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Abstract:
This study investigates whether biofuel policies or favourable taxation of electric cars should be employed to satisfy a green house gas emission target connected to private transport within the Norwegian economy. The study shows that implementation of biofuel generates a welfare gain in the presence of the current favourable taxation of electric cars in Norway. Implementation of biofuels, however, generates a welfare loss when the tax rate on purchase of electric cars is increased to the average tax rate on purchase of diesel powered cars.

Keywords: Biofuel, Mandates, electric cars, Greeen house gas emissions

JEL classification: Q54, R48, H23

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Sammendrag

En rekke land har innført påbud om at bensin og diesel skal inneholde en viss andel biodrivstoff. I Norge er det i dag et krav om at biodrivstoff skal utgjøre minst 3.5 prosent av det totale drivstoffsalget. I litteraturen diskuteres det om slike påbud er et ledd i en effektiv klimapolitikk. Denne studien bidrar til å belyse om slike påbud er samfunnsøkonomisk effektive når man tar hensyn til at myndighetene alternativt kan stimulere fremveksten av elbiler.

I analysen innføres det et krav om at 10 prosent av alt fossilt drivstoff i Norge erstattes av biodrivstoff. Samtidig økes skatten på kjøp av utslippsfrie elbiler slik at det totale utslippet av klimagasser holdes uendret. Analysen viser at en slik biodrivstoff-reform øker velferden når utskifting av fossilt drivstoff med biodrivstoff antas å halvere utslippet av klimagasser, og kostnadene ved å produsere biodrivstoff antas å være dobbelt så høye som produsentprisen på fossilt drivstoff. Årsaken er at velferdsgevinsten forbundet med substitusjon fra lavt beskattede elbiler til høyt beskattede konvensjonelle biler overgår velferdskostnaden forbundet med at drivstoffkostnadene øker. Hvis derimot utslippet av klimagasser per liter biodrivstoff overstiger 80 prosent av utslippet fra fossilt drivstoff, eller den gunstige initiale beskatningen av elbiler i Norge fjernes, så vil et slikt biodrivstoff-tiltak medfører et velferdstap. Årsaken er at velferdsgevinsten forbundet med substitusjon fra elbiler til konvensjonelle biler reduseres. Fjernes ekstra kostnadene ved å produsere biodrivstoff blir dette velferdstapet imidlertid marginalt.

Analysen fokuserer på de langsiktige effektene av å innføre et biodrivstoff-påbud. Det er stor usikkerhet forbundet med de framtidige produksjonskostnadene og utslippseffektene av å innføre biodrivstoff. Det gjennomføres sensitivitetstester for å avdekke betydningen av denne usikkerheten. Det langsiktige fokuset innebærer også at analysen ekskluderer momenter som er relevant for elbilens rolle i dagens samfunn. I analysen er det blant annet antatt at eksisterende gunstige ordninger forbundet med bruk av elbiler, som kjøring i kollektivfeltet, gratis parkering og lading, samt fritak fra å betale bompenger, blir faset ut.

1. Introduction

It has proven difficult to lower green house gas (GHG) emissions generated by road transport. General climate policy measures are expected to have a modest impact on the transition towards more climate friendly cars, see Devogelaer and Gusbin (2010). Governments in several countries have, however, implemented additional policy measures to boost the transition towards climate friendly cars. A range of countries have introduced biofuel policies which have contributed to boost the consumption of biofuels, se Sorda et al (2010). Alternative policy measures, capable of lowering GHG emissions from private transport at a lower welfare cost may however render biofuel mandates undesirable. One alternative is to offer tax exemptions and other benefits connected to purchases of electric cars. Several countries have introduced tax incentives to stimulate a transition to electric cars, the European Automobile Manufacturers' Association (2010). The literature on biofuels have however neglected to consider the welfare impact of biofuel mandates when subsidies/ tax exemptions for electric cars is an option for the government. This study contributes to the literature by shedding light on this issue.

A number of studies have analysed the welfare impacts of biofuel mandates and the interaction with taxes and subsidies for fuels. Lapan and Moschini (2012) find that mandates are equivalent to a tax on fuels combined with a subsidy on biofuel. They also show that mandates dominate biofuel subsidies with respect to welfare in a second best framework where taxation of fuel is restricted, and that combining fuel taxes with mandates would be welfare enhancing. This result reflect that mandates influence terms of trade effects for imported oil and exported corn, as well as the environment. The largest economic gain to the U.S. economy from such energy policies arise from terms of trade gains connected to a lower import price for oil, see Cui et al. (2010). De Gorter and Just (2009) find that biofuel tax credits reduce fuel prices. If tax credits are implemented alongside mandates, then tax credits subsidise fuel consumption instead of biofuels. This contributes to increase oil dependency, CO2 emissions and traffic congestion, while providing little benefit to producers of corn and ethanol. The subsequent social costs will be substantial. Lawrence (2010) argues that biofuel mandates are implemented because of political pressure even though such policies can not be justified on efficiency grounds. Indeed, mandates do not seem to fit into an optimal tax system. The literature on optimal environmental taxation argues that taxes should be levied on goods that generate external damage, see Sandmo (1975), Bovenberg (1999) and Jacobs and de Mooij (2011). De Gorter and Just (2010), however, investigate combinations of policies and find that a US biofuel mandate is welfare enhancing, especially when the fuel tax is suboptimal[1]. These studies, however, do not consider

[1] The benefits of a mandate can easily be eradicated if mandates are used in conjunction with biofuel subsidies.

welfare effects of mandates in the presence of policy options which stimulate a transition towards electric cars. Tax exemptions on purchase of electric cars might lower GHG emissions at a lower welfare cost, and hence, render biofuel mandates undesirable. Tax exemptions on electric cars are in many cases levied on both purchase of the car and the electricity/ fuel. The present study considers both of these tax exemptions. Electric cars are likely to become stronger substitutes to petrol and diesel powered cars in the future. This feature is likely to increase distortions, and hence, the welfare cost of tax exemption, see Bjertnæs (2013) and Hatta and Haltiwanger (1986). Cars which run on different types of fuels are treated as strong substitutes within an empirically tractable model framework in the present study. Terms of trade effects are however excluded by the small open economy assumption.

Biofuel mandates exempt biofuels from the market test which unveils whether consumer's willingness to pay for biofuel exceeds the production cost of biofuels. The welfare impact of mandates becomes more complex in the absence of this market test. This aspect is absent from most studies of biofuel mandates and taxation even though the literature support this assumption, see Hahn and Cecot (2009), de Gorter and Tsur (2010) and Eggert et al. (2011). One may also question whether implementation of biofuels contributes to lower consumption of fossil fuel at all. Greaker et al. (2012) find that a renewable fuel standard which resembles a mandate will have beneficial climate effects even when fossil fuels are treated as a non-renewable resource. The climate cost may even decline as global extraction of fossil fuels is postponed. A tax on emission is however found to be more efficient than the fuel standard. The present study contributes to the literature by analysing the welfare impact of mandates which are exempted from the market test. The study adopts the common assumption that a mandate replaces fossil fuel with biofuel, and that the supply curve for this mixed fuel is horizontal. Several sensitivity tests are conducted to take account of the uncertainty connected to the future production cost and emissions reduction of implementing biofuel mandates.

The analyzes is conducted within a model developed to study Norwegian households choice of different types of conventional and climate friendly cars, se Bjertnæs et al. (2011). The Norwegian case is interesting because Norway is the only country in the world with a sizable stock of electric cars, see Green car (2012)[2]. Substantial tax exemptions for electric cars in Norway have contributed to this transition towards electric cars, see Econ (2009), Rasmussen (2011) and Bjertnæs et al. (2011). This has made it possible to calibrate the model to this stock of electric cars, with current tax

[2]The number of electric cars per inhabitant in Norway is substantially larger than the number of electric car per inhabitant in any other country in the world.

exemptions implemented. The choice between costly second generation biofuels and current Norwegian tax exemptions for electric cars is, however, not obvious as Bjertnæs (2013) show that such tax exemptions are costly. The policy reforms analysed consists of replacing 10 percent of the fossil fuel with biofuel within a model framework where emission of green house gasses is fixed. The emission target for the transport sector is implemented to represent the goal of a cleaner transport sector. This target simplify the efficiency consideration of policy tools, as emission reductions of implementing the mandate is neutralized by an increase in emissions due to less favourable taxation of electric cars. Note however that emissions from production of electricity, production of cars, and extraction and refining of fossil fuels are excluded from the model framework to take account of leakage due to the EU ETS and to focus on the trade off between mandates and cars powered by clean electricity[3]. Model simulations shows that the welfare effect of implementing a mandate for blending biofuel is positive when the present tax rate on purchase of electric cars equals 8 percent, the producer price of biofuel is twice as large as the producer price of fossil fuel, and emissions from one litre biofuel equals half of the emission from burning one litre fossil fuel. The welfare gain connected to substitution from electric cars towards petrol and diesel powered cars, exceeds the welfare loss connected to the cost increase due to implementation of costly biofuels. This results is however sensitive to assumptions about the emission intensity of biofuels. The welfare effect becomes negative when the net emission per litre of biofuels exceeds 80 percent of the emission per litre of fossil fuel. The main explanation is that implementation of biofuels leads to less substitution from electric to petrol/ diesel cars. The welfare effect of implementing a mandate for blending biofuel becomes negative when the initial tax rate on purchase of electric cars equals 84 percent. The main reason is that the tax wedge between conventional cars and electric cars is reduced. Hence, welfare gains connected to substitution from electric to conventional cars is also reduced. Model simulations shows that the welfare is unaffected by a mandate when the producer price of biofuel equals the producer price of fossil fuel, and the initial tax rate on purchase of electric cars equals 84 percent.

The background and policy scenarios are presented in section 2. The model is presented in section 3. Results and welfare effects are analysed in section 4. Section 5 concludes.

[3] The Norwegian transport sector is excluded from the current EU quota market, EU ETS, while other emission intensive sectors are included. Emission reductions within sectors included in the EU ETS generates equivalent increases in emissions in other participating sectors. Emission reductions within the transport sector, however, are not hampered with this leakage problem.

2. Background and policy reforms

Biofuels provides 2-3 percent of the worlds fuels for road transport in 2010, IEA (2011a). The United States and Brazil are the world's largest producers of ethanol. The EU is the largest producer of bio diesel. The literature on GHG emission reduction indicates that emission reduction connected to first generation biofuels is modest or even negative, see Searchinger et al. (2008) and Crutzen et al (2008). Second generation biofuels have a grater potential to lower GHG emissions. The future cost of producing second generation biofuel is however large and uncertain. Different types of biomass and conversion technologies results in cost estimates from 0,8 to 1,97 USD/ litre gasoline equivalent according to Eggert et al (2011). Econ (2008) estimate a cost ranging from 7,4-10 NOK/ litre for bio-diesel, and 8,5-11,3 NOK/ litre for bio-ethanol. Hence, the potential cost is approximately twice as large as the current producer price of fossil fuel. The direct cost of replacing one litre fossil fuel with one litre biofuel amounts to approximately 5 NOK in this case. Assuming for illustrational purposes that this leads to an emission reduction equivalent to burning one litre fossil fuel implies that the cost of such emission reductions amounts to 2159 NOK/ ton for petrol and 1878 NOK/ ton for diesel. These costs by far exceed estimates of the social cost of carbon reported by US EPA.

A number of industrialised countries have also introduced subsidies for purchase of electric cars and hybrid vehicles, European Automobile Manufacturers' Association (2010). Gasoline and diesel are heavily taxed, while consumption of electricity is more gently taxed in most industrialised countries, Eurostat (2007). Purchase and use of electric cars is thus gently taxed in a number of industrialised countries compared with the purchase and use of petrol and diesel powered cars. The incentive to purchase an electric car is particularly generous in Norway. This contributes to explain why the number of electric cars per inhabitant sold in Norway by far exceeded the number of electric cars per inhabitant sold in any other country in the world in 2011, see Green car (2012). There are approximately 10.000 electricity powered cars in Norway as of 2013. Table 1 presents tax rates on purchase of cars and fuels within the Norwegian tax system. These tax rates are incorporated into the reference scenario. The tax rates are calculated as a percentage of the producer price, and contain all indirect taxes levied on each of the goods including VAT. Note that the current tax levied on GHG emissions on fuels is incorporated into the tax rates on consumption of petrol and diesel. The tax on GHG emission was 0,8 NOK/litre petrol in 2007, which amounts to 345 NOK/ton GHG emission. The average consumer price on 95 octane was 11,68 NOK/ litre that year.

Table 1 presentes current Norwegian tax rates. The tax rate on buying and owning an electricity powered car only amounts to 8 percent, while the tax rate on buying and owning petrol and diesel powered cars amounts to 93 and 84 percent, respectively. The tax rate on consumption of electricity equals 52 percent. The tax rate on petrol and diesel equals 167 and 119 percent, respectively. Favourable policy measures of electricity powered cars in the Norwegian economy includes: No tax on purchase, no VAT, reduced yearly tax, free public parking which often includes charging free of charge, no road tax, and access to drive in the bus line. The present analyses, however, assumes that free public parking, no road tax, and access to drive in the bus lane is abolished as the stock of electricity powered cars becomes substantial in the long run.

Table 1. Present Norwegian tax rates

	Hybrid	Petrol	Diesel	Electricity	Hydrogen
Car purchase	37	93	84	8	8
Fuels		167	119	52	

Source: Statistics Norway: Energy account and National account

The point of departure is the current Norwegian tax system with substantial tax rebates connected to purchasing and operating electric cars combined with heavy taxation of petrol and diesel powered cars. The present mix of 3.5 percent biofuel in petrol and diesel is excluded from the reference scenario. The biofuels are however implemented in policy reform scenarios. Implementation of biofuels will arguably lower GHG emissions per litre[4]. Hence, the tax on fuels is reduced when emissions are taxed with a fixed rate. The cost of producing fuels is however likely to increase when fossil fuel is mixed with more expensive biofuel. The net effect on the consumer price of fuels is influenced by both these effects. The present study, however, assumes that the government reduces the tax on fuels so that the consumer price of fuels is unaffected by a biofuel mandate. This assumption is introduced to preserve and purify the trade off between the impact of mixing bio fuel with fossil fuel and tax exemptions for electric cars. The assumption prevent a more complex trade off where a mandate generates a price increase on fuels, which lead to substantial reductions in GHG emissions due to substitution away from petrol and diesel cars towards electric cars. Similar tax exemptions for biofuels are currently introduced in Norway, see Econ (2008).

A range of scenarios are analyzed to study the impact of a biofuel mandate. Note that somewhat extreme assumptions connected to costs and emissions are chosen to test the robustness of results. The base line *biofuel scenario* consists of implementing a 10 percent biofuel share into petrol and diesel. The remaining 90 percent share consists of fossil fuel. The producer price of biofuel is assumed to be twice as large as the producer price of fossil fuel, which is slightly below the upper cost estimates

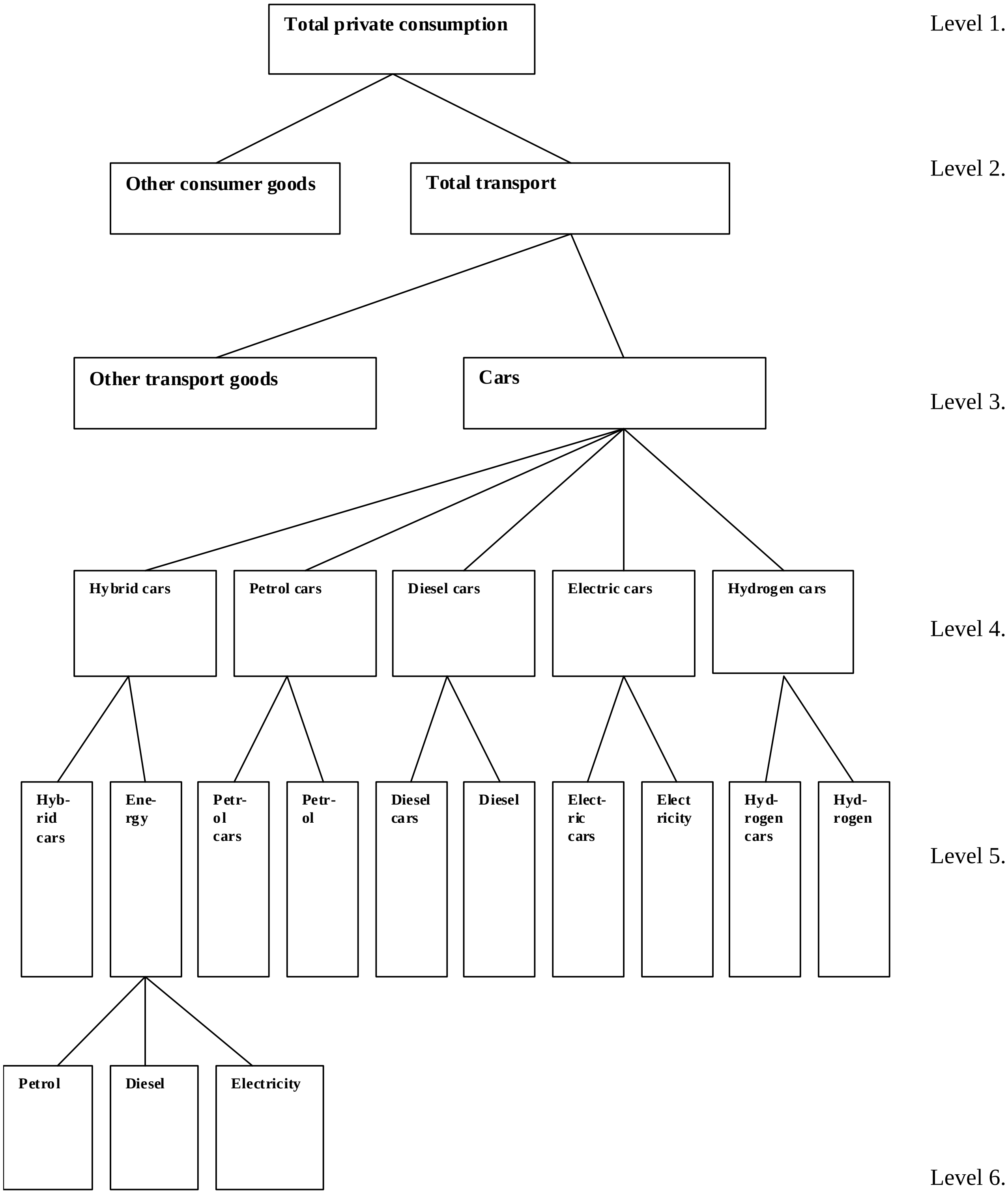
[4] There is an extensive discussion of whether implementation of biofuels actually lowers GHG emissions.

referred to above. The emission of green house gasses connected to one litre gasoline equivalent of biofuel is assumed to equal half of the emissions connected to burning one litre gasoline. This emission intensity is consistent with the Renewable Energy Directive within the EU. The scenario is compared with a reference scenario where current tax rates on cars and fuels are incorporated. A sensitivity test labelled the *high emission biofuel scenario* is conducted where the emission of green house gasses connected to one litre gasoline equivalent of biofuel is assumed to equal 80 percent of the emissions connected to burning one litre gasoline. The *biofuel, high tax scenario* consists of a sensitivity test where a mandate is introduced into a reference scenario where the initial tax rate on purchase of electric cars equals the average tax rate on purchase of diesel powered cars. The *low cost biofuel, high tax scenario* is identical to the *biofuel, high tax scenario* except that the producer price of biofuels equals the producer price of fossil fuel.

3. The model

The decision to purchase a car constitutes a discrete choice where households and individuals choose between cars with a range of different attributes and prices. Households with heterogeneous preferences for attributes connected with cars which run on different types of fuel lead to differences in the willingness to pay for these cars. Falling aggregate demand functions can be constructed by sorting households according to willingness to pay. Such demand functions can be exploited to calculate the sum of consumer surplus across a number of consumers, see Varian (1999). These demand functions and consumer surpluses are analogous to demand functions and consumer surpluses which can be derived from a single consumer that maximizes utility. Hence, the choice of cars is constructed by assuming that a representative consumer with preferences for each type of car maximize utility with respect to purchase of each type of car and fuel, see Bjertnæs et al. (2011). The model contains five different types of cars which are powered by different types of fuels: Plug-in hybrid, petrol, diesel, electric and hydrogen cars. The different types of cars and fuels are incorporated into a nested CES (constant elasticity of substitution) -utility function. The representative consumer behaves as if prices including tax rates are exogenous. The consumer price of each consumer good equals a fixed producer price plus the tax rate levied on that good. The CES-utility function is illustrated in figure 1.

Figure 1. The CES-utility function



The utility function consists of six levels. Level 1 consists of total private consumption, which includes total expenditures on private transport and all other consumer goods. Level 2 consists of private households total expenditures for private transport. This level includes other expenditures like maintenance and spare parts as well as expenditures for private transport. These two components constitute level 3. Level 4 consists of expenditures for each of the five types of cars. Expenditures for each type of car, level 5, consists of a service flow from that stock of cars, and expenditures on fuels for that type of car. Level 6 consists of different types of fuels used for plug-in hybrid cars. The CES-utility function is chosen to be able to study different types of tax changes levied on purchase of different types of cars and fuels. The substitution elasticity between fuels employed for hybrid cars are zero to simplify the model. Assuming zero substitution between the service flow and use of fuel for each type of car implies that there are no tax distortions between buying and using a car in this model.

There is considerable uncertainty connected to the future elasticity of substitution between types of cars. Empirical studies are not likely to remove this uncertainty because the quality of future types of cars is unobservable today. The resent development in purchase of petrol and diesel powered cars however suggest that the substitution elasticity between types of cars is substantial. The substitution elasticity between operating expenditures for each pair of the different types of cars is assumed to increase to 8 in the long run. Hence, differentiated tax rates generate substantial distortions in the allocation of types of cars in this model. Bjertnæs (2013), however, show that the substantial welfare gain per ton increase in GHG emission due to reduced tax exemptions for electric cars in Norway is only modestly affected by assuming that the substitution elasticity between types of cars equals 3 instead of 8. The tax wedge between types of cars is determined by differences in tax rates levied on each type of car. This tax wedge consists of differences in tax rates on purchase of the car and on fuels. This modelling approach is justified by an empirical study which finds that consumers consider both prices on fuels and cars when they decide which type of car to buy, see Heldal et al. (2009). The substitution elasticity between other operating expenditures and total operating expenditures is assumed to be 0,4. The model does not incorporate substitution towards public transport and/ or walking and bicycling. The current tax rates on purchase of petrol and diesel cars are calculated based on data from the National accounts. The tax rates on purchase of electric and hybrid cars are calculated by evaluating present tax rules and the quality of plug-in hybrid cars launched in 2011. The tax rates on fuels are calculated based on data from the energy accounts.

The GHG emissions are directly linked to the consumption of petrol and diesel, where one litre petrol generates 2,316 kg CO_2 and one litre diesel generates 2,663 kg CO_2. Emissions of CH_4 and N_2O is also incorporated and transformed into CO_2 - equivalents. The model does not include emissions from production of fuels and cars. Hence, emissions connected to extraction and refining of fossil fuels as well as emissions connected to production of electricity is not included. Total emissions of GHG's in the reference scenario amounts to approximately 6,7 mill ton CO_2 equivalents in 2005. The reference scenario does not incorporate bio-fuels, and hence, tend to exaggerate the level of emission. The model also seems to predict a faster growth in GHG emission from household transport compared to the development the last twenty years. This development is governed by drastic changes in the composition of petrol and diesel cars as well as technological progress. The future development is uncertain, but a transition to climate friendly cars can decrease well-to-wheel GHG emissions in EU by 35 to 57 percent according to Pasaoglu et al. (2012).

There are a range of external effects connected to automobiles that justifies taxation, see Parry et al. (2007) and Econ (2003). Replacing fossil fuel with biofuel is likely to affect GHG emissions, but it is not likely to alter other (external) effects like accidents, cueing and free use of public roads. Electricity powered cars is also likely to generate the same external effects except for noise and emissions to air. Hence, other external effects is omitted from the model as implementation of biofuel and/ or a transition from electricity powered cars to petrol and diesel powered cars is not likely to alter these types of externalities.

The budget of the representative consumer consists of a fixed income minus a direct lump-sum tax/ transfer. This after tax income finances the consumption of all consumer goods in each period. The government is assumed to consume a fixed amount of consumer goods. This consumption is financed by indirect consumer taxes and a direct lump-sum tax/ transfer. The government budget constraint is satisfied each future period by adjusting the lump-sum tax/ transfer levied on the representative consumer when tax reforms are introduced. The budget constraint of the representative consumer together with the government budget constraint implies that the fixed income of the representative consumer equals total consumption measured in producer prices. This is consistent with an economy where all income earned by the production sector is transferred to the representative consumer.

4. Policy analysis

4.1. The reference scenario

The reference scenario is constructed by calibrating total private consumption, other consumer goods and total expenditures on private transport to aggregates from National account, 2005. Expenditure on private transport is decomposed into purchase of cars and fuels for each type of car. A smooth development in purchase of petrol and diesel cars is implemented to improve the dynamic aspect of the model[5]. The development in the purchase of electric cars is implemented by assessing relevant statistics and studies containing information about the future development. Total expenditures on private transport is growing by 2,5 percent on average each year in the period 2001 to 2006. This growth rate is incorporated into total expenditures on transport in the reference scenario. The fuel consumption of cars has gradually decreased in the past. Future decreases in line with this development is incorporated by assuming a technological growth of 0,8 percent each year for all types of fuels.

The development in the stock of each type of car is determined by the development of the CES cost-share of each type of car and the development of relative prices between cars, see appendix. The initial stock of each type of cars is determined by calibrating CES-cost-shares for each type of car. Expected technological improvements related to production and us of electric and hydrogen cars is implemented by gradually increasing CES cost-shares connected to these types of cars. CES-cost-shares of petrol and diesel cars are gradually decreased as the stock of electric and hydrogen cars is increasing, see appendix. A detailed description is given in Bjertnæs et al. (2011). Implementation of technological improvement by lowering the price of these cars does not generate a substantial stock of such cars within this model framework. Hence, the technological improvement is implemented by increasing CES cost-shares to be able to arrive at substantial stocks of electric, hybrid and hydrogen cars in the long run.

There are approximately 10.000 electricity powered cars in Norway as of 2013. Electricity powered cars is however assumed to have a substantial market share in 2050 when the current favourable taxation is preserved. This assumption seems to be consistent with pridictions in the literature even though the future market share of electric cars is highly uncertain. A study of Eurelectric (Eurelectric, 2007), an association representing the interests of the electricity industry in Europe, argue that plug-in

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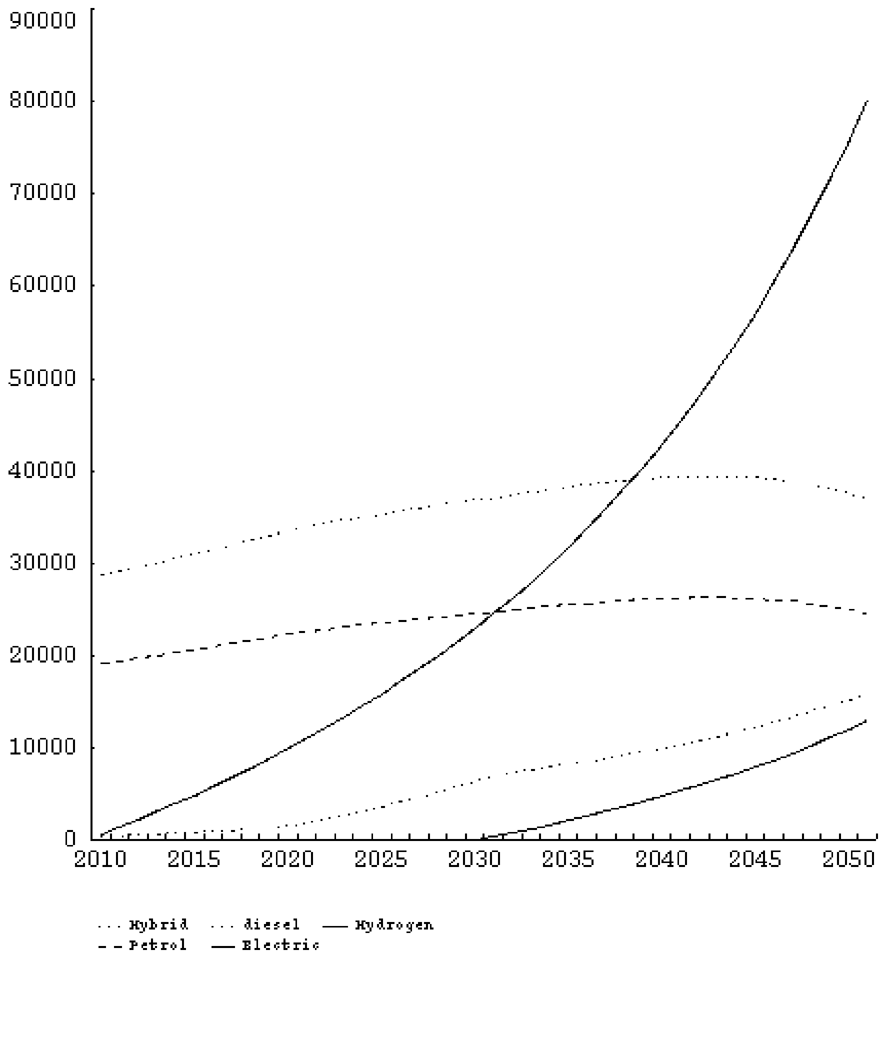
[5] Modest deviations from National accounts are generated when dynamic aspects of the model are improved. Electric cars are not included as a separate good in Norwegian National Accounts.

hybrid vehicles can have a market share of 8 to 20 percent in 2030. ECN (2009) show that the share of light electric vehicles can reach 20 percent in 2030. Most individuals also seem to have a positive willingness to pay for cars that use alternative fuels, see Dagsvik and Liu (2009) and Caulfield et al. (2010). Devogelaer and Gusbin (2010), however, predict a smaller share of electric vehicles and plug-in hybrid vehicles in Belgium in the period 2012-2030. General climate policy measures generate a share of electric and plug-in hybrid vehicles of about 2% of the fleet in 2020, and about 5% of the fleet in 2030 in their study. Note that it is necessary to some how decarbonise the electricity production to harvest emission reductions, see Thiel et al. (2010). Figure 2 show that electric cars dominate the market in 2050. The purchase of electric cars is more than twice as large as the purchase of any other type of car in 2050. The purchase of hybrid and hydrogen cars is marginal the first periods, but expands gradually and ends up with a modest market share in 2050.

Figure 2. Purchase of cars in the reference scenario, mill 2004-NOK



4.2. The biofuel scenario

The biofuel scenario is constructed by implementing biofuel into a reference scenario where current tax rates are incorporated. The share of biofuel is increased from zero to 10 percent when the biofuel scenario is implemented. The producer price of petrol (and diesel) mixed with biofuel increases by 10 percent because the producer price of biofuels is assumed to be twice as large as the producer price of fossil fuel. The tax rate on petrol and diesel is however reduced by approximately 15 percent, see table 4.1, so that the consumer price of petrol and diesel is unchanged. The implementation of biofuel contributes to lower GHG emission by 5 percent per litre petrol and diesel as emissions from biofuel is assumed to generate half of the emission compared with fossil fuel. The total amount of emissions each period is however fixed by the emission target set by the government. Hence, the government increases the tax rate on purchase of electric and hydrogen cars. The increase amounts to approximately 50 percent in 2030. This tax increase leads to substitution from electric and hydrogen cars, towards petrol and diesel powered cars. Table 2 shows that the purchase of electric and hydrogen cars is reduced by approximately 20 percent in 2030, and 6 percent in 2050. The consumption of petrol and diesel increases to a level which satisfies the emission target. Table 2 shows that consumption of petrol and diesel increases by 5,26 percent in both 2030 and 2050. This transition towards petrol and diesel powered cars contributes to increase tax revenue generated. The direct effect of the tax increase on electric and hydrogen cars also contributes to increase tax revenue, while the direct effect of a lower tax rate on petrol and diesel contributes to lower tax revenue generated. The net effect is positive, and this additional tax revenue is transferred lump-sum to the representative consumer.

The welfare effect is found by comparing aggregate utility in the biofuel scenario with aggregate utility in the reference scenario. The welfare effect of imposing this biofuel reform is positive. The increase in the producer price of petrol and diesel contributes to lower welfare as this constitutes a productivity loss. Substitution from electric and hydrogen cars towards petrol and diesel cars contributes to increase the welfare. This reallocation contributes to increase the welfare because of the substantial tax burden levied on petrol and diesel cars combined with tax exemptions on electric and hydrogen cars, see Bjertnæs (2013) for a detailed discussion. Hence, this biofuel reform is welfare enhancing even though biofuel implementation leads to a cost increase of fuels.

Table 2 Simulation results, biofuel reforms

	Reference scenario, current tax system, Mill 2004-NOK.	Biofuel scenario, Percentage changes from the ref. scenario	The high emission biofuel scenario, Percentage changes.	The biofuel, high tax scenario, % change from the high tax ref.	The low cost, high tax biofuel scenario, % changes from the high tax ref.
Petrol and diesel, 2030	23695	5,26	2,0	5,26	5,26
Petrol and diesel, 2050	16873	5,26	2,0	5,26	5,26
Electric and hydro cars, purchase 2030	22891	-19,9	-8,0	-19,9	-19,5
Electric and hydro cars, purchase 2050	87882	-5,8	-2,3	-5,8	-5,7
Tax rate, el and hydro cars, 2030	0,08	52,9	19,9	8,5	8,4
Tax rate, Petrol, 2030	167	-14,5	-14,5	-14,5	0
Tax rate, Diesel, 2030	119	-16,7	-16,7	-16,7	0
Consumer price, el and hydro cars, 2030	1	3,8	1,4	3,9	3,8
Producer price, petrol	0,37	10	10	10	0
Aggregate utility, 2030	1677920	0,06	-0,03	-0,08	0,01
Aggregate utility, 2050	2752758	0,05	-0,005	-0,04	-0,0004

4.3. Sensitivity tests

The high emission biofuel scenario

The implementation of biofuel in the high emission biofuel scenario contributes to lower GHG emission by 2 percent per litre petrol and diesel as emissions from biofuel by assumption amounts to 80 percent of the emission from fossil fuel. The total amount of emission each period is however fixed by the emission target set by the government. Hence, the government increases the tax rate on purchase of electric and hydrogen cars by approximately 20 percent. This tax increase leads to substitution from electric and hydrogen cars, towards petrol and diesel powered cars. Table 2 shows that the purchase of electric and hydrogen cars is reduced by approximately 8 percent in 2030, and 2 percent in 2050. The consumption of petrol and diesel increases to a level which satisfies the emission target. Table 2 shows that consumption of petrol and diesel increases by 2 percent in both 2030 and 2050. This transition towards petrol and diesel powered cars contributes to increase tax revenue generated. The direct effect of the tax increase on electric and hydrogen cars also contributes to increase tax revenue, while the direct effect of a lower tax rate on petrol and diesel contributes to lower tax revenue generated. The net effect is negative. Hence, an additional lump-sum tax is levied on the representative consumer.

The welfare effect of imposing this high emission biofuel reform is negative. The increase in the producer price of petrol and diesel contributes to lower welfare as this constitutes a productivity loss. Substitution from electric and hydrogen cars towards petrol and diesel cars contributes to increase the welfare. This reallocation contributes to increase the welfare because of the substantial tax burden levied on petrol and diesel cars combined with tax exemptions on electric and hydrogen cars, see Bjertnæs (2013) for a detailed discussion. This reallocation is however more modest in this high emission biofuel scenario compared with the biofuel scenario because the direct emission reductions of implementing biofuel are more modest.

The biofuel, high tax scenario

The biofuel, high tax scenario is constructed by implementing biofuel into a reference scenario where current tax rates are incorporated, but where the tax rate on purchase of electric and hydrogen cars is set equal to the average tax rate on purchase of diesel powered cars. Note that the initial consumer price of electric and hydrogen cars is unchanged as producer prices are reduced accordingly. This approach is chosen to isolate the impact of the change in initial tax rates. The government increases the tax rate on purchase of electric and hydrogen cars by approximately 8,5 percent in 2030. This tax increase leads to substitution from electric and hydrogen cars, towards petrol and diesel powered cars. Table 2 shows that the purchase of electric and hydrogen cars is reduced by approximately 20 percent in 2030, and 6 percent in 2050. The consumption of petrol and diesel increases to a level which satisfies the emission target. Table 2 shows that consumption of petrol and diesel increases by 5,26 percent in both 2030 and 2050. This transition towards petrol and diesel powered cars contributes to increase tax revenue generated. The direct effect of the tax increase on electric and hydrogen cars also contributes to increase tax revenue, while the direct effect of a lower tax rate on petrol and diesel contributes to lower tax revenue generated. The net effect is positive, and this additional tax revenue is transferred lump-sum to the representative consumer.

The welfare effect is found by comparing aggregate utility in the biofuel, high tax scenario with aggregate utility in the reference scenario where the tax on purchase of electric cars equals 84 percent. The welfare effect of imposing this biofuel reform is negative. The increase in the producer price of petrol and diesel contributes to lower welfare as this constitutes a productivity loss. Substitution from electric and hydrogen cars towards petrol and diesel cars contributes to increase the welfare. This reallocation contributes to increase the welfare because of the tax burden levied on petrol and diesel cars combined with tax exemptions on electric and hydrogen cars, see Bjertnæs (2013) for a detailed discussion. This tax wedge is however more modest in this scenario because the tax rate on electric cars is set higher. This explains why the welfare effect is no longer positive.

The low cost, high tax biofuel scenario

The low cost, high tax biofuel scenario is constructed by implementing biofuel into a reference scenario where current tax rates are incorporated, but where the initial tax rate on purchase of electric and hydrogen cars is set equal to the average tax rate on purchase of diesel powered cars. The producer price of petrol (and diesel) mixed with biofuel is unchanged because the producer price of biofuel by assumption equals the producer price of fossil fuel in this scenario. The consumer price of petrol and diesel is therefore also unchanged. Table 2 shows that consumption of petrol and diesel increases by 5,26 percent in both 2030 and 2050. This transition towards petrol and diesel powered cars contributes to increase tax revenue generated. The direct effect of the tax increase on electric and hydrogen cars also contributes to increase tax revenue. The net effect is positive, and this additional tax revenue is transferred lump-sum to the representative consumer.

The welfare effect is found by comparing aggregate utility in the low cost, high price, biofuel scenario with aggregate utility in the reference scenario where the tax on purchase of electric cars equals 84 percent. The effect on yearly utility of imposing this biofuel reform is positive in 2030 and negative in 2050. Substitution from electric and hydrogen cars towards petrol and diesel cars generates modest welfare effects because tax distortions are reduced. The cost increase connected to biofuel is not present in this scenario. This explains why the welfare effect becomes marginal.

4.4. Emissions in other sectors

The model employed calculates emission directly linked to consumption of fuels, often labelled tank to wheel. There are no emissions attached to consumption of electricity, and consumption of fossil fuel only generates emissions connected to consuming these fuels. Emissions connected to producing and consuming biofuels is included by downscaling emissions connected to consumption of fuels. This section discusses implications of incorporating emissions connected to production of electricity and fuel (well to tank), and emissions from other sectors and countries.

The emission reduction connected to a transition from fossil fuels to biofuels is highly uncertain. It takes years to grow a forest to store carbon dioxide. Converting rainforests, peatlands, savannas, or grasslands to produce food crop - based biofuels in Brazil, Southeast Asia, and the United States creates a "biofuel carbon debt" by releasing 17 to 420 times more CO_2 than the annual greenhouse gas (GHG) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages, according to Fargione et at. (2008). This should be taken into consideration when interpreting the results of this study. Substitution from electric to conventional cars leads to increased demand for petrol and diesel in this study. The production of fossil based petrol and diesel require production and refining of oil. Both these activities generate GHG emissions, see NOU (2006). One may, however, speculate whether an increase in consumption of petrol and diesel in Norway generates a reduction in consumption of petrol and diesel in other countries due to a world market with a vertical or increasing supply curve for oil.

The future design and existence of an international quota market for GHG emissions is highly uncertain. The design of such a market is relevant for analyses conducted in this study. The Norwegian transport sector is not included in the current EU ETS quota market, while other emission intensive sectors are included. Changes in emission from the production of energy would be neutralized by opposite changes in emissions in other sectors within this quota market. The model in this study only incorporate emissions directly linked to the transport sector, and hence, generate emission effects consistent with the current EU ETS quota market. Implementation of biofuels in the absence of the EU ETS requires a different approach. Electric cars require clean electricity to remain a low emission vehicle in this case, see Thiel et al. (2010) and Econ (2008). Close to 100 percent of the Norwegian production of electricity consists of clean hydro power. The Norwegian electricity grid is however connected with the European electricity grid. A downscaling of electric cars in Norway may consequently lead to reduced production of coal fired electricity plants in Europe. Hence, emission reductions may take place even though Norwegian electricity production remains unchanged.

5. Conclusion

This study analyses the welfare impact of introducing biofuel mandates in Norway when subsidies/ tax exemptions for electric cars which run on non-polluting electricity is an option for the government. The policy reforms analysed consists of mixing biofuels with fossil fuel within a model framework where emission of green house gasses is fixed. The tax rate on purchase of electric (and hydrogen) cars is endogenously increased to a level where electric cars is replaced with petrol and diesel cars so that emissions are unchanged. Model simulations shows that the welfare effect of a mandate which replaces 10 percent of the fossil fuel with biofuel is positive when the present tax rate on purchase of electric cars equals 8 percent, the producer price of biofuel is twice as large as the producer price of fossil fuel, and emissions from one litre biofuel equals half of the emission from burning one litre fossil fuel. This results is, however, sensitive to assumptions about the emission intensity of biofuels. The welfare effect becomes negative when the net emission per litre of biofuels exceeds 80 percent of the emission per litre of fossil fuel. The welfare effect of implementing a mandate for blending biofuel also becomes negative when the initial tax rate on purchase of electric cars equals 84 percent. Model simulations show that the welfare effect of this mandate becomes marginal when the producer price of biofuel equals the producer price of fossil fuel.

The welfare impact of a mandate is analyzed in the presence of a specific emission target within the transport sector. An alternative is to adopt a benevolent welfare function which incorporates a social cost of carbon. The solution to this approach would be to remove tax exemptions on purchase of electric cars, as Bjertnæs (2013) shows that this generates a welfare gain per ton emission which by far exceeds the social cost of carbon reported by US EPA. This study shows that a mandate lowers welfare when the tax rate on purchase of electric cars is set equal to the tax rate on purchase of diesel powered cars. Hence, both these policy tools are doomed to fail in the presence of a welfare function which incorporates a social cost of carbon instead of a specific emission target. A number of other factors are also likely to influence the choice of policy. First, noise pollution and emission of NOX and other gases are likely to increase when mandate replaces electric cars. Second, tax revenue recycling by cutting other distorting taxes may boost the welfare effect of introducing a mandate that leads to a reallocation from electric to petrol/ diesel cars. Third, clean electric cars require clean electricity production. This favours the mandate which do not require clean electricity production.

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Appendix

Operating expenditures of electric cars is given by

(1A) expel = omel *((pcel / pcall) ** (1-sigall)) *expall.

Equation (1A) shows that operating expenditures of electric cars, expel, equals the CES-cost-share of electric cars, omel, multiplied by an expression which includes the price of operating expenditures of electric cars, pcel, divided by the price aggeregate of operating expenditures of all cars, pcall. The impact of a relative price change is determined by the substitution elasticity between types of cars, sigall. This expression is multiplied with operating expenditures for all cars, expall. Note that operating expenditures of electric cars equals the CES-cost-share of electric cars multiplied with operating expenditures of all cars when pcel/pcall equals unity.

B

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