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Environmentally focused measures for sustainable vehicle transportation

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Master of Science in Energy and Environment
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Department of Energy and Process Engineering

Problem Description

Målet med oppgaven er å bidra med forslag til tiltak for å oppnå en bærekraftig utvikling som kan føre til reduksjon av klimagassutslipp og lokale utslipp fra veitrafikken.
Oppgaven begrenses til å studere bakgrunnsinformasjon, analysere denne sammen med teknologisk kunnskap og å utvikle forslag til endringer i eksisterende tiltak og til nye tiltak.
Problemstillingen er verdensomfattende, men tiltakene som foreslås bør primært fokusere på tiltak for reduksjon av utslippene i Norge. Tiltakene som foreslås kan være av teknisk, administrativ og fiskal karakter.

Assignment given: 15. March 2010
Supervisor: Per Olaf Tjelflaat, EPT

Norges teknisk-
naturvitenskapelige universitet
NTNU

Institutt for energi- og prosessteknikk

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MASTEROPPGAVE

for

Stud.techn. Lene Nesbjørg

Våren 2010

Miljøfokuserte tiltak for bærekraftig veitransport

Environmentally focused measures for sustainable vehicle transportation

Bakgrunn

Transport av varer og personer medfører årlige utslipp som er en betydelig andel av verdens samlede klimagassutslipp. Transporten skjer ved bruk av skip, fly, jernbane og kjøretøyer for veg. Nesten all transport er basert på bruk av fossil energi, og utslippene gir et betydelig bidrag til global oppvarming. Av Norges samlede klimagassutslipp utgjør, ifølge SSB, utslipp fra veitransport nær 20 %.

Utslipp fra veitransport utgjør i tillegg en betydelig lokal belastning for natur og befolkning i tett trafikkerte områder.

Reduksjon av behovet for fossil energi og økt bruk av fornybar energi for veitransport er viktig for å redusere klimagassutslipp og lokale utslipp. En reduksjon av energibehovet til transport er også viktig fordi vi møter en framtid med knapphet på fossil energi.

Den europeiske union (EU) er aktivt engasjert i å utarbeide informasjon, retningslinjer, normer og direktiver for å påvirke utviklingen i retning av reduserte klimagassutslipp og lokale utslipp og for å gjøre samfunnet mindre avhengig av fossil energi. Dette påvirker utviklingen av i Norge.

Mål

Målet med oppgaven er å bidra med forslag til tiltak for å oppnå en bærekraftig utvikling som kan føre til reduksjon av klimagassutslipp og lokale utslipp fra veitrafikken.

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Oppgaven bearbeides ut fra følgende punkter

1. Gi en kort oversikt over den internasjonale situasjonen mht. bekjempelse av global oppvarming og reduserte fossile resurser. Vis også hva situasjonen er i Norge.
2. Lag en oversikt over utviklingen i framdriftsløsninger for kjøretøyer generelt og utviklingen av forbrenningsmotorer spesielt. Beskriv utslipp fra motorene og relaterte ulemper.

3. Lag en oversikt over problemstillingen rundt lokale forurensningsutslipp fra kjøretøyer i EU og i Norge. Beskriv utviklingen av direktiver og veiledninger og utviklingen av innførte tiltak i land i EU/EØS-området.
4. Diskuter og sammenlign ulike tiltak for reduksjon av lokal og global forurensning fra kjøretøyer. Se dette i relasjon til bruk av fornybar energi og i relasjon til utviklingen innen EU med hensyn veiledninger, normer og direktiver.
5. Vurder og diskuter de viktigste tiltakene som kan bidra til at de lokale og globale utslippene fra veitrafikken i Norge reduseres fram mot år 2020.

" - "

Senest 14 dager etter utlevering av oppgaven skal kandidaten levere/sende instituttet en detaljert fremdrift- og eventuelt forsøksplan for oppgaven til evaluering og eventuelt diskusjon med faglig ansvarlig/veiledere. Detaljer ved eventuell utførelse av dataprogrammer skal avtales nærmere i samråd med faglig ansvarlig.

Besvarelsen redigeres mest mulig som en forskningsrapport med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse etc. Ved utarbeidelsen av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelsen legges det stor vekt på at resultatene er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte, og at de er diskutert utførlig.

Alle benyttede kilder, også muntlige opplysninger, skal oppgis på fullstendig måte. For tidsskrifter og bøker oppgis forfatter, tittel, årgang, sidetall og eventuelt figurnummer.

Det forutsettes at kandidaten tar initiativ til og holder nødvendig kontakt med faglærer og veileder. Kandidaten skal rette seg etter de reglementer og retningslinjer som gjelder ved alle (andre) fagmiljøer som kandidaten har kontakt med gjennom sin utførelse av oppgaven, samt etter eventuelle pålegg fra Institutt for energi- og prosessteknikk.

I henhold til "Utfyllende regler til studieforskriften for teknologistudiet/sivilingeniørstudiet" ved NTNU § 20, forbeholder instituttet seg retten til å benytte alle resultater og data til undervisnings- og forskningsformål, samt til fremtidige publikasjoner.

Ett -1 komplett eksemplar av originalbesvarelsen av oppgaven skal innleveres til samme adressat som den ble utlevert fra. Det skal medfølge et konsentrert sammendrag på maksimalt én maskinskrevet side med dobbel linjeavstand med forfatternavn og oppgavetittel for evt. referering i tidsskrifter).

Til Instituttet innleveres to - 2 komplette kopier av besvarelsen. Ytterligere kopier til eventuelle medveiledere/oppgavegivere skal avtales med, og eventuelt leveres direkte til de respektive. Til instituttet innleveres også en komplett kopi (inkl. konsentrerte sammendrag) på CD-ROM i Word-format eller tilsvarende.

NTNU, Institutt for energi- og prosessteknikk, 15. mars 2010

Olav Bolland
Instituttleder

Per Olaf Tjelflaat
Faglig ansvarlig/veileder

Preface

The work presented in this Master's thesis has been performed at the Norwegian University of Science and Technology, at the Department of Energy and Process Engineering. This thesis concludes my Master in Science education.

I would like to thank my supervisor Professor Per Olaf Tjelflaat for his guidance and encouragement during the Master study. I would also like to thank my fellow students for their support and for the good times we have shared.

Trondheim, 09/08-10
Place and date

Lene Nesbjørg
Lene Nesbjørg

Abstract

Emissions from road traffic contribute a substantial part of the total CO_2 emissions from the transport sector. The amount of passenger cars is rapidly increasing, which leads to an increase in CO_2 emissions, even though the average CO_2 emissions from new cars are decreasing.

This thesis has evaluated the vehicle technologies available at present and examined the measures currently in use to reduce CO_2 emissions from passenger cars, focusing on the European Union and Norway.

Suggested measures for reduction in CO_2 have been discussed. A harmonisation in fiscal taxation system throughout the European Union should be implemented, where a purely and directly CO_2 based taxation system would give the largest CO_2 reductions.

In Norway a large part of the taxation potential is already utilized through registration tax and fuel tax. The taxes should be altered to be purely CO_2 based if the objection of a tax is to prohibit the increase in emissions.

By using a taxation system that affects a person's usage of a car, and not the ownership, could make more people seek other means of transportation.
A taxation system should not be implemented without measures to expand and upgrade the public transportation. Vast improvements in the Norwegian public transportation is a must if the reduction of CO_2 possible and significant.

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1 Introduction - Global Warming, what is the situation at present?

1.1 Background

The world is at present faced with one of its largest man-made climatic challenges ever, global warming. The energy production in the world is dominated by fossil energy sources, and if this consumption is to continue the surface temperature of the planet will increase dramatically [1].

After power generation, road transportation is the second largest source of green house gas emissions in Europe. Road transportation contributes to nearly one-fifth of the total emission of carbon dioxide. Passenger cars alone are responsible for 12% of the European Union's CO_2 emissions. Carbon dioxide emissions from passenger cars and other vehicles are a major contribution to climate change, particularly in industrialized countries. Not only the use of the cars them selves but also extracting the raw materials and the manufacturing of vehicles [2].

1.2 In Norway

From 1990-2008 the green house gas emissions in (from) Norway increased with 8%, from 50 million ton CO_2 equivalents in 1990 to 54 million ton in 2008. The three largest contribution sectors to the climate gas emissions are at present transportation sector, petroleum sector and industrial sector [3].

Without vast and radical measures in the transport sector the climate effects will increase. Knowledge about which measures work is insufficient.

Statistics show that the average passenger car has reduced its CO_2 emission over the resent years, but with a large growth in consumption of vehicles, the total emissions from road traffic are still increasing. Therefore additional measures for reducing CO_2 emission from passenger cars must be implemented.

This thesis will give an overview over passenger car technology currently available, and look into some of the promising technologies for the future. The focus will be on the European market.

Further legislation and tax systems with the objection to reduce CO_2 and green house gas emissions from passenger cars for the European Union and Norway will be examined. Thus giving insight to what measures are currently used for regulating emissions.

An overview over some of the suggested measures for future reductions in form of legislation, regulations will be presented. And thereby investigate the measures that could be relevant to implement in the Norwegian transport sector.

This thesis will limit its focus to concentrate on the emissions from passenger cars, and various scenarios of how to reduce both CO_2 emissions and the usage of cars. Reductions in other areas of the transport sector, such as transport of goods, air traffic, shipping etc. and the cost of measures will not be examined.

2 Overview over vehicle technologies used in cars today

In resent years there has been a great focus on developing vehicles with low green house gas emissions, especially CO_2 emissions. These reductions can be made by a great many different measures, such as reducing the weight of cars, making the car body more aerodynamic, more energy efficient engines, or use of renewable energy as fuel instead of fossil fuels. These modifications are all aimed at making vehicles use less fuel per kilometre, and as a result emit less CO_2. This chapter gives an overview over the technologies available for passenger cars today;

2.1 Fossil fuelled engines

The development of the modern internal combustion engine started in the late 19th century and coincided with the development of the automobile.

The internal combustion engine is a heat engine that converts chemical energy in a fuel into mechanical energy, which is usually made available on a rotating output shaft. The chemical energy in the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. The thermal energy raises the temperature and pressure of the gases within the engine and the high-pressure gas then expands against the mechanical mechanisms of the engine. The mechanical mechanisms then rotate a crankshaft linked to the engine, and this is the output power of the engine. This rotation is in turn used for a desirable target, such as propulsion power in a vehicle [4].

The internal combustion engines in cars are reciprocating engines, which have pistons that reciprocate back and forth in cylinders internally within the engine. There can be one or up to twenty or more cylinders in a reciprocating engine, which can be arranged in many different geometric configurations.

The combustion chamber is located in the closed end of each cylinder. Most of the internal combustion engines operate on either a four-stroke cycle or a two-stroke cycle, where the four-stroke cycle is most common in cars [4].

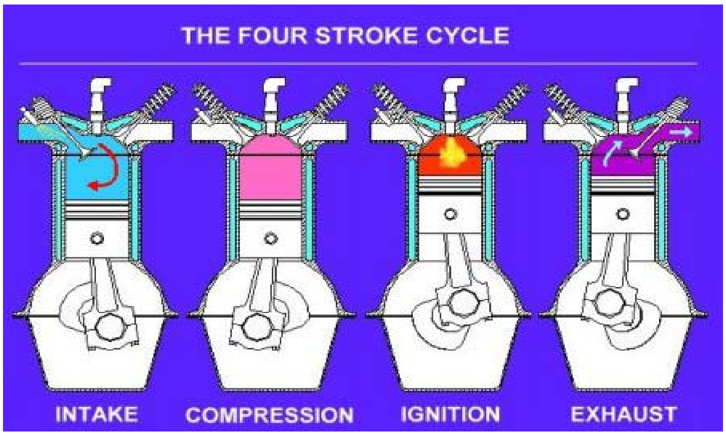


Figure 1: four-stroke engine [5]

As the name implies the four-stroke internal combustion engine has four basic steps that it repeats every two revolutions of the engine

1. **Intake stroke**, air or a fuel-air mixture is sucked in to the combustion chamber through an open intake valve.
2. **Compression stroke**, the intake valve is closed and air or fuel-air mixture is then compressed. For a compression ignition the fuel is injected directly into the combustion chamber late in the compression stroke, where it is mixed with very hot air.
3. **Power stroke**, the mixture is combusted, and expands pressing on and moving parts of the engine to produce the work.
4. **Exhaust stroke**, the cooled combustion products are exhausted into the atmosphere.

It was first in the 1970s that the air pollution from passenger cars and other vehicles were recognized as a major problem, especially in cities and urban areas. Laws were passed in industrialized countries which limited the amount of various exhaust emissions that are allowed [4].

The major emissions produced by internal combustion engines are hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), sulphur and solid carbon particulates. Other emissions also found in the exhaust include aldehydes, lead, phosphorus etc.
To reduce these emissions two main methods were used.

- Improved engine technology, so that better combustion occurred and fewer emissions are generated.

- Exhaust gas aftertreatment to clean the exhaust before it is released into the atmosphere.

By introducing these two methods emissions were reduced by 95% during the 1970s and 1980s. Lead was also phased out as a fuel additive during the 1980s seen as this was a major pollutant [4].

2.1.1 Petrol Vehicles [4]

A petrol engine is an internal combustion engine designed to run on petrol and similar volatile fuels. Most of the petrol engines in cars are as mentioned four-stroke engines, with spark ignition. A spark ignition (SI) engine starts the combustion process each time by use of a spark plug that sends an electric current to start ignition. In petrol engines the fuel is premixed with oxygen in a carburettor, before it is sent into the cylinder where the combustion process is initiates.

If the air-fuel ratio in a petrol internal combustion engine is non-stoichiometric more emissions are produced. If the engine is operated with a fuel-rich mixture there is not enough oxygen to convert all the carbon to CO_2, and some carbon ends up as CO, also some fuel does not get burned and results in HC. If the air-fuel ratio is too lean poor combustion occurs, again resulting in HC emissions. Even with a stoichiometric mixture, perfect combustion does not occur and HC ends up in the exhaust. This could be due to incomplete mixing before entering the combustion chamber, so that not all the fuel particles have found oxygen to react with.

Aftertreatment is an important part of reducing the emissions from the exhaust gas. Catalytic converters are the most effective aftertreatment system for exhaust gas. A catalytic converter is a chamber placed somewhere in the flow system through which the exhaust gases flow. The catalyst is a substance that accelerates a chemical reaction by lowering the energy needed for it to proceed. Because catalytic converters remove HC, CO and NOx they are generally called a tree-way converters. With certain catalyst present they can oxidize HC and CO to H_2O and CO_2, at a temperature of 250°-300°C. Also the NOx can be reduced by 95% in a catalytic converter, when the combustion process is near-stoichiometric.

If the mixture is too fuel-lean very poor control of the NOx occurs, and this creates more emissions. HC and CO are not affected by lean mixtures, and 98-99% CO and more than 95% HC is removed.

A problem with catalytic converters is that they have to reach a certain temperature to be efficient, typically 400°C. So ideally a catalytic converter should be preheated before use. So in a cold start-up the catalytic converter is very inefficient, it uses several minutes to reach an efficient operating temperature. So for short distances the catalytic converter never reaches efficient operating temperatures, and therefore emissions are high.

Impurities in the fuel, lubricating oil and air can over time poison the catalyst material, leaving it with reduced efficiency or totally useless. Impurities could be lead, sulphur, zinc, phosphorus, antimony, calcium and magnesium. Lead would completely poison a catalyst.

Lead was a major additive to petrol when it was introduced in 1923. The lead was added to improve the octane number of petrol to allow higher compression ratios and more efficient engines. But the lead in the engine exhaust was a highly poisonous pollutant, and in the 1980s it was phased out of the fuel. The lead could not be removed all at once because engines were designed to run on this type of fuel, new octane increasers had to be developed, and the metals in engines had to be changed as the lead was phased out. Leaded fuel hardened the surfaces of the engine when used, therefore when the lead was removed harder metal and added surface treatment was used. So over the years the lead was phased out, and non-lead petrol was introduced.

2.1.2 Diesel vehicles [4]

The diesel engine is also an internal combustion engine, which uses diesel as fuel. The diesel engine uses compression ignition to start the combustion process. So in diesel engines the air is compressed and at the last stage of the compression the fuel is injected into the combustion chamber and the heat from the compression makes the fuel self-ignite. The diesel engine has the highest thermal efficiency of any regular internal combustion engine due to its very high compression ratio.

Compression Ignition (CI) engines operate with a fuel-lean equivalent ratio, this results in much lower HC emissions about one-fifth that for a SI engine. NOx is formed when high combustion reaction temperatures occur, the high temperatures make diatonic nitrogen, N_2, dissocate to monatomic nitrogen, N, and more NOx is formed. So the higher the temperature, the more NOx is created, but at low temperatures very little NOx is created.

Seen as CI engines generally have higher compression ratios and higher temperatures they tend to generate higher levels of NOx.

NOx is the primary cause of photochemical smog. In larger cities smog has been a severe problem. The NOx reacts with the sunlight and forms photochemical smog.

The exhaust from CI engines also contain solid carbon soot particles, these are generated in the combustion chamber in the fuel-rich zone where there is not enough oxygen to convert all the carbon to CO_2.

In CI engines catalytic converters are not so efficient at removing NOx seen as a CI engine operates with lean mixtures. To reduce the NOx a CI engine uses exhaust gas recycle (EGR). EGR is done/executed by ducting some of the exhaust flow back into the intake system, usually immediately after the throttle. EGR and low combustion temperatures however, contribute to an increase in solid soot.

Therefore CI engines have been equipped with particulate traps. The exhaust flows through the particulate traps and reduces particulates released into the atmosphere by 60-90%. As the traps catch, and slowly fill up with soot particulates, the exhaust gases flow is restricted. This causes the engine to run hotter because of high back pressure, the exhaust temperature to rise and fuel consumption to increase. To avoid this happening the particulate traps are regenerated as they begin to become saturated. Regeneration consists of combusting the particulates in excess oxygen contained in the exhaust gas of the lean-operating CI engine.

2.1.3 Natural gas vehicles

Internal combustion engines can use a number of different fuels one of them is natural gas. Natural gas is a mixture of components, consisting mainly of methane with small amounts of other hydrocarbon fuel components. Existing petrol fuelled vehicles can be converted to use natural gas. There is also an increasing amount of vehicles being manufactured to run on natural gas.

The octane number for natural gas is very high and this makes it desirable as a fuel for SI engines. The exhaust gas emissions from combusting natural gas are mainly CO_2. So the use of natural gas vehicles in cities will reduce NOx emissions [4].

Despite advantages the natural gas vehicles face limitations, fuel storage and infrastructure available for delivery and distribution. Natural gas is stored as compressed natural gas (CNG) at high pressures typically 16 to 25 MPa, or liquid natural gas (LNG) at pressures of 70 to 210 kPa and at a temperature around -160°C. CNG is most common to use in vehicles [4].

To convert an existing petrol car to natural gas will leave little room in the trunk for use, since a large tank would have to be installed to store the natural gas onboard. In manufactured vehicles the tank is placed under the car or for some vehicles such as buses they are placed on the roof.

Some of the drawbacks with natural gas are that it has low energy density, this results in low engine performance. It needs a large pressurized fuel storage tank, and refuelling is a slow process.

2.1.4 Biofuel

Biomatter or biomass is a term for all natural organic material associated with living organisms, including terrestrial and marine vegetable matter, such as trees, algae, animal tissue and manure. Biomass represents an important source of renewable fuel, biofuel [6]. Biofuel is a term that covers solid biomass, liquid fuels and various biogases. The primary biomass-based liquid fuels are biodiesel and bioethanol [7].

Biodiesel is made from animal fats, food oils or recycled greases. The biodiesel is produced using transesterification, and is the most common biofuel in Europe. Biodiesel is an oxygenated fuel, meaning that it contains reduced amounts of carbon and higher content of hydrogen and oxygen than fossil diesel. This improves the combustion of fossil fuel diesel and reduces the particulate emission of unburned carbon. Biodiesel can be used as a fuel in it pure form, but it is normally used as a fuel additive. B20 is a blend of 20% biodiesel and 80% diesel. Biodiesel can be used in any diesel engine when mixed with mineral diesel [8].

Bioethanol is an alcohol made by fermenting the sugar components of plant materials, and it is usually made from sugar or starch corps. The bioethanol is blended with petrol and this improves the octane number, oxygenates the fuel and reduces emissions. E85 is a fuel with 85% ethanol and 15% petrol. This is the most common biofuel world wide [8].

Biofuel is said to be CO_2 neutral seen as the biomass has reduced CO2 in the atmosphere through celluloses while growing.

The biofuel used at present is first generation biofuel, meaning that they are crop based and potentially compete with food for acreage [7]. Because of the issues associated with using food crops for fuel when people in the world are starving technology for second generation biofuel is being developed. Second generation biofuel uses trees and tree residue as biomass. The development of technology for second generation biofuel is still at an early phase, and it is uncertain how long it will be before this biofuel is possible to industrialize [3].

2.2 Electric Vehicles

Electric vehicles were first introduced as early as the middle of the 19th century, even before the introduction of petrol powered vehicles. But when starter motor in gas vehicles were invented, which made gas vehicles much easier to start, the electric vehicle disappeared. The electric vehicle was reintroduced in the 1960s because of environmental issues and the unpleasant dependence on oil. Then in the 1990s major automobile manufacturers embarked on plans for introducing their own electric or hybrid electric vehicle [9].

The electric car uses an electrical motor for propulsion. The energy source is portable and chemical or electrochemical in nature. The electrical power is either stored in battery. Lead-acid batteries have been the primary choice, because of their well-developed technology and lower costs. The range of battery-driven vehicles currently in use are limited so new promising battery developments for more efficient batteries are being tested. Batteries have to be charged to restore the energy, which is a slow process.
An electric motor is at least three times more efficient than an internal combustion engine [9].

The primary components in an electric vehicle system are the motor, controller, power source and transmission.

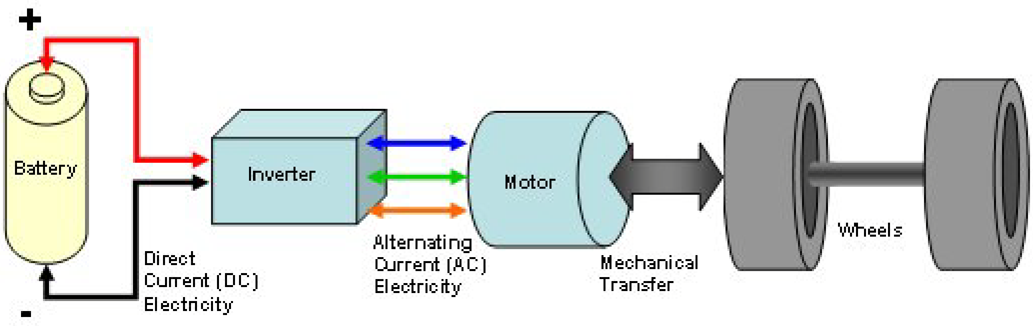


Figure 2: Electric vehicle [10]

One of the greatest technological challenges with the electric vehicle is the battery. The weight, size and capacity of the battery create problems for the car, and it is a continual process trying to develop batteries smaller and more efficient.

The electric car is one of the best solutions for passenger car transportation in cities with no emissions directly from the car itself, a so called zero-emission vehicle. Electric cars reduce the particle emissions and greenhouse gases in cities.

2.3 Fuel cell Vehicles

An alternative to the battery used in electric cars is fuel cells. A fuel cell is an electrochemical device that produces electricity by means of a chemical reaction. The basic operation of a fuel cell is simple. The fuel cells structure consists of an anode, a cathode and an electrolyte. The fuel used in fuel cell vehicles is hydrogen and oxygen, where hydrogen and oxygen are recombining in an opposite electrolysis and an electric current is being produced. The electric current is used to power an electric motor, so a fuel cell vehicle is still an EV but with an onboard supply of energy. The fuel cell can produce electricity as long as there is fuel supplied to the system, whereas batteries require frequent recharging.

The exhaust from the fuel cell process consists of water, so a fuel cell vehicle is a zero-emission vehicle [9].

There are a range of different fuel cell types. The most common fuel cell used in vehicles is proton exchange membrane (PEM) fuel cells [9]. The limitation in PEM fuel cells is its lifetime. The challenge is to produce PEM fuel cells that have the lifetime of the vehicle they are powering [3].

Hydrogen storage is a critical issue in development of infrastructure of fuel cell-powered vehicles. Storing hydrogen at atmospheric pressure results in low energy density and it is not a suitable fuel for storage. The hydrogen gas has to be stored as compressed or liquefied gas or in a more advanced manner by using metal hydrides or carbon nanotubes [9].

Compressing the hydrogen is the most common way of storage, but this requires a large amount of energy. To make the storage viable the pressure of hydrogen has to be several hundred atmospheres. The more advanced methods of storing the hydrogen still use compression, but at a lower pressure [9].

The process of separating hydrogen is also largely energy consuming. Hydrogen is separated from fossil fuels, such as natural gas, a process which emits CO_2. The process is not economically viable, although the technology is a good alternative for the environment.

The fuel cell vehicle is superior to the electric vehicle when it comes to comparing refuelling time [3].

2.4 Hybrid vehicles

A hybrid combines at least two sources for the propulsion of a vehicle. Possible combinations include diesel or petrol/electric, petrol/flywheel and fuel cell/battery. Typically, one energy source is used as storage and the other is conversion of fuel to energy [9].

Currently the hybrids on the road are hybrid electric vehicles, HEV. The hybrid electric vehicles use both an internal combustion engine and an electric motor as a power source. The internal combustion engine in a hybrid car is smaller than that of a traditional car power only by an internal combustion engine since it is only part of the power needed. A full hybrid vehicle will have an internal combustion engine that is 40-50% of a full sized engine. Dimensioned to handle the average load, and not the maximal power load needed for the car. The car also has regenerative braking, where the kinetic brake power is converted into battery-replenishing electric energy. The hybrid car uses less fuel than a normal car, and is well adapted for shorter trips [9].

There are three different types of hybrid electric vehicles on the commercial market today; Series hybrids, parallel hybrids and series-parallel hybrids.

Series hybrids are the simplest type of hybrid. There is only one of the energy converters which can provide propulsion. The internal combustion engine acts as a prime mover in this configuration to drive an electric generator that delivers power to the battery or energy storage link and the propulsion. In the series hybrid only the electric motor provides the propulsion power. The internal combustion engine drives a generator, which supplements the batteries and can charge them when they fall below a certain state of charge. Beyond the internal combustion engine and generator the propulsion system is the same as for an electric vehicle [9].

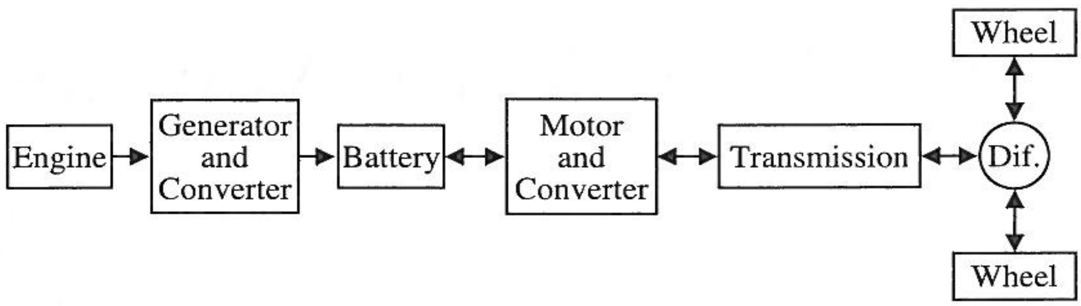


Figure 3: series HEV drivetrain [9]

Parallel hybrids also have an electric motor and an internal combustion engine, which are configured in parallel, with a mechanical coupling that blends the torque coming from the two sources. That implies that the two sources can be utilized simultaneously or as separate propulsion power. The power requirements for the electric motor in a parallel hybrid are lower than that for an electric vehicle or a series hybrid. The electric motor is also used as a generator, which implies that a parallel hybrid can not replenish the battery while the electric motor is used [9].

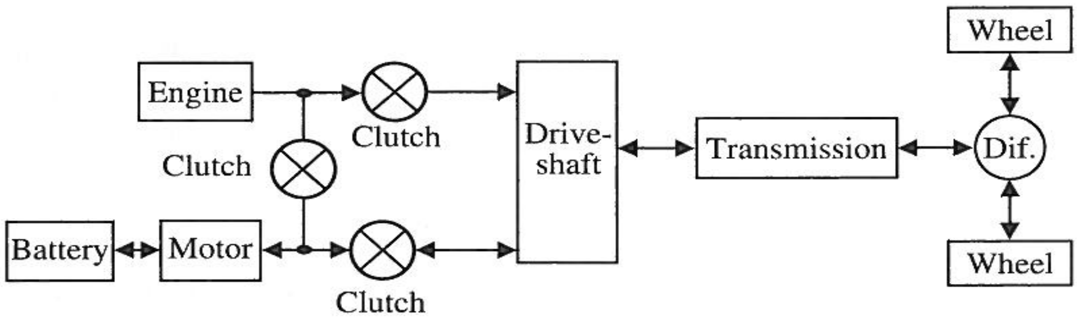


Figure 4: parallel HEV drivetrain [9]

Series-parallel hybrids are the most advanced type of hybrid vehicle. It can operate in both parallel and series mode, and is therefore the most energy efficient type of hybrid car. The series-parallel hybrid is basically a parallel hybrid with an extra generator which replenishes the battery even though the electrical motor is in use. These combination hybrids can be categorically classified under parallel hybrids, because they retain the parallel structure of a component arrangement. Use of the internal combustion engine should be minimized when maximizing the efficiency. Energy is always lost when the battery is charged and discharged, and during power flow through the inverter [9].

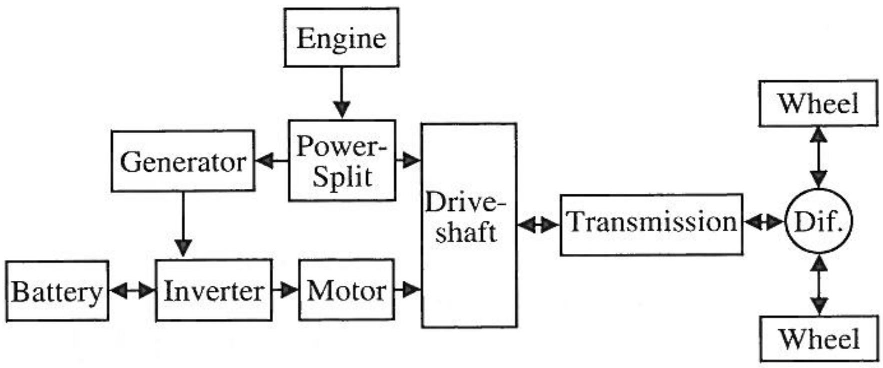


Figure 5: series-parallel HEV [9]

2.5 Plug-in hybrid

A Plug-in hybrid differs from the other hybrids by the fact that it can be connected to an external power source a plug to recharge the battery. So a plug-in hybrid shares both the characteristics of a conventional series-parallel hybrid with the electric motor and an internal combustion motor, and that of an all-electric vehicle.

With a fully charged energy storage the vehicle favours the electricity over the liquid fuel. This could potentially make a plug-in hybrid emit less CO2 than the other hybrid types, if the electric power supplying the car is produced from renewable energy with low to none green house gas emissions. When the battery is depleted the vehicle will run on the internal combustion engine.

The plug-in hybrid is said to be the next generation of hybrid vehicles [11].

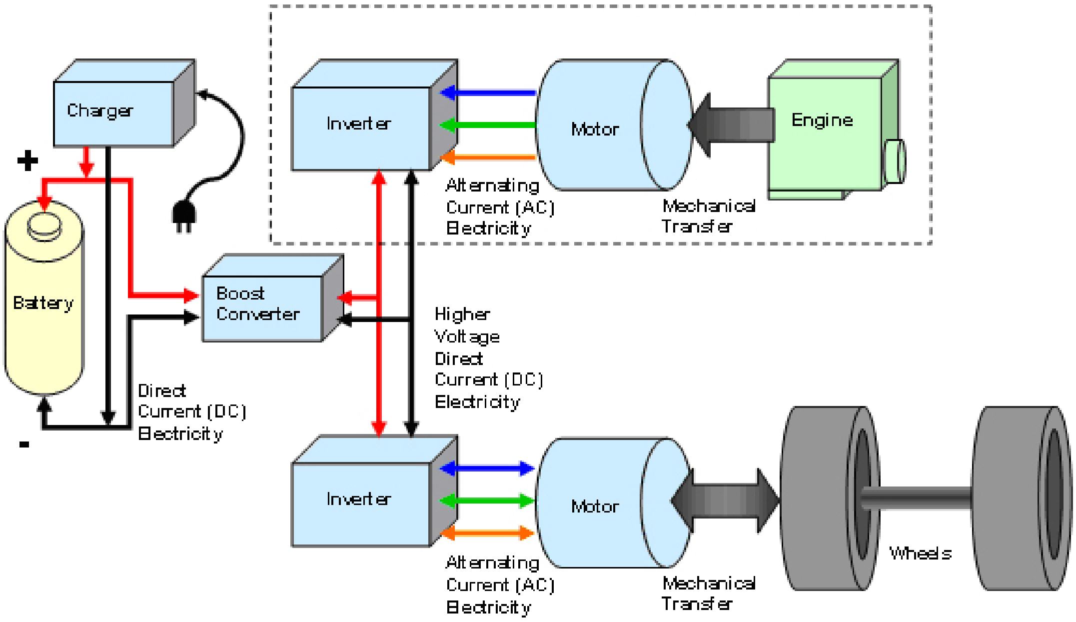


Figure 6: Plug-in Hybrid [10]

3 Regulations and taxes to minimize emissions

This chapter will provide an overview over which legislations to reduce emissions from passenger cars are in action in the EU and Norway at present, and some of the regulations on emissions and air pollution.

3.1 European Union

The European Union, EU, was formally established in 1993, but has been an active community among the European countries since after the Second World War. EU's primary goal was to prevent the European countries from going to war with one another. The EU is an economical and political union, currently with 27 member countries [12].

The EU has a set of institutions in order to have a joint decision-making process, this is unique in international cooperation. The EU also has a joint legal system to solve conflicts that may occur and make sure that the member states live up to the mutual agreements [13]

The European Parliament is the world's largest multinational parliament. The representatives of parliament are from the member countries and are elected every five year. The parliament passes laws, approve the EU budget, approve new member countries and regard the activity of the European Commission [12].

The European Commission is the Executive institution in the EU. The Commission has 27 commissioners one from each member country. The Commission has the exclusive right to propose new legislations, which have to be passed by the Parliament. It is the Commissions responsibility to ensure that final decisions are carried out and fulfilled [12].

The main legal acts from the EU come in three forms, regulations, directives and decisions.

- Regulations become law in the member states the moment they come into force.
- Directives require member states to achieve a certain result, while leaving the choice of how to achieve the result up to each member state.
- A decision offers an alternative to the two legislation forms above. They are only applied to specified individuals, companies or a particular member state.

Regulations, directives and decisions are of equal legal value and apply without any formal hierarchy.

3.1.1 Legislations

Emission Standards

The European emission standards define the acceptable limits for exhaust emissions from new vehicles sold in EU. In 1970 the first European Union Directive 70/220/EEC for emissions standards for new vehicles was introduced, and has since been upgraded several times. The emission standards are defined in a series of EU Directives staging the progressive introduction of increasingly stringent standards.

The emission standards currently include nitrogen oxides, NOx, hydrocarbons, HC, carbon monoxide, CO, and particulate material, PM, but not carbon dioxide, CO_2. New vehicles are tested through a standardized test-cycle to verify that they are within the acceptable limit for emissions. There are no specified technologies that are favoured to reach the emission target, but the standards are sett considering the available technology [14].

The stages are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6 fuels for light-duty vehicle standards. Light-duty vehicles are passenger cars and light commercial vehicles. Each of the Directives supersedes the original Directive from 1970 [14].

Important regulatory steps implementing emission standards:

- Euro 1 standards in 1993
- Euro 2 standards in 1996
- Euro 3 standards in 2000
- Euro 4 standards in 2005
- Euro 5 standards in 2009
- Euro 6 standards in 2014

Since Euro 2 there has been a difference in the emission limits for diesel and petrol cars. The diesel cars are allowed higher NOx emissions, but have more stringent CO standards.

In the standards Euro 3 and Euro 4, the fuel regulations became more stringent, with a maximum content of sulphur in fuel. Sulphur-free diesel and petrol had to be available from 2005, and became mandatory in 2009.

In the Euro 5 directive petrol cars were no longer exempted from PM standards. Petrol cars with direct injection will have a limit of 0,005g/km [14].

Table 3.1: EU Emission Standards for Passenger Cars, (g/km) [14]

	HC	NOx	HC+NOx	CO	PM
Positive Ignition (Petrol)					
Euro 1[a]	-	-	0.97 (1.13)	2.72 (3.16)	0.14 (0.18)
Euro 2	-	-	0.5	2.2	-
Euro 3	0.20	0.15	-	2.3	-
Euro 4	0.10	0.08	-	1.0	-
Euro 5	0.1	0.060	-	1.00	0.005*
Euro 6	0.1	0.060	-	1.00	0.005*
Compression Ignition (Diesel)					
Euro 1[a]	-	-	0.97 (1.13)	2.72 (3.16)	0.14 (0.18)
Euro 2	-	-	0.7	1.0	0.08
Euro 3	-	0.50	0.56	0.64	0.05
Euro 4	-	0.25	0.30	0.50	0.025
Euro 5	-	0.18	0.23	0.50	0.005
Euro 6	-	0.08	0.17	0.50	0.005

a – Values in brackets are conformity of production (COP) limits
* Applies only to vehicles with direct injection engines

In 2000 the emission testing was modified, so that the 40 s engine warm-up period before the emission sampling was removed. The test is now performed with a cold start, and this test is referred to as the New European Driving Cycle (NEDC) [14].

A problem with the standard cycle-test is that Manufacturers would engage in "cycle-beating" they would optimize emissions performance for the cycle-test, and pass without actually reducing emissions to the standard limits. So when the cars were used in real-world driving the emissions would exceed the accepted limits.

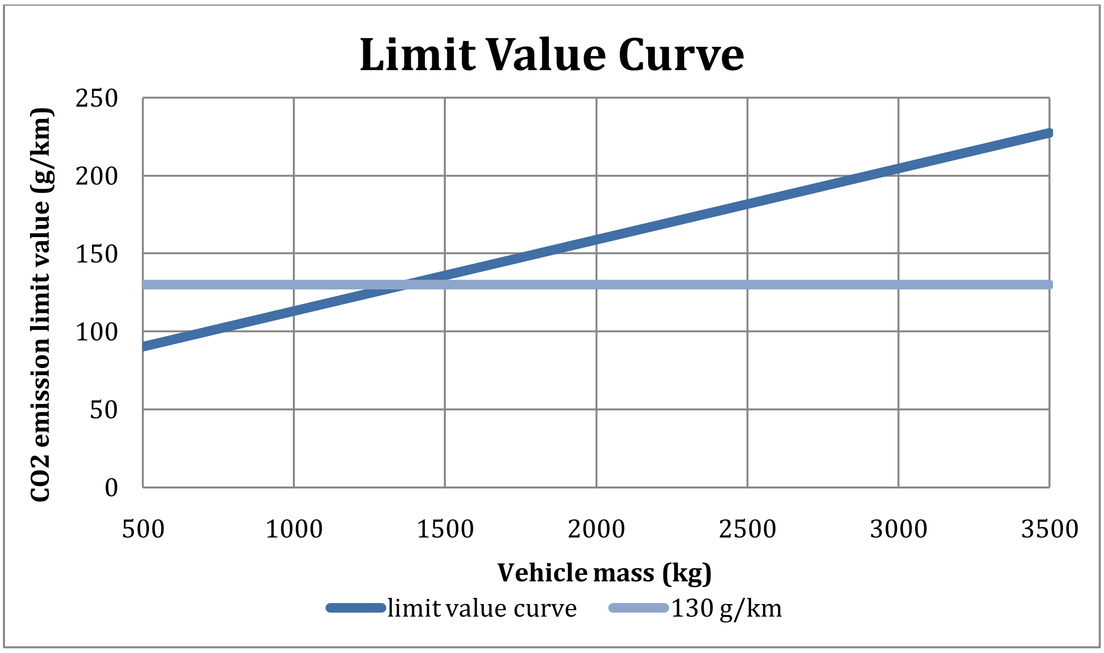
CO_2 emissions standards from light-duty vehicles

On April 23rd 2009 a new regulation was officially published by the European Parliament and the Council, with the objective to set a CO_2 emissions performance standard for passenger cars as an integrated approach to reduce CO_2 emissions from light-duty vehicles.

The aim of this Regulation is to create incentives for the car industry to invest in new technologies. The Regulation also actively promotes eco-innovation and takes into account future technological developments [15].

Some of the key elements in this Regulation are; limit value curve, phasing-in of requirements, lower penalty payments for excess emissions, long-term target and eco-innovations.

The **limit value curve**, which states that the average emission for the car fleet registered in the EU, should be 130g CO_2/km. This is a curve that shows permitted emissions of CO_2 for new vehicles based on the mass of the vehicle. So that heavier vehicles would be able to emit more CO_2 than the lighter vehicles. The curve is set so that the heavier vehicles will have to improve more than the lighter ones. For manufacturers to make cars with emissions above the limit they will have to balance them out with vehicles that emit less than the limit. To monitor the progress of the manufacturers, new car registration data would check once a year by the Member States [2].



Limit value curve

Limit value curve, Permitted specific emissions:

1) From 2012 to 2015:
   Specific emissions of CO_2 = 130 + a x ($M - M_0$)
   Where:
   a = 0.0457
   M = mass of the vehicle in kilograms (kg)
   M_0 = 1372.0

2) From 2016:
   Specific emissions of CO_2 = 130 + a x ($M - M_0$)
   Where:
   a = 0.0457
   M = mass of the vehicle in kilograms (kg)
   M_0 = by 2014 and every three years thereafter measures shall be made to adjust this figure, to the average mass of new passenger cars.

The average emission is to be phased in over the next years, so that an increasing percentage of the newly registered cars will have to meet this requirement. A table over the percentage of new passenger cars that have to meet the target of CO_2 emission is presented here:

Table 3.2: Percentage of new passenger cars that have to meet the requirements [15]

Year	Amount of cars
2012	65%
2013	75%
2014	80%
2015	100%

From 2015 and onwards 100% of the new cars produced in the EU have to meet the emission standard. Excess emissions from the year 2012 and onward will result in penalties payments, so called excess emission premiums.

If the average emission from a manufacturer's fleet exceeds the specific emissions target of 130 g CO_2/km in that year, they will have to pay a premium for every excess g CO_2/km the car emits. The premium will be lower the first four years, and then rise in 2019 [15].

From 2012 until 2018:

Table 3.3: Premium for excess emissions

g CO_2/km that exceeds	Premium in Euro, €
First	5€
Second	15€
Third	25€
Each subsequent	95€

From 2019: every g CO_2/km of excess emission will be fined with €95.

The long term target is to reduce the emissions to 95 g CO_2/km in 2020.

The testing procedure used for vehicle type approval is outdated, thus certain innovative technologies cannot demonstrate their CO_2-reducing effects under the approval test. In 2014 the test procedure will be reviewed. As an interim procedure manufactures are granted a maximum of 7 g CO_2/km emission credit on average for their fleet if they equip vehicles with innovative technologies. The credit is based on data for the different types of technologies.

The European Commission started work on reducing CO_2 emissions from cars in 1995. The strategy was based on three pillars: voluntary commitments from the car industry to cut emissions, improvements in costumer information and the promotion of fuel-efficient cars by means of fiscal measures [15].

The first pillar was to get the automobile manufacturers' associations in Europe, Japan and Korea (ACEA, JAMA and KAMA respectively) which supply 98% of the cars sold in EU market, to negotiated and implemented some important voluntary commitments. These commitments were that all parties are to work towards the same quantified average emission objectives for passenger cars, and that this goal is to be reached mainly by technology development and market change. The goal was then emissions of 140 g CO_2/km by 2008 for European manufacturers, and 2009 for the Japanese and Korean manufacturers [15].

The second pillar was to raise awareness among the consumers, so that they know the fuel efficiency information and CO_2 emissions of the car they are purchasing. This is done through a label displayed on each new car showing its characteristics [15].

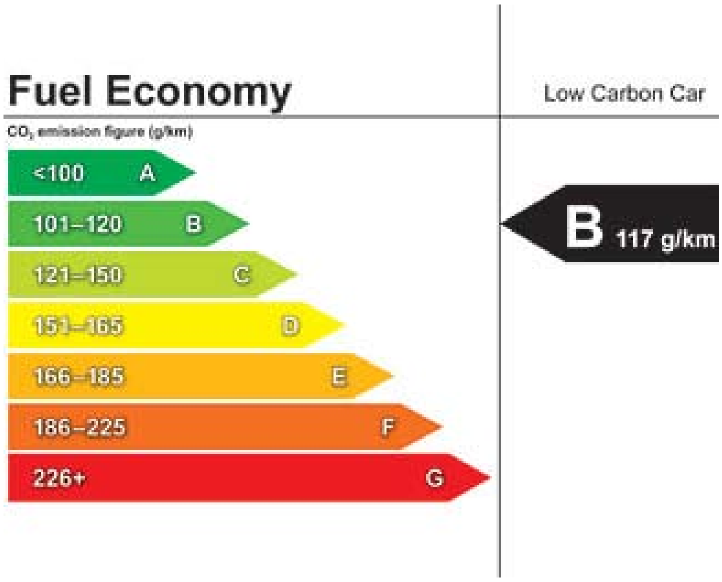


Figure 8: EU-energy label [16]

The third and last pillar aims to promote fuel efficient cars through fiscal measures. Some member states had already implemented such measures, and the council have

In 1998 the ACEA adopted a commitment to reduce CO_2 emissions from new passenger cars. The commitment was to reduce average emissions from new passenger cars to 140 g CO_2/km by 2008. A year later, in 1999, the Japanese and Korean Automobile Manufacturers' Associations also adopted a commitment. They committed to reducing the average emissions to 140 g CO_2/km by 2009 [15].

After revising the strategy in 2006, the commission reached the conclusion that the voluntary approach had delivered a solid reduction in CO_2 emissions, but the expected progress was to slow. So the target of 120g CO_2/km would not be met by 2012 without additional measures.

The revised strategy was then to make a comprehensive set of measures to influence the EU market, both supply and demand for light-duty vehicles. These measures were to promote affordable fuel efficiency improvements and reductions in CO_2 emissions [2].

Some of the main measures for the revised strategy were:

- Introduce a new legislation to reduce CO_2 emissions from light-duty vehicles.
- Improvement in motor technology to reduce the emissions to 130 g CO_2/km. Additional reductions should be made through efficiency improvements for cars such as tires, air conditioning systems, and gradual reduction in the carbon content of road fuels, notably through greater use of biofuels. These complementary measures should cut the emissions by up to 10g CO_2/km, reducing the overall emissions to 120g CO_2/km.
- Support research efforts aimed at achieving the long-term goal of average 95g CO_2/km for new passenger cars.
- Measures to promote the purchase of fuel efficient vehicles.

It was in the proposal from 2006 that the limit value curve was first introduced.

The legislation should also provide a guideline for penalties for exceeding the average emission target, so that manufacturers that have not met this target will have to pay a fine. The fine will be based on the numbers of grams per kilometre (g/km) that an average vehicle is above the curve, multiplied by the number of vehicles sold. The fine penalties should be set at a level which encourages manufacturers to innovate and deploy new fuel technologies, rather than accepting to pay the fine. The manufacturers are expected to meet the target set by the legislation and not have to pay significant penalties [15].

The legislation will affect all of the manufacturers that sell vehicles in the EU, so that the competitiveness of the European car industry maintained. Two or more manufacturers can go together and form a pool, so that the manufacturers can jointly reach the target.

Eco-innovation, by using innovating technology that make verified contributions to CO_2 reductions, a manufacturer can be granted a credit of maximum 7 g CO_2/km. The standard test cycle is not able to test emissions from innovating technology, so until 2014 when the test cycle has been reviewed emissions will be calculated from data.

3.1.2 EU periodic roadworthiness test

The Council Directive 96/96 EC of December 1996 mandated all the member countries to carry out roadworthiness tests of vehicles in their country. The Directive states that vehicles registered in the member countries have to undergo a roadworthiness test. Since 1996 the directive has been amended several times. The latest is Directive 2009/40/EC of the European Parliament and of the Council [17].

The objection of this Directive is to create a framework to assure that certain road traffic within the community should operate under the most favourable circumstances. This Directive is a measure to maintain low emissions from vehicles throughout their useful life by regular testing of the exhaust emissions. And then to remove vehicles that are major polluters until they are brought to a proper state of maintenance [17].

Each member state is responsible for testing the roadworthiness of motor vehicles that are registered in that state, and make sure that the test are conducted methodically and to a high standard.

The Directive states clearly the category of vehicles to be tested, the frequency of the roadworthiness test and the items that must be tested. The testing of a vehicles lifecycle should be relatively simple, quick and inexpensive [17].

3.2 Norway

3.2.1 EEA agreements

Norway is not at present a member of the EU, but became a member of European Economic Area (EEA) in 1994, in context of being a member of European Free Trading Association (EFTA). The EEA include the EU member countries, Norway, Iceland and Liechtenstein. The EEA agreement regulates the restrictions on trade and other economical relations between the EFTA countries and the EU member countries. So the EFTA countries that also are members of the EEA have the same advantages as the EU member countries in the single market. And thereby subordinating one self to EU rules of competition the four freedoms; free exchange of goods, service, labour and capital.

The EEA agreement also involves participation in a number of other EU programs. Such as innovation, research work, education, information services, energy, transport, public health, social policy, cultural work, media and disaster contingency [18].

Seen as Norway is not a member of the EU, they can not participate in the European Parliament or the European Commission. Norway is not able to join in on the decision-making process.

Through the EEA agreement, Norway is obligated to cooperate with the EU in the environmental field. Therefore the environmental policy in EU has a great impact on the Norwegian environmental policy. As a receiver of the pollution from the European countries, it is in the Norwegian interest that the EU member countries have a strict environment policy [18].

3.2.2 Norwegian legislations

In Norway the fiscal measures to reduce CO_2 emissions from passenger cars is applied through a registration tax, an annual vehicle duty and fuel tax [19].

The registration is paid when the car is source recorded for the first time in Norway. This tax is a combination of the cars CO_2 emissions, weight and engine rating. In 2009 the registration tax was revised for cars that emit less than the target of 120g CO_2/km, this was done by a reduction in the tax, so that for every gram less the car emits the tax is reduced by 500 NKR, to entice buyers to purchase a car with low emissions [19].

The annual vehicle duty is a fiscally explained duty which all car owners in Norway have to pay. The duty was first introduced in 1917, as a taxation of "luxury". From 2008 a new environmental aspect of the annual vehicle duty was introduced, this meant that owners of diesel vehicles without a manufactured particle filter would have to pay an additional 430 NKR on their annual vehicle duty, the reason for the additional payment was to stimulate purchase of less polluting vehicles [19].

The fuel tax includes the petrol fuel tax and the diesel fuel tax; these are taxes dependent on the use of a vehicle. They are meant to cover the negative effects associated with the use of a vehicle, such as queues, local emissions, noise, accidents, road ware etc. The fuel tax for both petrol and diesel fuel is paid per litre of fuel, the tax is the same throughout Norway.

The petrol fuel tax was introduced in 1933. In 1985 there was a differentiation in petrol containing lead and unleaded petrol, this has resulted in nearly no use of leaded petrol. In 2005 the tax distinguished between petrol that was free from sulphur, low sulphur petrol and other petrol. This resulted in a complete transition to sulphur free petrol.

The diesel fuel tax came to in 1993. In 2005 the tax was also distinguished between sulphur free and sulphur diesel fuel, which resulted in the sulphur being phased out of the diesel fuel

In 1999 a CO_2 tax was introduced, with the purpose to reduce CO_2 emissions. From 1991 until 1998 the CO_2 tax was embodied in the fuel tax. In 2009 the CO_2 tax was 0,84 NKR/l for petrol and 0,57 NKR/l for diesel fuel [20].

In Norway there are some economical benefits from purchasing electrical cars and cars that run on hydrogen. As stated earlier the registration tax for vehicles that emit less than the EU target is lower, but electrical and hydrogen cars are exempted from this tax. These vehicles are also exempted from paying road toll and other expenditures such as parking charge. Electrical and hydrogen cars also have authorized access to the public transportation lane for buses and taxies.

3.2.3 EU Periodic Roadworthiness test in Norway

In accordance with the EEA agreement Norway introduced a periodic roadworthiness test of vehicles in 1995, though only for heavy vehicles. The inspection scheme was extended to include vans and combined vehicles in 1996, and in 1998 passenger cars were also included to undergo a periodic roadworthiness test [6]. The inspection scheme is regulated through EU Directive 2009/40/EC, and also includes the exhaust gas from vehicles [5].

The environmental reasons for such a periodic test are; to check that the motor on each vehicle is correctly adjusted, and monitor the car fleets environmental standard with a view to evaluate and plan future measures. The main contributions to local emissions in built-up areas and cities come from road traffic, where the worst components are CO, HC and NOx. A periodic test is a measure to reduce emissions, especially local emissions [21].

In Norway an owner of a car that weighs less than 3500 kg, has to have an EU periodic roadworthiness test every other year from the fourth year after the car is first registered in Norway. Heavier cars have to be checked after two years from the car is first registered and have to have a periodic test every year. The test is performed at a test station approved by the Public Road Administration (Statens Vegvesen) or duly authorized private bodies.

In this test the exhaust gas emissions of a vehicle are measured. Through a periodic test vehicles that do not fulfil the requirements can be removed from the road traffic and repaired to meet requirements.

The emission requirements are sett from when the car was produced. So the emission requirements are more stringent for newer cars, than for older ones [21].

Table 3.4: Parameters of measurement at a periodic roadworthiness test [21]

Vehicle type	Parameter of measurement
Petrol car with a catalyst	CO-contents in the exhaust on idling speed CO-contents and the excess air ratio on raised idling speed
Petrol car without a catalyst	CO-contents in the exhaust on idling speed
Diesel vehicles	Opacity/smokiness at free acceleration

Opacity is a term used for the particulate concentration in an exhaust gas. When opacity is measured the motor is accelerated from idle speed to de regulated rotational speed with no other resistance then the motors inertia [21].

The effect of such a periodic inspection scheme will depend on the composition of the total car fleet in use, the average age and the amount of maintenance of the cars. HC and CO from vehicles cars and particulates from diesel vehicles are generally maintenance related emissions. NOx is usually not a maintenance issue, unless the catalyst is defect or has been poisoned [21].

4 Overview of suggested measures to reduce CO_2 emissions

4.1 European Union

The emissions from the transport sector are rapidly increasing. There is a large potential to reduce the emissions from passenger cars through different measures. In resent years there has been an increase in vehicles sold, and the consumers want larger vehicles. Even though the average CO_2 emission per car has been reduced over the past years, the increase in purchased vehicles has a negative effect on the total emissions.

4.1.1 Fiscal measures

In the EU the member states have different tax systems for passenger cars. Therefore a harmonisation in the national passenger car taxation systems could be implemented. EU could require a re-structure of the taxation systems for passenger cars, so that taxation systems were equal in all of the member states. Within this requirement there should also be a CO_2 tax.

Fiscal measures were a CO_2 taxation could be implemented are registration tax, annual vehicle duty and fuel tax, along with fiscal incentives for the purchase of more fuel efficient vehicles. The purpose of CO_2 taxation is to entice consumers to purchase and use of low emission vehicles.

Fiscal measures provide a strong incentive value, and could be essential to encourage the rapid renewal of the car fleet.

In 2002 COWI A/S was assigned the contract to examine a fiscal framework measures for the EU member countries for the reduction of CO_2 emissions from new passenger cars. They investigated different scenarios of national vehicle taxations and the effect they would have and how taxation can help to produce cars that will emit less CO_2 [22].

The report has investigated three different taxation scenarios; effectiveness of the existing tax system, adding CO_2 differentiation and purely CO_2 differentiated taxes.

- Existing taxes: As mentioned the member states operate with different taxation systems, some do not utilize registration tax. A simple increase of tax with no alteration to either tax base or the differentiation schemes provides only very small reduction in CO_2 emissions

- Adding a CO_2 differentiation to the existing tax system provides a significant reduction in CO_2. If incentive for the most energy efficient vehicles were given simultaneously, the reductions would increase further.

- If the tax system was entirely based on CO_2 emissions, where the taxes were significantly differentiated the CO_2 could be largely reduced. This system of taxation has the largest potential for reducing CO_2 emissions through fiscal measures.

In the conclusions the report COWI emphasizes the need to differentiate taxes in such a way that for very energy effective cars the taxes are significantly lower than that for cars with poor energy efficiency.
It is obvious that a taxation system which favours vehicles with low CO_2 emissions would give significant reductions in CO_2. The EU could order the member states to implement a national taxation system that differentiates CO_2 emissions and give incentives to vehicles that are more efficient [22].

Fuel tax has also been investigated, and the COWI report states that an increase in the fuel tax only provide a very small reduction in CO_2 emissions compared to vehicle taxes. Fuel taxes may however be an effective mean of controlling the total CO_2 emissions from passenger cars.
Since CO_2 emissions are linked to the fuel consumption, a car which uses less fuel will emit less CO_2. Therefore by increasing the price of fuel, or the taxes on fuel, the consumer will be enticed to buy a more efficient vehicle.

In Denmark they have decided to remove all taxes on electric vehicles until 2015. To boost the number of electric vehicles and reduce CO_2 emissions, and encourage manufactures and wind projects [23].

There has been put forward a suggestion to increasing the proportion of diesel vehicles, since diesel vehicles generally emit lower amounts of CO_2 than petrol vehicles. This would only have an effect in countries where the current proportion of diesel vehicles is low. If that is the case relatively high CO_2 reductions could be achieved. Such a replacement is not entirely positive, seen as diesel vehicles emit larger amounts of NOx.

The EU could require member countries to mix a higher percentage of biofuels in the fossil fuels. This lowers the CO_2.

Road cost for vehicles is a type of taxation which is not at present a widespread measure. A GPS-based taxation system has been recently been up for discussion in the Netherlands. They propose to replace the registration tax with the road cost system. The aim is to make a consumer pay for the use of a car and not the ownership.
A GPS registers the distance a vehicle travels and calculates the road cost based on the distance covered. This is a system that makes it more expensive for those who use the vehicle more frequently, and for longer distances. The GPS-based system has met some scepticism through claims that such a system is a violation of privacy.

The alternative to a GPS-based system for road cost could be to base it on trust. A car owner would have to state the distance covered in a year, as one would for a car insurance company, and pay for usage of the car. The principle for the road cost would be the same. [13]

4.2 Norway

In March 2010 the Norwegian government presented a report called climatic treatment 2020 (klimakur 2020). This report was composed on request by the

Department of Environment. Several different agencies came together and assessed climatic problems and examined measures and policy instruments to reach the Norwegian climatic targets of 2020. The Norwegian target is to reduce national emissions with 15-17 million ton CO_2 equivalents by the year 2020. This reduction is a total of all the sectors in Norway, this chapter will concentrate on the measures of the transport sector [3].

Within the transport sector a reduction of 3-4.5 million ton CO_2 equivalents is feasible by the year 2020. Such a reduction requires stern measures, large investments and a strong political will. A long-term strategy for the transportation sector is needed, were the measures must be adjusted over time as the effect of them are known [2].

The largest emission reduction can be achieved through use of biofuels and energy efficient vehicle technology. An upgrade and expansion of the public transportation combined with a significant increase in vehicle taxations will result in a reduction of emissions. The measures assessed in the climatic treatment 2020 report are intended for Norway, and they are also based on a sufficient supply of biofuels. The report has not taken into account the impacts that the increasing use of biofuels might have in other countries [2].

The Norwegian transport sector is complex and there is large range of different needs. Measures within the sector are often dependent on each other, and therefore the cost and effect will vary based on the formulation and dimension of the measures.

4.2.1 Vehicle technology

- Improvements in engine efficiency of petrol and diesel fuel passenger cars and vans
- Introducing electrical cars, plug-in hybrids and hydrogen cars.
- Car tyres for passenger cars
- Environmental driving in passenger cars

Efficiency improvements of fossil fuelled passenger cars could be more effective internal combustion engine technology, hybridisation of propulsion systems, reduction in driving resistance and improvements in components and systems.

Introducing new vehicle technologies such as electrical vehicles, hydrogen vehicles and vehicles powered by renewable biofuel shows a large potential in reducing emissions. Replacing the entire car fleet in Norway will be a long process and fossil fuels will still be a main part of the energy used in many years to come.

Car tyres with less rolling friction could potentially reduce the emissions from cars, by fuel reduction.

Eco-driving courses for car owners, teaching them how to use less fuel while driving. the CO_2 reductions from this measure has a small potential, and is also dependent on that drivers actually use this knowledge when driving.

4.2.2 Reducing road traffic from passenger cars

- Improved public transportation in the six largest cities with and without restrictions in car traffic.
- Long distant coach
- Reduced car traffic through increased fuel prices, queue pricing, parking restrictions and reduced public transportation prices
- Doubling the share of bicycles (investments, maintenance, signage/information)
- Intercity-trains
- High-speed trains (Oslo-Trondheim, Oslo-Bergen)

In 2000 the Norwegian Department of the Environment started up a project to reduce local emissions in the largest cities in Norway. The goal of this project is to develop sustainable cities for the future, so called environmental city. One of the benefits of Co-ordinating the planning of area and transportation in the inner city areas is to reduce the use of passenger cars and increase the use of public transportation [24].

In the largest cities in Norway improved public transportation would be an important measure in reducing the CO_2. Upgrade and increase in the frequency of departures could tempt more travellers to use their car less.

Reducing prices in public transportation could lead to an increase in people using public transportation.

Parts on the cities could be off limits for cars, so that only public transportation could traffic the city centre. Or a road toll for cars driving into the city could be introduced. Road toll can make car owners leave the car at home and use public transportation, or park outside the city or increase the amount of people travelling per car.

In London city road toll is used to restrict the road traffic going through the centre. To drive into the heart of London you have to pay a significant road toll. This has resulted in a reduction of cars travelling in to London [25].

Long distant coaches are an important alternative to passenger cars. By having long distant coaches travelling from the district areas and into the larger cities and densely populated areas would give people how are dependent on their car an alternative.

As mentioned above, reducing car traffic and thereby emissions trough fiscal measures has a large potential. Norway has already a significant taxation system compared to other countries in Europe, with the registration tax, annual vehicle duty and fuel tax. But also in Norway a differentiation of CO_2 emissions could result in reduced CO_2.

Reducing the amount of parking spaces in the cities, making it harder for car owners to find parking, could make public transportation, bicycling or walking a more tempting way of travelling. This measure could be reinforced by increased parking charges.

Increasing the amount of bicycle paths and creating bicycle-networks in cities and built-up areas is an option. This requires some enticement through advertisement and campaigning to make more people aware of the option

Build Intercity-trains in the largest cities in Norway. The trains would travel from the city and till the surrounding areas. Frequent departures and easy access form commuting areas could make intercity-trains a preferred mean of transportation.

More junctions for the public transportation, making it is easier for people commuting to change the mean of transportation. By placing trains, buses and the underground in junctions makes it more accessible for persons travelling both in and out of the city

Introducing high-speed trains between the largest cities in Norway, such as Oslo-Bergen and Oslo-Trondheim would make it easier for people travelling over longer distances. High-speed trains would have fewer stops than the regular train, and cover distances in a shorter space of time. This could reduce some of the long distant drives, but would more likely be a competitor to the air traffic.

5 What is the best solution for Norway?

5.1 On a National level

In Norway some of the potential of reducing CO_2 emissions through taxation systems is already utilized through the fuel tax and the registration tax, though improvements should be made.

The registration tax in Norway has over the past year had minor alterations. The tax is as mentioned in chapter 3.2.2 based on weight, motor rotation and CO_2 emissions. All of these components are highly progressive and do not serve an environmental cause.

The tax can vary greatly for two cars that have the same CO_2 emission. Dependent on weight, size and numbers of seats, a larger amount of these parameters results in a larger tax. The CO_2 part of the registration tax is currently not large enough to make a difference.

An example; a manufacturer may introduce a new car model which emits less CO_2 and is safer, than the one before. The registration tax for this car would be larger than for its predecessor if the engine efficiency is higher, or the weight has increased, even though the predecessor emitted more CO_2 [26].

Today's registration tax system does neither take into account that every car uses the same space on the road, nor the transportation volume of a car. This results in a large difference in price for small and large vehicles.

A rational solution to reform this tax is to have a basic tax for every new car, and then have a taxation that rewards cars with low CO_2 emissions per passenger-kilometre. Passenger-kilometre is the amount of CO_2 emitted per passenger there is room for in the car.

The objection of creating this tax system is to reduce CO_2 emissions and encourage consumers to purchase safer and fewer vehicles [26].

The price of fuel can have an impact on a traveller's choice of transportation. In Norway there is already a CO_2 tax within the fuel tax, so part of the potential for CO_2 reductions through this measure is already utilized. Increasing the CO_2 tax on fuel significantly could alter a consumer's choice when purchasing a car and/or direct them over to a different mean of transportation.

Introducing road tax in Norway could give significant reductions in car usage. If every car owner had to pay a tax for the distance covered every year, they might use other means of transportation, especially for long distances. Implementing such a measure should not be done independently.

By introducing one or more of the taxation system that favours cars with low CO_2 emissions and fuel efficient engines will encourage consumers to purchase more environmentally friendly vehicles.

It will also make manufacturers invest in more eco-innovative technologies if they know that the vehicles will be sold. This implies that a CO_2 based taxation system also would be utilized in the EU member countries it might not be the case if only Norway were to have such a tax system.

5.1 Local emissions in cities

Norway is a country with vast differences in need for transportation. There are a large number of cities and densely populated areas where transportation over short distance is most needed. But there are also many district areas where the need for long distant transportation is essential and efficient vehicle technology for the people living there who are dependent on their cars.

For the cities and densely populated areas the need for public transportation, in form of buses, intercity trains and undergrounds should be introduced and upgraded. In such a way that there are more frequent departures and that the transportation means are easy to access from outside the centre.

By prioritising lanes for bicycle and pedestrians, creating a network through city centres and making it easy to access could increase the transportation choice.

Restricting the inner city from passenger cars, making it only available for public transportation, or restricting parking spaces and introducing road toll to travel into cities could potentially have a large impact on local emissions and the choice of transportation mode. These measures should not be utilized before the public transportation has been improved.

By only improving the public transportation, without any additional fiscal measures, such as tax, would not give considerable reductions in emissions.

Land planning in cities and densely populated places could reduce the transportation need. By strategic placing of housing area, work area, service functions and public transportation junctions the need for transportation could be reduced.

Zero-emission vehicles are the best solution for cities and densely populated areas. As mentioned they do not emit green house gases while used. For the use of zero-emission vehicles to benefit not only local but also global emissions, the energy must come from renewable energy sources.

Though electric cars can be good for the environment, especial in cities, replacing the entire car fleet with electric cars is not a sustainable solution. The reason for that is the electricity needed to power such a large amount of cars could not in the near future be made by renewable energy. The energy would come from a process that is more harmful to the environment, such as a coal-fired power plant. This electrical production is potentially worse compared to the commercial internal combustion engine when considering well-to-wheel emissions.

6 Conclusion

In this thesis the focus has been to find the optimal measures for reducing CO_2 emissions from the road traffic in particular passenger cars. Vehicle technology, legislations and fiscal measures have been examined, while focusing on the development of the European Union.

Vehicle technology plays an important role in reducing CO_2 emissions. Improving vehicle efficiency and mixing a higher percentage of biofuel in fossil fuel will give large reductions. The passenger car fleet will in years to come be dependent on fossil fuel, and replacing the entire car fleet will not be a rapid process without further measures.

Through the EU regulation for emissions from passenger cars the manufactures have committed to produce more efficient vehicles. This measure alone will not reduce the emissions from passenger cars rapidly. Further legislations from the EU government should be implemented.

By introducing the CO_2 based taxation systems, manufactures will have to produce and develop and produce more energy efficient vehicles.

Creating a harmonised passenger car taxation system for the European member states is essential for reducing emissions. This should be a taxation system that is directly or indirectly CO_2 related, for a significant reduction in CO_2. The purely and directly CO_2 related taxes would offer the largest reductions.

In Norway an alteration of the registration tax is needed, so that the tax is directly CO_2 related, if the tax objective is to prohibit CO2 emissions. This offers consumers and manufacturers an opportunity to purchase and develop more energy efficient vehicles.

For a significant reduction of CO_2 emissions there has to be a large political will, both to regulate the national taxation system, but also to invest in means of public transportation. Implementing one measure alone will not have a large impact, several measures should be used simultaneously to have the greatest effect.

Not only reducing emissions from passenger cars, but also reducing the use of passenger cars by means of public transportation is important, to reduce the total emissions. Investments in public transportation should occur before or simultaneously as other measures for reducing usage of cars are implemented.

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