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ECONOMIC RISK OF USE OF VARIOUS ELECTRIC VEHICLES IN THE SERBIAN TRANSPORT SECTOR

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Abstract: *This paper presents an economic analysis of different introduction strategies, as well as different elements thereof, for different kinds of electric vehicles, including hybrid vehicles. A cost-benefit analysis is a tool for comparing effects, positive and negative, of different activities or projects. A cost-benefit analysis is undertaken for increasing the number of various kinds of hybrid vehicles in the Serbian transport sector. We use a standard cost-benefit model where we are fundamentally interested in consumer welfare, or utility. Utility depends positively on both consumption of transport services and other goods, as well as on environmental quality. Hence, people are willing to sacrifice consumption, to a certain extent, for improving environmental quality, and since environmental quality is linked (negatively) to emissions, they are willing to pay for reduced emissions as well. It is found that, although the local and regional environmental costs will decrease, this is generally not profitable for purely (battery) electric passenger cars. We also found that hybrid cars which are not grid-chargeable, i.e. that have a relatively small battery pack, appears to be much more promising, and it is possible that such cars may even be privately profitable in 10 years perspective, due to their high fuel efficiency and modest additional production costs. We have also analyzed city-based hybrid delivery trucks and a hybrid bus, which seem to have an even larger potential profit.*

Key words: *risk economic, cost-benefit analysis, electric vehicles, hybrid vehicles, consumer surplus*

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1. INTRODUCTION

In this paper we will focus on two types of EVs: battery electric vehicles (BEVs) and hybrid vehicles (HVs). There are in practice many types of HVs which can be broadly categorized into two main types of HVs: hybrid gasoline vehicles (HGVs), which use gasoline as the “primary” energy, and hence are independent of central electricity production, and hybrid battery vehicles (HBVs), used as a battery electric vehicles (BEVs) most of the time, which also largely use centrally produced electricity as primary energy and have a combustion engine as an auxiliary engine in order to increase performance and driving distance. We will focus on HGVs since it is more likely that they will become socially beneficial. Furthermore, from the perspective of car manufacturers, there seems to be much more activity on HGVs compared to HBVs. Cars such as Toyota Prius and Honda Insight that have already been placed on the market are indications of this. Also, we will analyze city-based hybrid delivery trucks and a hybrid bus.

The purpose of this paper is to shed some light on a more fundamental question: Is it profitable for population in Serbia to use various kinds of EVs? Cost-benefit analysis (CBA) is a tool for comparing effects, both positive and negative, of electric vehicles. To be able to make a comparison between different effects it is convenient to calculate all the effects in monetary units. Doing this requires simplifications, simplifications that can be more or less strong. It is important to be aware of the simplifications and to discuss these so that we could easily perceive the results/benefits of their usage.

Considering the important role of electric vehicles in transport and their environment impact in most industrialized countries, it is somewhat surprising that few CBA have been undertaken. Kazimi [1], [2], using a micro-simulation model estimated the environmental benefits of introducing more pure EVs, or battery electric vehicles in the USA, but no policy conclusion could be offered since the cost side was not analyzed. Funk and Rabl [3] undertook a CBA for BEVs in France. However, it considers the environmental effects of average, and not marginal, electricity production. This may not always be a major problem, but in France it seems to be, since the dominating bulk of all electricity is produced by nuclear power which does not produce any air pollution problems. The marginal production, on the other hand, is based on some kind of fossil energy. This situation is very similar to that in Serbia. Hahn [4] discussed the cost-effectiveness of various measures in the transport sector to improve environmental quality. The main conclusion was that tighter air pollution standards and improved fuel qualities, rather than e.g. introduction of BEVs, appeared to be the most cost-efficient measures. Similarly, Wang [5], in a survey of other American cost-effectiveness studies concluded that zero-emission vehicles were among the least cost-effective measures. However, these studies did not consider the fact that BEVs may largely be driven in cities, where the social value of reduced emission is higher than elsewhere.

2. THE THEORETICAL COST-BENEFIT MODEL

We will use a standard cost-benefit model where we are fundamentally interested in consumer welfare, or utility. Utility depends positively on both consumption of transport services and other goods, as well as on environmental quality. Hence, people are willing to sacrifice consumption, to a certain extent, for improving environmental quality, and since

environmental quality is linked (negatively) to emissions, they are willing to pay for reduced emissions as well.
As is common, we will disregard possible distributional welfare effects. Not because we consider these to be unimportant per se (see e.g. [6], Johansson-Stenman), but because they are believed to be relatively minor (relatively poor people cannot afford to buy new cars anyway).
The theoretical cost-benefit model for introducing various kinds of EVs in the Serbian transport sector (table 1).

Table 1 The theoretical cost-benefit model [7]

Social costs	Social benefit
increased expenditure on infrastructure	reduction of air pollution
reduction of consumer surplus (CS)	reduction cost for health care
	reduction cost of damage to flora and fauna
	increase the comfort of living in major cities
	increase consumer surplus (CS)

3. Basic Information

3.1. Production costs for different vehicles

For BEVs, characteristics and incremental price are presented in Table 2; the baseline is a small gasoline car (Fiat Punto size). The comparison is undertaken for two different battery capacities, where both are of Nickel-Metal Hydride (NiMH) type. We see directly that both the car weight and price increase drastically with battery capacity, and hence with driving range and performance.

Table 2 Characteristics and incremental price for BEV, compared to a comparable gasoline car, [7]

Characteristics BEV	Low range	High range
Weight, kg	830	1720
Motor power, kW	41.5	81
Battery weight, kg	225	775
Battery size, kWh	16.9	58
Refuel rate, h	4	6
Range to 20% dod, km	120	200
Incremental price, EUR	14180	26420

For HGVs, characteristics and incremental price are presented in Table 3; for the comparisons is instead a Fiat Grande Punto.

Table 3 Characteristics and incremental price for HGVs compared to a comparable gasoline car, [7]

Characteristics cars	Conventional car	Mild hybrid	Advanced hybrid
Weight, kg	1290	1320	1340
Test weight, kg	1418	1475	1475
Engine type	2.5L I-4	1.8L I-4	1.6L I-4
Motor power, kW	112	90	70
Elec. motor, kW	None	12	30
Transmission	5-spd man.	5-spd man.	Elect. CVT
Axle ratio	3.73	3.27	3.27
Fuel cons., l/100 km	6.8	5.1	4.3
Battery	-	1 kWh, 12 kW	2.5 kWh, 30 kW
Incremental price, EUR	Base	3800	5560

Table 4 presents the characteristics and prices for hybrid diesel trucks (HDTs), compared to conventional diesel trucks.

Table 4 Characteristics and incremental price for hybrid diesel truck, compared to a comparable diesel truck, [7]

Characteristics trucks	Conventional trucks	HDTs mild hybrid	HDTs advanced hybrid
Gross weight, tons	12	12	12
Payload, tons	6.5	6.5	6.2
Engine power, kW	165	125	125
Engine type	6L I-6 diesel	4L I-4 diesel	4L I-4 diesel
Elec. motor, kW	None	40	125
Generator, kW	None	None	90
Battery	None	6 kWh, 40 kW	12 kWh, 80 kW
Pure BEV range	None	None	12 to 15 km
Fuel cons., l/100 km	28	22.5	20.2
Incremental price, EUR	base	7575	28270

Table 5 presents the characteristics and prices for hybrid diesel bus (HDBs), compared to conventional diesel bus.

Table 5 Characteristics and incremental price for hybrid diesel bus, compared to a comparable diesel bus, [7]

Characteristics bus	Conventional bus	HDBs mild hybrid	HDBs advanced hybrid
Gross weight, tons	17	17	17
Payload, tons	12.2	12.2	12.2
Engine power, kW	170	130	130
Engine type	6L I-6 diesel	4L I-4 diesel	4L I-4 diesel
Elec. motor, kW	None	40	130
Generator, kW	None	None	90
Battery	None	7 kWh, 40 kW	14 kWh, 80 kW
Pure BEV range	None	None	15 to 20 km
Fuel cons., l/100 km	29	23,5	21
Incremental price, EUR	Base	7665	28890

3.2. The costs of infrastructure

The cost of infrastructure could be important, especially when the costs have to be covered by a small amount of cars. The use of BEVs will require investments in infrastructure. Introduction of BEVs will probably not imply that there is a need for investments in the general electricity net. Instead, the investments for charging the vehicles are needed. There are two types of charging analyzed:

- conventional (slow) charging (at home), and
- rapid charging (one station per 40 cars, distributed in the city-centre).

The latter possibility turns out to be very expensive, even though the service level obviously increases since the risk of a sudden electricity shortage decreases. It should be noted, however, that rapid charging is fairly slow compared to fuelling of gasoline and may require almost half an hour. If, for instance, there are two cars in front of you in the line, this can obviously be very time consuming. It is therefore not at all obvious that such public investments are motivated, and we will present results with and without rapid charging. The average infrastructure costs for slow charging is 82 EUR per vehicle and for rapid charging 855 EUR per vehicle.

3.3. Emission factors

The environmental costs associated with different types of vehicles constitute an important part of our analysis. There are two important components: the emissions associated with different vehicles, and the valuation of these emissions.

For the emission factors in case of gasoline vehicles we use the study by Sudarević et al. [8]. These are average emission factors, during the lifetime of a car, based on many sources including decided and planned future emission standards within the EU. The factors such as increasing emission with vehicle age and cold-start effects are also accounted for.

Emission factors for HGVs are 50% of the emission factors for gasoline cars (except for CO_2 where emissions are about 75% of the emission factors for gasoline cars) [8]. Table 6 presents emission factors for vehicles.

Table 6 Emission factors for vehicles, [8]

Different vehicles	VOC, g/km	NO_x, g/km	Particles-PM, mg/km
Gasoline cars	0.38	0.08	5
HGV (mild)	0.19	0.04	2.6
HGV (advanced)	0.1	0.02	1.3
Trucks diesel	0.3	4.9	100
Bus diesel	0.32	5.1	100

BEVs do not produce any local or regional emissions. The important question here is what consequences in terms of emissions that an additional kWh electricity produced will cause (or, rather, the emissions that are caused by the additional electricity production due to BEVs), and not the average consequences incurred by all the electricity currently produced. There are three different kinds of electricity production:

1. Clean non-fossil production. There are no external costs from electricity production.
2. Clean fossil production. The electricity is produced by fossil fuel (natural gas).
3. Fossil production. The electricity is produced by fossil fuel (coal).

We argue that the third alternative is in principle the most reasonable in Serbian, and that the first alternative should be viewed as an extreme case.

3.4. Noise costs

Unfortunately, very little has been done to estimate the external noise cost per km for different vehicles, under varying circumstances. Still, we know that EVs, and hybrid vehicles, are less noisy than gasoline and diesel vehicles, and ignoring these differences would obviously bias the CBA. Table 7 presents noise costs from different vehicles.

Table 7 Noise costs from different vehicles, EUR/100 km, [9]

Different vehicles	External cost, EUR/100 km
Gasoline cars	0.6
BEV	0.1
HBV	0.2
HGV (mild and advanced)	0.4
Diesel truck	6
HDT (mild and advanced)	3
Diesel bus	6
HDB (mild and advanced)	3

It is sometimes argued that there are negative side effects of quiter vehicles, since it would be more difficult to discover them, and hence safety could be jeopardized. On the other hand, one could also argue that noise makes it more difficult to concentrate, and to communicate with other people, such as children, and hence that safety could be improve by lowering the noise levels. In the lack of clear evidence on this point we do not include any possible indirect effects on safety.

3.5. Willingness to pay for non-conventional vehicles

One important part of the possibility and effects of an introduction of non-conventional vehicles is the consumers maximum willingness to pay (WTP) for these vehicles, and the corresponding effects on consumer welfare. There are several differences between standard vehicles and non-conventional vehicles, and these differences will of course affect the WTP.

In September 2014, fuel price in Serbia was 1.3 EUR/l for the gasoline/diesel, whereas the electricity price was 0.1 EUR/kWh. Table 8 presents consumer surplus (CS) for passenger non-conventional cars. We use the data by Maddison D. et al. [10]: life-length of 15 years for all vehicles, and an average driving distance of 15000 kilometres per year.

Table 8 Consumer surplus (CS) for passenger non-conventional cars, EUR

Different passenger cars	Cost saving	Incremental price	CS (cost saving - incremental price)
BEV (low range)	$(6.8\cdot1.3 - 44.8\cdot0.1)\cdot150\cdot15 = 9810$	–14180	–4370
BEV (high range)	$(6.8\cdot1.3 - 65.4\cdot0.1)\cdot150\cdot15 = 5175$	–26420	–21245
HGV (mild)	$(6.8 - 5.1)\cdot1.3\cdot150\cdot15 = 4972$	–3800	1172
HGV (advanced)	$(6.8 - 4.3)\cdot1.3\cdot150\cdot15 = 7312$	–5560	1752

4. Cost-benefit Analysis

4.1. External costs per distance unit

Given the discussion above we can calculate the environmental cost per 100 km for different types of vehicles. BEVs have in general lower environmental costs, as expected (table 9). We also see that the regional environmental costs from electricity production are non-negligible but smaller than the corresponding regional environmental costs from gasoline cars.

Table 9 Environmental benefit of replacing a passenger gasoline car, EUR/100 km, [5]

	Gasoline cars	BEV (low range)	BEV (high range)	HGV (mild)	HGV (advanced)
Local environmental costs	0.18	-	-	0.07	0.03
Regional environmental costs	0.08	0.05	0.04	0.02	0.01
Base CO_2	0.59	0.17	0.16	0.52	0.45
High CO_2	2.34	0.67	0.66	2.05	1.77
Noise	0.6	0.1	0.1	0.4	0.4
Environmental costs base CO_2	1.45	0.32	0.3	1.01	0.89
Environmental costs high CO_2	3.2	0.82	0.8	2.54	2.21
Net benefit of replacing a gasoline car (base CO_2)	Base	1.13	1.15	0.44	0.56
Net benefit of replacing a gasoline car (high CO_2)	Base	2.38	2.4	0.66	0.99

Local environmental costs for trucks and buses are substantial, particularly in larger cities mainly due to particulate emissions and noise (tables 10 and 11).

Table 10 Environmental benefit of replacing a diesel truck, EUR/100 km, [11]

	Diesel truck	HDT (mild)	HDT (advanced)
Local environmental costs	5.28	2.23	2.2
Regional environmental costs	1.37	0.58	0.59
Base CO_2	2.82	1.86	1.75
High CO_2	11.14	7.36	6.85
Noise	6	3	3
Environmental costs base CO_2	15.47	7.67	7.54
Environmental costs high CO_2	23.79	13.17	12.64
Net benefit of replacing a gasoline car (base CO_2)	Base	7.8	10.62
Net benefit of replacing a gasoline car (high CO_2)	Base	7.93	11.15

Table 11 Environmental benefit of replacing a diesel bus, EUR/100 km, [11]

	Diesel bus	HDB (mild)	HDB (advanced)
Local environmental costs	5.28	2.23	2.18
Regional environmental costs	1.37	0.58	0.56
Base CO_2	2.83	1.88	1.82
High CO_2	11.15	7.38	6.92
Noise	6	3	3
Environmental costs base CO_2	15.48	7.69	7.56
Environmental costs high CO_2	23.8	13.19	12.66
Net benefit of replacing a gasoline car (base CO_2)	Base	7.79	10.61
Net benefit of replacing a gasoline car (high CO_2)	Base	7.92	11.14

4.2. Full cost-benefit analysis

In addition to the cost and benefit components included in the last sub-section, we include here the consumer surplus (CS) and infrastructure investments needed. The results are reported in tables 12-18.

Table 12 Annual social net benefit of replacing a gasoline passenger car by a BEV, EUR

BEV (low range)			
		Low CO_2	High CO_2
Environmental benefit		1.13·150·15 = 2542	2.38·150·15 = 5355
CS – consumer surplus		– 4370	– 4370
Infrastructure	No rapid charge	– 82	– 82
	Rapid charge	– 855	– 855
Total	No rapid charge	– 1909	903
	Rapid charge	– 2682	130
BEV (high range)			
		Low CO_2	High CO_2
Environmental benefit		1.15·150·15 = 2587	2.40·150·15 = 5400
CS – consumer surplus		– 21245	– 21245
Infrastructure	No rapid charge	– 82	– 82
	Rapid charge	– 855	– 855
Total	No rapid charge	– 18739	– 15927
	Rapid charge	– 19512	– 16700

From table 12 we see that BEVs are socially very unprofitable in all cases except from the case BEV (low range) with the extreme assumptions of a high valuation of CO_2 emissions. We can also see that rapid charging appears to be very expensive and constitute a large part of the social deficit.

Hybrid vehicles, on the other hand, are much more promising (tables 13 and 14). We see that mild HGVs (table 13), which will never be driven as a pure BEV, and advanced HGVs (table 14) which will be powered as a pure BEV below a certain speed (e.g. 15 km/h) are profitable.

Table 13 Annual social net benefit of replacing a gasoline car by HGVs (mild), EUR

	Low CO_2	High CO_2
Environmental benefit	0.44·150·15 = 990	0.66·150·15 = 1485
CS – consumer surplus	969	969
Total	1959	2454

Table 14 Annual social net benefit of replacing a gasoline car by a HGVs (advanced), EUR

	Low CO_2	High CO_2
Environmental benefit	0.56·150·15 = 1260	0.99·150·15 = 2228
CS – consumer surplus	1172	1172
Total	2432	3400

Tables 15 and 16 provide the results for hybrid trucks, of which the advanced type is possible to grid-charge, and hence is possible to use as a pure BEV truck for shorter distances. Nevertheless, despite better environmental performances with respect to local and regional pollutants, the mild HDT is profitable.

Table 15 Annual social net benefit of replacing a diesel truck by a HDT (mild), EUR

	Low CO_2	High CO_2
Environmental benefit	7.8·300·15 = 35100	10.62·300·15 = 47790
CS – consumer surplus	24600	24600
Total	59700	72390

Table 16 Annual social net benefit of replacing a diesel truck by a HDT (advanced), EUR

	Low CO_2	High CO_2
Environmental benefit	7.93·300·15 = 35685	11.15·300·15 = 50175
CS – consumer surplus	17360	17360
Total	53045	67535

Tables 17 and 18 provide the results for hybrid bus.

Table 17 Annual social net benefit of replacing a diesel bus by a HDB (mild), EUR

	Low CO_2	High CO_2
Environmental benefit	7.79·300·15 = 35055	10.61·300·15 = 47745
CS – consumer surplus	24510	24510
Total	59565	72255

Table 18 Annual social net benefit of replacing a diesel bus by a HDB (advanced), EUR

	Low CO_2	High CO_2
Environmental benefit	7.92·300·15 = 35640	11.14·300·15 = 50130
CS – consumer surplus	17910	17910
Total	53550	68040

5. CONCLUSIONS

There are a number of conclusions or insights. First, compared to conventional gasoline passenger cars, BEVs seem simply not to be profitable, unless an unanticipated major breakthrough in battery technology takes place. Obviously, if there happens to be a surprising technological breakthrough in battery technology, which would largely improve performance at a much lower cost, then we would certainly not rule out BEVs. Second, there are a number of other EVs that appear to be much more promising from a social point of view, including various kinds of HGVs, HDTs and HDBs. We also found that hybrid cars which are not grid-chargeable, i.e. that have a relatively small battery pack, due to their high fuel efficiency and modest additional production costs. Third, that the environmental costs increase drastically for the larger CO_2 valuation in big cities. Finally, it is not obvious that hybrid EVs will need subsidies to be sold. Indeed, the private profitability seems in most cases to be of a similar order of magnitude compared to the social profitability, which is largely due to the relative advantage in fuel economy.

There are also issues worth reflecting on, which are normally not part of a conventional CBA, but which may nevertheless be important from a social welfare point of view. For example, technological path dependency is obviously a crucial phenomenon in the history of car and particularly engine development. Indeed, if we started from the very beginning of each possible technology today, it seems very unlikely that such an odd and complicated technology such as Otto-engine would even be considered a reasonable option. Still, we do not start from scratch, and billions of dollars have been put into the development of this peculiar technology. Hence, trying to affect the path to an overall more beneficial one by "creating the market" for EVs seems very difficult, and it is possible that some policy makers have been overly optimistic in this respect. Still, there is of course a social value of knowledge with respect to different technologies etc, e.g. since we do not know which technologies will survive and develop in a few decade perspectives.

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EKONOMSKI RIZIK KORIŠĆENJA RAZLIČITIH VRSTA VOZILA U SRPSKOM TRANSPORTNOM SEKTORU

U radu je prikazata cost-benefit analiza upotrebe različitih vrsta električnih vozila uljučujući i hibridna vozila. Cost–benefit analiza predstavlja polazni element u donošenju odluke o primeni nekog projekta i predstavlja metod kojim se vrednuju i porede elementi projekta u smislu troškova i koristi. U konkretnom slučaju cost-benefit analiza se odnosi na sagledavanje opravdanosti upotrebe električnih i hibridnih vozila u transportnom sistemu Republike Srbije. Primenjeni standardni metod CBA, sa stanovišta koristi potrošača ukazuje da su potrošači spremni da u izvesnoj meri podnesu troškove smanjenja emisije polutanata u cilju poboljšanja kvaliteta životne sredine i okruženja, naročito u urbanim sredinama. Sa druge strane totalni prelazak na električn pogon nije u potpunosti društveno profitabilan zbog velikih benefita koje društvo ostvaruje kroz zahvatanja iz komercijalnih fosilbih goriva. Trba istaći i mnogobrojne poteškoće u implementaciji pojedinih tehničkih rešenja vezanih za električna i hibridna vozila koja ih znatno ograničavaju u odnosu na konvencionalna, a koja se ogledaju u ceni, ograničenom radijusu kretanja i veku trajanja baterija – punjača, lošoj infrastrukturi za punjenje akumulatora, performansama vozila itd. Jedan od naj važnijih elemenata je i element stvaranja tržišta i prihvatljive cene, a što nije uvek u odgovarajućoj srazmeri sa strategijama razvoja energetike, tehnološkog napretka i očekivanja na polju zaštite životne sredine.

Ključne reči*: ekonomski rizik, kost-benefit analiza, električna vozila, hibridna vozila, potrošački višak*