technology, which would largely improve performance, then we could certainly not rule out BCs. Similarly, if the development of diesel trucks were better than we assume with respect to noise, fuel economy and particle emissions, then the profitability of HTs will correspondingly decrease, or possibly disappear. The same applies to the assumed valuations of noise and $CO_2$, which are, in comparison with other studies, on the high side On the other hand, the epidemiological knowledge of the health effects are still quite limited, and it is possible that new relations implying higher damages than assumed today will be obtained in the future. Equally, the reverse outcome from increased knowledge cannot be excluded either.

The profitability of FCCs is largely reduced by the fact that a distribution system for hydrogen was not considered realistic in a 10-year perspective. The use of methanol leads both to more costly cars, since a reformer is needed, and to lower energy efficiency. Even so, it is possible (and perhaps likely) that a widespread hydrogen distribution system will never be designed. However, there are other alternatives besides

[17] This was the motivation by Duleep (2000, personal communication) for why hybrid delivery trucks may be more promising than city-buses. However, Sperling and Lipman (2000) argue for a high potential for city-buses. Even so, they do not seem to compare these with city-based delivery trucks, but rather with trucks in general. See Schimek (2001) for social cost estimates of hybrid buses.

methanol, and there are even discussions about using gasoline in the fuel cells, but a reformer is still needed to make hydrogen. The major advantage of using gasoline as a substitute for methanol is the existing widespread distribution system. In addition, the gasoline itself may in the future be cheaper than the quality of gasoline that we currently use because no octane-increasing additions would be needed since there would be no combustion. One disadvantage is that energy efficiency will achieve the potential energy efficiency that the technology itself permits, but it could still be better than conventional gasoline or diesel engines, It could also be a virtually zero emission vehicle from a local and regional point of view. Furthermore, the reformer need not be in the vehicles: it would be possible to have large-scale reformers at fuel stations so that the cars will still be driven on hydrogen. Nevertheless there remain non-negligible technological difficulties and unsolved questions.

Even though the uncertainties involved are large, a number of conclusions and insights appear fairly solid. First, compared to conventional gasoline passenger cars, BCs simply do not seem to be socially profitable, unless an unanticipated major breakthrough in battery technology takes place. Second, there are a number of other EVs that *may* be socially profitable, including various kinds of HCs, HTs and FCCs. However, since the *private* profitability in most cases seems to be of a similar order of magnitude as the *social* profitability, there is no clear case for public subsidies here either.

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**Table 1**. Characteristics and incremental price for a small BC relative to a comparable size gasoline car by year 2010. Source: Duleep (2000).

| | Low range | High range |
|---|---|---|
| Weight | 830 | 1720 |
| Drag coefficient | 0.28 | 0.28 |
| Energy efficiency (kWh/km) | 0.11 | 0.23 |
| Motor power (kW) | 41.5 | 81 |
| Battery wt. (kg) | 225 | 775 |
| Battery size (kWh) | 16.9 | 58 |
| Range to 20% dod | 120 | 200 |
| Units produced per year | 20,000 | 20,000 |
| Expected life length (years)* | 17 | 17 |
| Annual driving distance (km) * | 15,000 | 15,000 |
| Incremental price (over small car), USD | 6406 | 22686 |

* Own assumptions

**Table 2**. Characteristics and incremental price (2000 USD) for HCs and FCCs relative to a comparable Volvo V70 gasoline car. Source: Duleep (2000).

| | 2000 base | 2010 conventional | 2010 mild hybrid | 2010 adv. Hybrid | 2010 hydrogen fuel-cell | 2010 methanol fuel-cell |
|---|---|---|---|---|---|---|
| Weight | 1430 | 1290 | 1320 | 1340 | 1376 | 1340 |
| Engine type | 2.5L I-5 | 2.5L I-4 | 1.8L I-4 | 1.6L I-4 | Fuel cell | Fuel cell |
| Combustion | Homog. | GDI | Homog. | Atkinson | Hydrogen | MeOH reformer |
| Motor power (kw) | 121 | 112 | 90 | 70 | 70 | 75 |
| Elec. Motor | None | None | 12 kW | 30 kW peak | 70 kW | 75 kW |
| City FC (L/100 km) | 10.60 | 8.0 | 6.5 | 5.34 | 2.89 | 3.93 |
| Highway FC | 6.44 | 5.3 | 5.2 | 4.80 | 2.70** | 3.59*** |
| Composite FC | 8.72 | 6.8 | 5.95 | 5.10 | 2.80** | 3.78*** |
| Battery | - | - | 1 kW-HR, 12 kW | 2.5 kW-HR, 30 kW | | |
| Units produced per year | | | 100,000 | 100,000 | 20,000 | 20,000 |
| Expected life length (years)* | 17 | 17 | 17 | 17 | 17 | 17 |
| Annual driving distance (km) * | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 |
| Additional costs, USD | Base case | 805 | 2197 | 4225 | 4845 | 6568 |

* Own assumptions
** Ignoring energy losses when producing the hydrogen; see table 5 below.
*** Ignoring energy losses when producing the methanol; see table 5 below.

**Table 3**. Characteristics and incremental price (2000 USD) for conventional and hybrid trucks. Source: Duleep (2000).

| | Conventional diesel | Mild hybrid truck<br>Parallel hybrid<br>Not grid chargeable | Advanced hybrid truck<br>Series hybrid<br>Grid chargeable |
|---|---|---|---|
| Gross weight (tons) | 12 | 12 | 12 |
| Payload (tons) | 6.5 | 6.5 | 6.2 |
| Engine power | 165 kW @ 2200 | 125 kW @ 2800 | 125 kW @ 2800 |
| Engine type | 6 L I-6 diesel | 4 L I-4 diesel | 4 L I-4 diesel |
| Elec. Motor | None | 40 kW peak | 125 kW continuous |
| Generator | None | None | 90 kW |
| Battery | None | 6 kWh, 40 kW | 12 kWh, 80 kW |
| Pure BC range | None | None | 12 to 15 km city |
| Fuel cons. (L/100km) | 28 | 18.5 | 20.2 |
| Units produced per year | | 2,000** | 2,000** |
| Expected life length (years)* | 17 | 17 | 17 |
| Annual driving distance (km)* | 30,000 | 30,000 | 30,000 |
| Additional costs, USD | Base case | 7575 | 28270 |

* Own assumptions

** The batteries and other components are assumed to be produced at a large scale.

**Table 4**. Estimated emission factors for vehicles of different vintages. Sources: Ahlvik et al. (1996) and own calculations, assumptions in text.

| Year | *VOC g/km* | *$NO_x$ g/km* | *Pm mg/km* |
|---|---|---|---|
| | Passenger cars, gasoline | | |
| 1996 | 0.89 | 0.26 | 13 |
| 2010 | 0.08 | 0.04 | 1.2 |
| | Passenger cars, gasoline (city) | | |
| 1996 | 1.87 | 0.34 | 7 |
| 2010 | 0.17 | 0.05 | 1.2 |
| | Passenger cars, mild gasoline hybrid | | |
| 1996 | 0.45 | 0.13 | 6.5 |
| 2010 | 0.04 | 0.02 | 0.6 |
| | Passengers cars, advanced gasoline hybrid | | |
| 1996 | 0.225 | 0.07 | 3.25 |
| 2010 | 0.02 | 0.01 | 0.3 |
| | Diesel trucks | | |
| 1996 | 0.72 | 9.7 | 200 |
| 2010 | 0.30 | 4.9 | 100 |
| | Mild hybrid trucks | | |
| 1996 | 0.36 | 4.85 | 100 |
| 2010 | 0.15 | 2.45 | 50 |
| | Advanced hybrid trucks | | |
| 1996 | 0.15 | 2.04 | 21 |
| 2010 | 0.06 | 1.03 | 10.5 |

**Table 5**. Estimated energy use per distance unit expressed in different units. Composite fuel driving cycle assumed except for small vehicles and trucks where a city-based driving cycle is assumed.

| | Gasoline eq. l/10km | Diesel eq. l/10km | kWh/km |
|---|---|---|---|
| Gasoline passenger car* | 0.67 | 0.61 | 0.59 |
| Battery car (low range), electricity from grid | 0.13 | 0.12 | 0.11 |
| Battery car (low range) in terms of fossil natural gas energy* | 0.25 | 0.23 | 0.22 |
| Battery car (high range), electricity from grid | 0.27 | 0.24 | 0.23 |
| Battery car (high range) in terms of fossil natural gas energy** | 0.52 | 0.47 | 0.46 |
| Mild hybrid gasoline car | 0.59 | 0.53 | 0.52 |
| Advanced hybrid gasoline car | 0.51 | 0.46 | 0.44 |
| Fuel cell car, Methanol | 0.38 | 0.34 | 0.33 |
| Fuel cell car, Methanol including methanol production*** | 0.54 | 0.49 | 0.47 |
| Fuel cell car, Hydro energy | 0.28 | 0.25 | 0.24 |
| Fuel cell car, Hydro energy including hydrogen production**** | 0.33 | 0.29 | 0.28 |
| Diesel truck | 3.10 | 2.80 | 2.70 |
| Mild hybrid truck | 2.05 | 1.85 | 1.79 |
| Advanced hybrid truck, pure diesel mode | 2.24 | 2.02 | 1.95 |
| Advanced hybrid truck, 15% electricity (0.5 kWh/km) | 1.99 | 1.79 | 1.73 |
| Advanced hybrid truck, 15% electricity in terms of fossil natural gas | 2.07 | 1.87 | 1.80 |

* The same values are used for smaller cars, which are compared with battery cars, as for bigger cars that are compared with hybrid and fuel cell cars. The reason is that the smaller cars are only driven in bigger cities, implying higher fuel consumption *per se*.

** Based on 50% energy efficiency from natural gas power production and 7% distribution losses.

*** Based on 70% energy efficiency from natural gas (Katofsky, 1993).

**** Based on 85% energy efficiency from natural gas (Johansson and Åman, 1999).

**Table 6**. Local environmental costs per kilogram emissions in Sweden for different regions. Source: SIKA (2000).

| | *Regional costs (USD/kg)* | | *Local health costs (USD/kg)* | | |
|---|---|---|---|---|---|
| | *VOC* | *$NO_x$* | *VOC* | *$NO_x$* | *Particles* |
| Average Stockholm | 3 | 6 | 4.1 | 4.9 | 690 |
| Average rest of Sweden | 3 | 6 | 1.5 | 4.9 | 260 |

**Table 7**. Estimated external environmental costs for different EVs in USD / 10 km.

| | Local Env. Costs | Regional Env. Costs | $CO_2$ Costs | Noise | Total |
|---|---|---|---|---|---|
| | | | Gasoline passenger cars | | |
| Stockholm | 0.018 | 0.008 | 0.082 | 0.07 | 0.178 |
| Avg. Sweden small cities | 0.008 | 0.008 | 0.082 | 0.02 | 0.119 |
| | | | Battery cars, $CO_2$ from electricity production excluded | | |
| Stockholm | 0 | 0 | 0 | 0.03 | 0.030 |
| | | | Battery cars, $CO_2$ from electricity production included | | |
| Stockholm | 0 | 0 | 0.024 | 0.03 | 0.054 |
| | | | Fuel cell cars | | |
| Stockholm | | | 0.051 | 0.04 | 0.091 |
| | | | Mild hybrid cars | | |
| Stockholm | 0.007 | 0.002 | 0.073 | 0.06 | 0.142 |
| Avg. Sweden small cities | 0.003 | 0.002 | 0.073 | 0.018 | 0.096 |
| | | | Advanced hybrid cars | | |
| Stockholm | 0.003 | 0.001 | 0.062 | 0.05 | 0.117 |
| Avg. Sweden small cities | 0.002 | 0.001 | 0.062 | 0.016 | 0.067 |
| | | | Diesel trucks | | |
| Stockholm | 0.528 | 0.137 | 0.394 | 0.5 | 1.558 |
| Avg. Sweden small cities | 0.267 | 0.137 | 0.394 | 0.3 | 1.098 |
| | | | Mild hybrid trucks | | |
| Stockholm | 0.264 | 0.068 | 0.260 | 0.30 | 0.892 |
| Avg. Sweden small cities | 0.134 | 0.068 | 0.260 | 0.18 | 0.642 |
| | | | Advanced hybrid trucks, $CO_2$ from elect. production excluded | | |
| Stockholm | 0.111 | 0.030 | 0.242 | 0.25 | 0.633 |
| Avg. Sweden small cities | 0.056 | 0.030 | 0.242 | 0.15 | 0.478 |
| | | | Advanced hybrid trucks, $CO_2$ from elect. production included | | |
| Stockholm | 0.111 | 0.030 | 0.257 | 0.25 | 0.649 |
| Avg. Sweden small cities | 0.056 | 0.030 | 0.257 | 0.15 | 0.494 |

**Table 8**. Present value of costs and benefits in 1000 USD per car. Real discount rate 4% per year.

| | Battery car $CO_2$ from electricity production excluded | Battery car $CO_2$ from electricity production included | Mild hybrid car | Advanced hybrid car | Fuel-cell car | Mild hybrid truck | Advanced hybrid truck |
|---|---|---|---|---|---|---|---|
| | | | Private calculation | | | | |
| Incremental price | - 6.40 | - 6.40 | - 2.20 | - 4.23 | -6.57 | - 7.58 | - 28.27 |
| Cost saving fuel | 10.24 | 10.24 | 1.28 | 2.68 | 3.52 | 17.34 | 19.74 |
| Required WTP for private profitability | - 3.84 | - 3.84 | 0.92 | 1.54 | 3.05 | - 9.76 | 8.50 |
| | | | Social calculation | | | | |
| Environ. benefit | 2.95 | 2.73 | 0.53 | 1.02 | 1.56 | 23.62 | 32.12 |
| Tax revenues | - 6.41 | - 6.41 | - 0.79 | - 1.65 | - 2.98 | - 11.53 | - 12.62 |
| Motivated electric-vehicle subsidy | - 3.46 | - 3.68 | - 0.26 | - 0.63 | - 1.42 | 12.09 | 19.05 |