D3.1 Traffic and Transport Integration Report

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14 June 2011
Version 1.1

Preface

In industrialized countries, such as the EU and Finland, climate change has given rise to a desire to reduce CO_2 emissions caused by traffic. The CO_2 emissions of traffic are caused by the dominant status of fossil fuels as the main source of energy for transportation. Traffic-wise, the most significant amounts of emission are caused by passenger cars, which has led to the idea of developing electrically-powered cars.

At the current level of technical know-how, it is impossible to convert a present-day passenger car to an electrically-powered car so that the usage of that car would be totally equivalent to that of liquid fuel-driven car. The essential difference is the range of electric car, which is only one third or fourth of the range of a car powered by liquid fuel. Partly this is due to the high cost of the batteries, and partly to the technical properties of the batteries. One significant factor is that charging a battery pack takes time long compared to filling a fuel tank. These differences affect the usability of the car, since they change the ways the car is used. Furthermore, to facilitate the usability of electric cars within their range everywhere, a standardized system of energy supply similar to the liquid fuel supply system needs to be created for electric cars.

A general goal in the development of electric cars has been to resolve the differences in the usability of electric cars and current internal combustion engine cars. This goal is understandable, considering that transport habits and community structure in industrial countries are largely based on using private passenger cars. At current technological level, the properties of an electric car are equivalent to those of an internal combustion engine vehicle in city conditions. Car’s one-time or daily drive-kilometres are considerably less than the range of electric car, and car is left unused for so long that it is possible to charge the batteries with low power, if electricity is available.

Therefore, in city conditions the conversion of cars into electrically-powered vehicles does not necessarily affect traffic and transport habits, if the charging of the cars is possible to arrange feasibly. However, the conversion of cars as they are today into electric ones is not necessarily enough to meet the emission quotas set for automotives. There are several other reasons as well for considering the electrically-powered vehicle technology in a larger view than as the concept of present-day car, where the energy charged into the vehicle is electricity. Special problems are the spatial needs of present-day cars concerning parking and the capacity of street network.

This study researches the opportunities that electricity as the energy source for a vehicle offers to the development of vehicle technology, traffic system and community structure. The nature of potential development scenarios and their feasible schedules are defined in the next stages of this study. The research work and report writing is done by Antero Alku, M.Sc. under guidance of Iisakki Kosonen, Dr.Sc.

This study is a part of the SIMBe (Smart Infrastructures for Electric Mobility in Built Environments, see www.simbe.fi) research project funded by TEKES, which started at Aalto University School of Science and Technology at the beginning of 2010. Participants of the project include both public authorities and companies, whose operations and activities are associated with or based on electric vehicle technology. SIMBe is part of the TEKES Sustainable Community program, which aims to generate renewable business activities in designing, constructing and maintaining sustainable and energy efficient areas and buildings.

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Executive summary

Electricity has been used as propulsion power in transportation as early as from the late 19th century, but fuels refined from oil have remained as the dominant power source of private transport. Since the late 1900s there has been an increased interest in electricity for environmental reasons. Electricity has no local emissions and it can be generated with renewable resources and in a carbon dioxide neutral manner.

In Finland the energy consumption of the passenger car stock, when converted to electric cars, would mean a 10 % increase in electricity usage. With intelligent night-time recharging this amount of electricity can be produced with the current power plant capacity, but it has to be produced with load-following power, which means hydropower or coal power. The required 9.2 TWh of electricity could also be produced with the biomass growing in Finland. This electricity could also be generated with solar panels or wind farms, when utilizing both the compensatory effect of the batteries in energy production and the long-term production balancing with other energy production, such as cogeneration of electricity and district heating.

The pricing and taxation of electricity is based on industrial and household usage. Transportation energy has a special tax, which cannot be levied on electric vehicles without intelligent charging technology. Without this technology, the government will subsidize each electric car being charged with household electricity with approximately 1100 € of annual tax breaks compared to the current taxing scheme of petrol. A significant part of the price of transportation electricity is the cost of batteries. If the transportation electricity tax is the same in euros as the current fuel tax, together with the batteries transportation electricity is currently more expensive than liquid fuel at the moment.

The energy requirement per person kilometer at a steady speed for various vehicles varies within a ratio of 1:10 so that a passenger car with an unladen mass of 1450 kg requires ten times the energy of passenger rail traffic. In practice and especially in city traffic, stopping is crucial to the energy need. A significant benefit of electric vehicle technology is the possibility to recuperate kinetic energy back to batteries. This improves the position of a passenger car in relation to passenger rail traffic, but the car still needs about six times the energy needed by rail traffic. The energy requirement is mainly affected by the passenger car’s large mass, which is unnecessarily large for most of the passenger car usage.

From the viewpoint of both energy need and city and street space usage, the possibilities of electric vehicles lie in the new vehicle concepts available. Converting combustion engine cars to electric cars does not affect the functioning of the transportation system, nor will it remove congestion or other environmental problems, except eliminating exhaust fumes. An electric drive is structurally more flexible than a combustion engine, which makes such vehicle and usage concepts possible for which a combustion engine has been unsuitable.

Electrifying motoring and changing movement habits and community structures are long-term processes. This gives time to adapt to the change but also delays the realization of the sought effects. Adapting new types of areas and their traffic with old community structures will also be a challenge. Already the incompatibility between the traffic systems of low-density habitation zones and regional centers causes problems: public transport can not be arranged in sparsely populated areas, but in city centers the majority of passengers cannot travel by car due to the lack of space.

Electric vehicles, such as pedelecs or trikes, driverless electric conveyors or Segway-like vehicles expand people's mobility from that of just walking. But these devices can not fit into the same traffic space as modern automobiles. To save street and traffic space with less space-using solutions requires dividing street space between various uses, as the current split between pedestrian, bicycle and motor traffic is not enough.

The technology for electric battery-operated vehicles is still under development and for the time being both expensive and limited in availability. Western automobile industry does not seem to be willing to give up oil-based technology and the significant aftermarket connected with it. In some countries the government has strongly supported the proliferation of electric cars. The initial high prices and expectations of cheaper and better products reduce consumer interest in buying electric cars and their batteries. Various rent-based policies could be a way to improve the proliferation of electric vehicles.

The technical possibilities for the electrification of cars exist, but the desired development direction of transportation system and the desired goals must be decided politically. Meeting the EU-accepted emission goals by the year 2050 does not seem to be possible merely by electrifying the cars, if the concept of the car remains the same and energy production does not become CO_2-neutral. Electrifying cars does not remove the need to reduce movement needs and traffic in order to improve living environments. Reducing energy consumption requires lighter vehicles, the replacing of passenger car trips with a delivery system and a high-quality public transport in dense structures, such as city centers.

1 Introduction

The history of electrically-powered vehicles begins in the late 19th century, when electric motor was developed. Electrically-powered transportation became more common on a significant scale when overhead lines situated above rail tracks were invented. Overhead line was situated at a safe distance from people so that it was possible to start using high voltages and thus transmit enough energy for vehicles. In city mass transport electricity has been a significant energy source from the late 1800s.

Electrically-powered cars equipped with batteries were produced in the early 1900s. Their benefit was that they were easy to use, since starting a combustion engine with a crank was a strenuous and to some degree even dangerous task. However, the invention of electric starter motor ended the development of electric cars. Electrically-powered vehicles were used only in special situations, such as in warehouses, at railway stations for transporting luggage or for delivering milk bottles early in the morning. In other words, in locations or situations where exhaust fumes or the noise caused by combustion engine was out of question.

The basic structure of internal combustion engine cars has not changed since the serial production of passenger cars started at the early 1900s. One substantial change has been that diagonally situated motor and front-wheel drive became more common after 1960s, but otherwise the basic concept of a car has remained the same. More significant has been the change that car has brought about in the life style and community structure of people.

As a result of lowered real price of cars and car use, it has become possible for all households to own a car and use it. In consequence, workplaces and services have been able to situate themselves in locations beneficial to them without having to take into account public transport services. Likewise, families have been able to choose their place of residence mainly on other grounds than traffic communications. The outcome has been the diffusion of city and regional structures and the increase in drive-kilometres per person.

The real cost of motoring based on petroleum-based fuels is so low that the price of motoring does not have a significant effect on transport habits. Due to low cost, there has been no market-driven reason to develop alternative modes of transport either. Due to better operating efficiency, electrically-powered cars use less energy than liquid fuel-driven cars, but due to the cost of battery technology electric cars are clearly more expensive to use than combustion engine cars for motoring. The environment-friendliness of electric cars has not appealed to consumers as selling argument that would have made electric cars more popular.

Electric cars are considered as one way to reduce the CO_2 emissions of traffic. The operating efficiency of electric cars in proportion to the energy charged into cars is better than with internal combustion engine cars, but electricity has to be produced with some primary energy. The most essential question concerning electrifying motoring is how to produce the electricity needed by cars. With Finland's current electricity production profile, electric motoring is not CO_2 neutral, and it is obvious that in order to meet the environmental goals one has to address not only the form of energy used by the cars but also the quantitative consumption of energy by cars.

The development of electric cars and making them more popular and common require public investments and guidance, since market forces do not guide towards the transition from combustion engines to electric battery use. Converting a present-day passenger car to use electricity as its energy source will probably have practically no effect on the traffic system and community structure. Instead, along with electricity use potential nontraditional vehicle concepts can change transport habits and community structure.

This study researches the opportunities that electricity as the energy source of a vehicle offers to the development of vehicle technology, traffic system and community structure. The nature of potential development scenarios and their feasible schedules are defined in the next stages of this study.

2 Traffic and community structure

Community structure is a commonly used concept with a loose definition. In general, community structure refers to all kinds of environment built for human activity. In this context, the size of an area or density of structure are not considered as limiting factors. For example, buildings located apart from each other in the countryside are considered a part of community structure as well as the city blocks of an urban center.

Terms “urban structure” and “regional structure” are also used in connection with community structure. Urban structure means the internal community structure of densely built areas. Regional structure refers to community structure viewed at a rough level, as areas and as their relationships with each other. The term community structure may also be used to refer to urban structure alone.

Land Use and Building Act defines four levels of community structure planning in Finland: national area use objectives, regional land use plans, and local master plans and local detailed plans used in municipalities. According to Andersson's (1993) definition, all levels of community structure include habitation, workplaces, services and the connections between them. Concrete connections are pedestrian and vehicular connections, but also data communications form a part of community structure.

The interaction between traffic and community structure posed by Andersson (1993) in his doctoral thesis is nowadays a generally acknowledged phenomenon. One of the most concrete recent results of this interaction has been the diffusion of community structure in towns and cities which has been made possible by the use of passenger cars.

The significance of the interaction between traffic and community structure can be observed in history in several ways. Since antiquity cities and towns have been situated on the coast or along rivers that offered good connections. Travel and transport by land was scarce in proportion, but cities and villages grew at the nodal points and maintenance nodes of trade routes. The invention of railroad in the 19^{th} century provided more mobility at the countryside even outside the reach of waterways and around towns and cities, since the daily environmental range of people increased as the speed and capacity of transportation increased.

Traffic routes have been a dominant factor in urban planning. In addition to their monumental purpose, streets have formed the nucleus of urban transportation. The locations of ports and railway stations have defined the structure of cities and towns. City plans have been revised and reshaped rather intensively because of the spatial needs of transport. Smith-Polvinen traffic plan for Helsinki (Smith and Polvinen 1968) outlined motorways being partly built above sea and intersecting inner city, the demolition of rows of city blocks to make room for these motorways and the conversion of several buildings to meet parking needs. The plan was indicative of the radicalness of the changes planned for Helsinki inner city when the traffic system was undergoing a change from a public transport system into a passenger car-based system.

2.1 Spatial needs of traffic

Passenger car-based motoring has domineered traffic planning and through that community structure planning from the early 1900s as local material standard of living gave rise to motorization. The property of motoring affecting community structure the most has been the space required by cars. Space required by parked cars must have been taken into consideration when planning both residences and workplaces and services. Space required by cars on the move has set the dimensions for planning traffic routes.

The significance of the space required by cars can be illustrated by comparing it to the space required by people. In Europe, occupancy rate is 30–50 floor square meters per resident; in Helsinki the rate is 33.6 m^2 (statistical year 2004). Floor area designates the total constructed floor area of buildings, including also the stairways of apartment buildings, so apartment/flat area per resident is smaller than floor area per resident. A garage or a parking space in a parking facility requires 25–35 square metres per car, in a parking lot the required space is 20–25 m^2. A passenger car on the move requires, depending on its speed, about 80–160 m^2 as calculated based on the width of the lane and the safe distance from the car ahead.

The actual values realized in practice can be seen in the statistics. The following section scrutinizes the characteristics of Helsinki land use and traffic prior to the annexation of Östersundom area of Sipoo to the city of Helsinki. Excluding Östersundom from this scrutiny is appropriate because the area is countryside by its nature and will be converted into urban area. The scrutiny concerns statistical year 2004, which was a period of stable development for Helsinki prior to the removal of port functions from Jätkäsaari and the Sörnäinen and Kalasatama areas and to the development of these areas into residential and business areas.

According to the Statistical Yearbooks of Helsinki, before the annexation of Östersundom 1.1.2009 the total residential area of Helsinki was 41,3 km^2, areas reserved for other construction purposes covered 24,8 km^2, and total street area was 32,9 km^2, of which 14,2 km^2 was used for traffic or parking purposes or by filling and service stations. In regard to the functionality of traffic, it is essential to proportion the land area to the factors connected to the spatial needs of traffic (Table 1). Traffic is generated on the one hand because people reside somewhere and leave their residences to go somewhere, and on the other hand trips are always directed at some destinations, such as stores, workplaces, service points and holiday or leisure time destinations. Residency produces home-based travel, and other construction and development attracts travels.

The mean values of Helsinki do not reflect the city structure's capability to meet the demands of traffic. Inner city and suburbs differ from each other structurally. Inner city has the same amount of street area needed for movement per resident as suburbs, but with regard to workplaces only about half of the area offered by suburbs.

Helsinki inner city southern sub-district has 124 000 workplaces and 96 000 residents. Workplaces are thus the decisive factor in determining the traffic load. The car traffic directed to inner city is regulated by the traffic lights of entry roads. The pass-through capacity of the lights has been set experientially so that there will be no traffic congestion in the inner city street network. The purpose of the arrangement is to keep the inner city traffic flowing smoothly, which reduces the emissions caused by idling cars stuck in traffic jams in street canyons. Idle emissions occur on the entry roads, where they cause less harm to people (Sane 2010).

The "peninsula boundary" (niemen raja) used in Helsinki city traffic volume calculation is not totally congruent with the statistical Southern Sub-district, but the transport modal split of the peninsula boundary gives an idea about the significance of the street area size. During morning rush hours between 6 and 9 am, the traffic calculation line is crossed by about 32 000 persons travelling towards inner city in passenger cars, whose average load is 1.3 persons per car (Haataja et al.

2003). Considering the daily fluctuation, inner city street network of 2.46 km^2 is capable of dealing with 8 200 arriving passenger cars per hour. Therefore, Helsinki inner city street network capacity is 3 300 arriving passenger cars in hour per street area square kilometre.

Land use characteristics in Helsinki					
Land use [m^2]	Traffic area	Town squares and other street areas	Street area in total	Residential use	Other construction
All of Helsinki					
per resident	25	34	59	74	44
per passenger car	73	97	170	214	128
per workplace	38	51	89	112	67
Inner city (Southern sub-district)					
per resident	26	12	38	25	48
per workplace	20	9,2	29	19	37
Suburban areas					
per resident	25	38	63	84	44
per workplace	48	72	120	160	83

Table 1. Land use characteristics in Helsinki prior to the Sipoo annexation 1.1.2009. Statistically, Helsinki city's Southern Sub-district includes Vironniemi, Taka-Töölö, Kamppi and Lauttasaari. Statistical values from year 2004.

Street area comprises more than just the roadway used by vehicles. In Helsinki streets are classified into three maintenance classes according to the street width and the roadway is allotted half of the width of street area. (Hänninen et al. 2005). Passenger car traffic cannot use the area reserved for streetside parking or the lanes reserved for public transport. The proportion of these is about 0.2 km^2. When street network is two-way, one-way traffic uses only half of the roadway. One-way traffic has in its use an area of 1.1 km^2 or 320 km as a roadway lane, whose width is 3.5 metres.

In inner city traffic uses 20 m^2 of street area per one morning traffic destination, in other words, per workplace, when the assumption is that commuting is the purpose of the passengers travelling during the morning rush hours. According to the previous calculation, there is 2.6 metres of lane per one workplace. Experience-based observation about Helsinki is that this street area is not sufficient to facilitate travel to all workplaces by passenger car. Instead, it is known from experience that the 320 kilometres long lane network of inner city can receive 8200 passenger cars per hour. Thereby the receiving capacity of Helsinki inner city street network is 26 passenger cars/h/street km or 3 600 passenger cars/h/street km^2.

When we know from experience the number of cars entering inner city, 24 600 passenger cars in three hours, inner city can have as many workplaces for employees who arrive alone by car. Based on this, if we accept three hours as the working hour shift, inner city has 100 m^2 of street area per one workplace of an employee travelling there by car. The length of roadway lane available is 13 metres.

There is no data about how long a car entering Helsinki inner city is on the move in the street network (Sane 2010). Therefore there are no statistics about how many passenger cars are driving in the street network simultaneously, which would make it possible to determine how much street area or lane length is available for one passenger car. The only basis for assumptions is, that the area in question is about 2.5 x 2.5 kilometres.

If the cars are distributed evenly on this grid, a car moving on straight streets travels an average of 1.25 km and a car that turns into an intersecting street travels an average of 1.9 km. Assuming equal amounts of both, a car travels an average of 1.6 km. If we set an average car speed in the inner city of 15 km/h, the cars travel for an average of 6.25 minutes. When 8200 cars arrive per hour, during 6.25 minutes 854 cars arrive and depart, this being the amount of cars simultaneously moving within the area.

Based on the afore-mentioned assumptions about distance and speed, a car entering the inner city has 375 meters of car lane or 1300 m^2 of lane area at its disposal. If the assumptions are correct, in Helsinki inner city the above-mentioned numbers are a requirement for congestion-free passenger car traffic.

It should be understood that the numbers calculated above cannot apply to all cities or even grid plans. The purpose of street network is to pass incoming vehicles from main streets to parking facilities. How well this can be accomplished depends on the structure of street network, location of parking facilities, and availability of single parking squares, as well as on the outbound traffic, its volume and effect on the inbound traffic. The size of city blocks affects the number of crossings and therefore the number of crossing delays. Parking facilities and their drive-in arrangements have an effect on how fast a car can leave the street and thus make room for other cars. Or how fast the car can cause a traffic jam, for example when being backed into a parking space, or increase drive-kilometers when the driver is looking for a free parking square.

Since inner city contains 124 000 workplaces and passenger car -based motoring can serve 24 600 workplaces, in other words about 20 per cent of the current workplaces, the land use efficiency and the functionality of the inner city are based on public transport services.

In order for private transport to serve the inner city workplaces better than now, one vehicle should contain more passengers or vehicles should be able to operate in a smaller area than that required by a passenger car. The normal capacity of a passenger car is 5 persons, which means that in theory passenger cars would be able to serve all workplaces of inner city, if each car was filled to its maximum capacity and all cars were driving to the same destination. If we accept the parking of a passenger car in that manner that the passengers of the car use public transport or walk to their destinations, traffic within inner city area does not increase and there is no need to decrease the volume of inbound passenger cars. However, in this case the use of passenger car is no longer up to the service level of private transport. In practice it is not realistic to try to raise the used capacity of a passenger car.

Increasing the capacity of a street network by decreasing vehicles' need for surface area means taking into use vehicles that are smaller than passenger cars, such as bicycles and other two-wheeled vehicles. Increasing the efficiency of street area use presupposes that the vehicle in question needs less space sideways than a passenger car, in which case the streets can hold more vehicles side by side than normal cars. For example, three bicycles or scooters can drive side by side on one lane. In the direction of traffic, the need for space is determined by the safety distance, which can be shortened only by decreasing the maximum speed of traffic flow. Traffic behaviour will be problematic, since heavy vehicles present-sized require street network, for example the current lane width, even though private passenger transport would start using vehicles that do not need lanes with present-day width.

Being different by nature, traffic consisting of light vehicles may require the partitioning of street network for different kinds of traffic or a traffic practice that differs radically from the present-day one in order to allow side-by-side driving in one lane. The arrangement is similar to the present practice where traffic network has been divided into parts reserved for light traffic, motor vehicle traffic and public transport.

2.2 Different city structures

In the oldest part of the city, in other words, in inner city (statistical Southern Sub-district) the land use ratio differs from the figures of whole city. There is only little land area reserved for residential use and plenty of land area reserved for other construction. In all of city the land area used by traffic is 80 per cent of the residential land area, but in inner city traffic uses 149 per cent of the residential land area. Instead, if we compare the land area used by traffic to all land area used for construction, inner city and suburban areas do not differ from each other. Traffic uses everywhere about 50–51 % of the land area used by buildings, but in inner city the proportion of land area used for other construction purposes is equal to the proportion of land area used for residential purposes in suburbs.

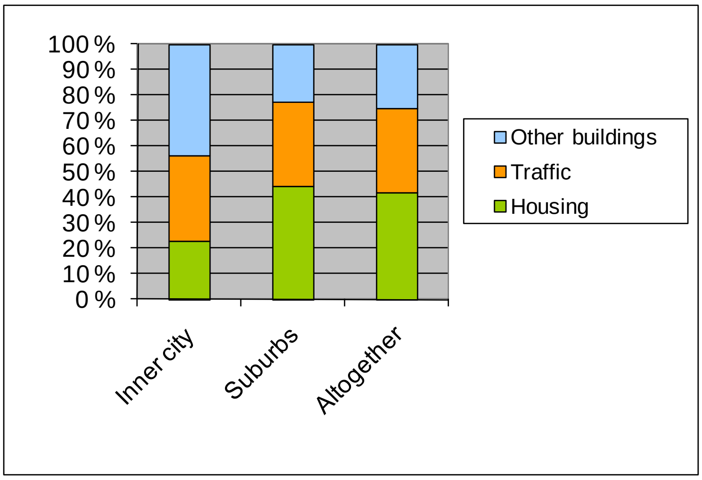

Figure 1. Distribution of built-up land area in Helsinki inner city and suburbs prior to the Sipoo area annexation 1.1.2009. Statistical values from year 2004.

Helsinki has equal amounts of built floor area for residential use and for other use. Residential floor area is 18.8 million floor m^2 and other floor area 18.7 million floor m^2. There is 33.6 floor m^2 of residential floor area per resident and 33.5 floor m^2 of other floor area. Per one passenger car there is 194 floor m^2 of built floor area, of which half is residential floor area and half other building floor area. Floor area is distributed in inner city differently from the whole city in average. In inner city only a generous third of floor area consists of apartments, whereas in suburbs over half is residential floor area (Figure 2).

There are 368 000 workplaces in Helsinki and workplace self-sufficiency is 134 %. There is about 51 m^2 of non-residential floor area per workplace. The difference in density between inner city and suburbs is small, as inner city has 49 square metres of other floor area per workplace.

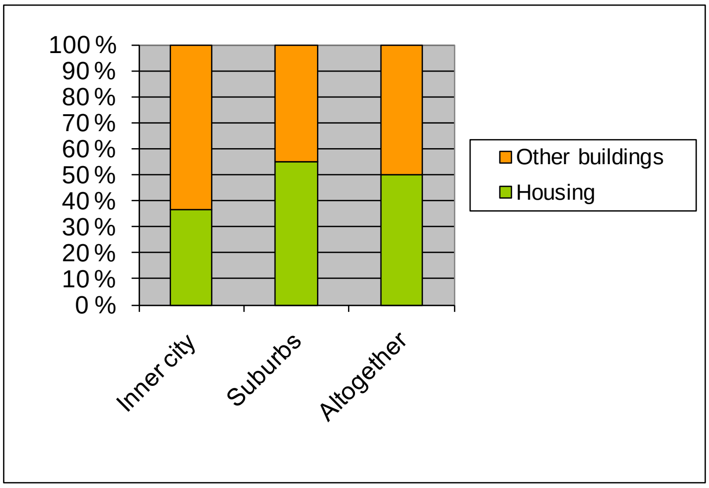

Figure 2. Distribution of built floor area in Helsinki inner city and suburbs prior to the Sipoo area annexation 1.1.2009. Statistical values from year 2004.

Land use is more efficient in inner city than in suburbs. Block density in inner city is 1.39, whereas in suburbs it is 0.47. Residential and other construction is approximately equally efficient in inner city, but in suburban areas other construction is more efficient than residential construction. In suburban areas the block density of other construction is 0.62. Due to the differences in block density the proportion between street area and floor area is considerably smaller in inner city than in suburbs. The ratio of street area to built floor area is 0.88 in entire city, but in inner city there is considerably less street area and the ratio is 0.37. In suburbs, there is more street area than floor area, the ratio being 1.06 (Figure 3).

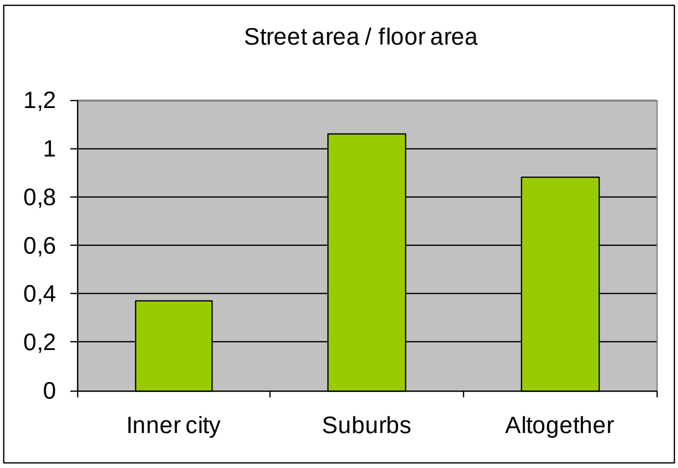

Figure 3. The ratio of street area and floor area in Helsinki inner city and suburbs prior to the Sipoo area annexation 1.1.2009. Statistical values from year 2004.

Inner city represents both efficient land use and mode of construction from an era before the dominance of motoring. Of the passenger journeys directed towards inner city, about 55 per cent on daily level and 60 per cent during morning rush hours between 6 and 9 am are carried out by public transport (Haataja et al. 2003). The number of passenger cars has remained the same since the 1980s. In inner city the space available for traffic is therefore not sufficient for all passenger car traffic, and the capacity limit has been reached as far back as over 20 years ago.

The positive workplace self-sufficiency of Helsinki means that there is net growth in Helsinki area population during work day and that traffic system and street network are used by a greater number of people than merely the population of Helsinki.

Based on statistics, it can be deduced that due to the amount of street space required by a passenger car, the amount of street space should be considerably larger than the amount of floor area in order to facilitate traffic based on the use of private vehicles. The amount of street space cannot be increased significantly in built city structure, so the passenger transport capacity of street network can be increased only by optimizing the use of street space. The use of street space is more efficient, if traffic control can shorten the time vehicles remain in street space or if the amount of street space reserved by a vehicle per person can be reduced. The most efficient way to make the use of street space more efficient is public transport. The need for street space is increased by regional growth, if community structure and transport habits increase drive-kilometers, in other words, the length of the journey, in connection with the growth.

2.3 Regional structure

The connection between region growth and the increase in drive-kilometres depends on the properties of community structure. Monocentric city structure increases drive-kilometres, since the average journey from a residential area to the centre lengthens as the region grows. Multicentric structure reduces the increase of drive-kilometres, since services are accessible at a shorter distance than the regional centre. When city structure is completely diffused or decentralized, regional growth will not increase drive-kilometres, since services and workplaces are accessible within the same distance from everywhere in the region.

Traffic directs regional growth through a person’s time budget. Since passengers cannot increase the time used for travel infinitely, transportation technology and the time available set the limit for the daily journey taken. This directs the development of community structure towards multicentric solutions or diffusion or both. This also seems to have been the end result, when we examine the development of community structures in urban regions.

In regard to community structure and traffic it is essential that the nature of community structure is a question of scale related with mode of transport, as Joutsiniemi (2010) has stated in his thesis. Helsinki region has the following three scale levels:

1. From a **pedestrian’s or public transport** user’s, mainly tram user’s, point of view, Helsinki inner city is a diffuse and mixed city structure. Residences, services and workplaces are easily accessible everywhere. Retail trade structure development has strongly decreased the amount of trade services in inner city during the past 40 years, but density has not surpassed the service accessibility available for pedestrians or public transport users. **Inner**

city is thus **a diffuse and mixed city area** in which people travel by foot and public transport.

2. From the point of view of **a car user or user of a public transportation mean equivalent to travelling by car**, inner city is one centre of a multicentric structure. Inner city is the destination of the journey, not the area in which the journey is taken. The journey has to be continued at the destination at least by walking, even though the destination had parking capacity of its own. Due to the space requirements of cars outlined above, parking arrangements will inevitably be large so that there will be a minutes-long walking journey between the car and the building that is the destination of travel. Especially from a car user's point of view, **Helsinki region is** an area with a **mixed city structure**, where services (commercial centres) and workplaces (industrial areas) are all around and reasonably accessible. People travel by car in this area.

3. Helsinki region as a whole is the destination of journey for **commuters**. For them the multicentricism and mixedness of community structure are apparent at city level. Community structure is a region structure where it is everywhere possible at least to live within accessible distance from Helsinki region that has a substantial selection of workplaces available. Commuters use fast train services and motorways or less used lower class roads for travel. For commuters, the journey includes a connection travel that differs from the actual travel mode. For car users this means driving in a slow local street network, for train users it means walking or using a public transport connection. **The region with mixed community structure** where daily journeys take place **encompasses the whole southern coast** with travel distance of about an hour.

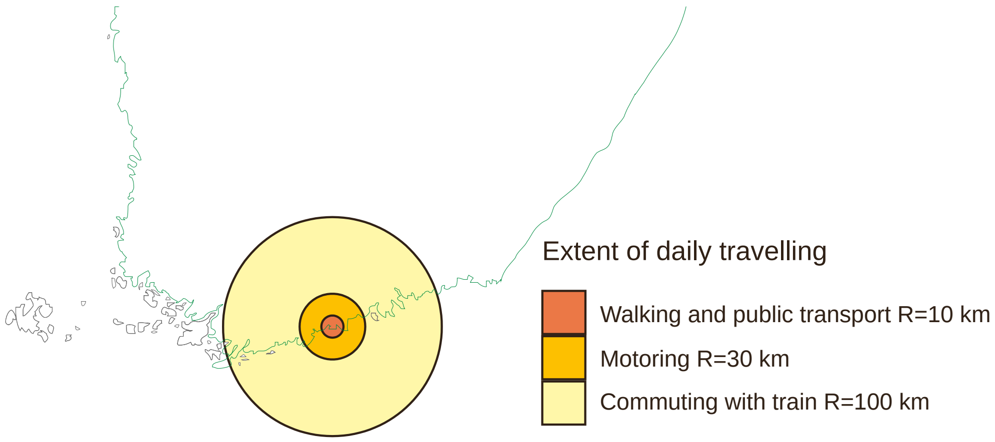

Figure 4. Mixed city or community structure from the aspect of different travel modes in regard to Helsinki. Areas correspond to the extent of daily travelling. When train is used for commuting, the extent of daily travel and therefore the extent of mixed community structure experienced spans nowadays distances even over 100 kilometres.

In the three cases outlined above, the basis for scale difference is the speed of travel. The practical territory of travelers consists of those elements that are accessible by using the travel modes available. The possibilities offered by community structure that are outside the accessibility range are meaningless. The technical solutions of traffic are therefore a crucial factor in determining which kind of community structure is feasible. In regard to traffic technology all community structures can be seen as equal, in other words, as mixed and diffuse structures. Centralization and decrease in accessibility occur when the traffic technology used does not make existing destinations accessible.

3 Electric vehicles

Nowadays, electric vehicles or hybrid electric vehicles are in commercial use both in rail and road traffic. The majority of electric passenger traffic capacity is in use in public transport where fixed routes make it possible to power vehicles constantly. The geographical operating range of vehicles is therefore equal to the extent of the powering system built. Operating time or the distance driven is not limited as in battery electric vehicles.

In public transport, part of the passengers travel standing up. Therefore, the capacity of a public transport vehicle is calculated on the basis of standing room occupation efficiency. In the EU, the acceptable standing density for a registered vehicle is 8 persons per m^2, but the acceptable number of standing passengers can be limited by the vehicle’s largest allowed carrying capacity. Registered number of standing passengers means the number of standing passengers accepted by authorities on the basis of safety views.

In practice, the actual number of standing passengers is a part of public transport service level. In Western Europe, the conventional number of standing passengers used for calculation is 4 persons per m^2 which has been used in this work in connection with reporting a public transport vehicle's capacity. In traffic dimensioning it may be appropriate to use lower density as well in order to allow for transitory load variation in actual service. Standing room travel is also dependent on travel time. If the journey takes over 30 minutes, offering standing room travel should be avoided.

In private transport, vehicles have only seats, and travelling is allowed only in seated position and the use of vehicle-specific safety gear, such as safety belt or helmet, is required.

There are no regulations about freight capacity in passenger transport. As the proportion of leisure time trips taken for hobbies and for conducting personal business grows, the significance of freight transport grows as well. In public transport it is possible to use standing room for transporting goods as well as prams or handicap vehicles. In private transport vehicles are often equipped with separate cargo transport capacity. Seats left free are also often used for transporting goods in private transport.

3.1 Rail traffic

Electrically operated vehicles became common in rail traffic in the late 1800s. Rails make powering of electric vehicles easy. After the early development stage, overhead wires became the dominant means of providing power to rail vehicles during the whole 1900s. Another common solution is a third rail that is used mainly in underground systems. In the early 21st century systems without overhead lines have been developed for historical city environments.

The power feed and power control of electric vehicles were initially based on using direct current and rheostats as well as connecting motors and their field coils and armature coils in series and in parallel. Due to this principle, the voltage of overhead line in DC systems was confined to low, therefore limiting the power usage of rail traffic. The solution for providing sufficient power was to use alternate current, the voltage of which could be lowered with a transformer in the railway engine. At the same time the efficiency of electric operation improved, since energy was not transformed into heat in resistors. Nonetheless, low voltage (600–1500 V) DC systems have remained the preferred solution in urban transport.

Semiconductor technology revolutionized the power control of electric vehicles in the 1960s. At first series resistors were replaced with thyristors, and in the 1970s three-phase AC induction motor drives and variable-frequency drives for controlling speed were taken into use.

3.1.1 Multiple unit and motor coach

Multiple unit is a carriage equipped with its own motor. Motor coach or motorcar is a powered passenger train that consists of at least two carriages. The basic design of multiple units and motor coaches is similar to trams and metro trains. The only difference between these all lies in the basic dimensions of the carriages.

Railways have large turning radiuses, which means the carriage can be long, usually 25 meters. The greatest width of railway stock is usually about three meters. Each railway carriage seats about one hundred passengers.

Figure 5. Motor coach "Flirt", i.e. series Sm5, operated by Pääkaupunkiseudun junakalusto Oy at the Leppävaara train station in April 2010. The train consists of four carriages, with a total length of 75.2 meters.

3.1.2 Tram

A tram is a motor unit derived from horse-drawn carriages. The tram was developed because a horse could pull far larger loads on tracks than on a street paved with stone or gravel. When overhead wires were invented in the 1890's, horses were quickly replaced by electric motors. Electric trams could be made larger and faster. Tram width is limited by road traffic laws. Currently the widths are 2.3 – 2.65 meters. Currently the German maximum length standard of 75 meters for street-going trams is in use in Europe. One unit of this length has a capacity of 500 – 750 passengers.

Trams were first operated on tracks laid in the streets. Nowadays, where possible, the tracks are separated from the rest of the traffic to avoid congestion to slow down trams. Tram track is laid on its own lane or on a separate track and traffic lights at crossings are synchronized according to tram traffic to avoid needless stopping of both trams and cars. Trams operate also on railway and metro tracks.

Figure 6. Alstom Citadis 402 tram of Paris tram line T3 in June 2010. The tram has seven parts and its total length is 43.7 metres.

3.1.3 Metro train

Metro trains are a development of passenger train traffic, which was adapted to city block environments. In the USA of late 19th century it was common to build the track above the street on steel bridges on which the trams were pulled by steam locomotives. In Europe metros became common only after 1890, when the first electrically powered underground train system was introduced in London. Once electric engines made continuous tunnel operation feasible, it was common in Europe to build the track under the streets. Since then, the standard practice of metro system operation has been to build the systems in tunnels.

Metro systems are mainly closed systems, totally isolated from other city traffic. This complete separation from other traffic makes it possible to automate metro trains for driverless operation. In the 1980s Matra developed in France an automatic VAL metro system that ran on rubber wheels. Later automation has been applied to full-sized metros with steel-wheeled trains.

Nowadays the operating current for metro trains is generally 750 V DC, carried usually in a third rail situated beside the metro track. Trains and stations are 100–130 meters long and the usual rolling stock width is 2.65 metres. The length of one carriage is 16–22 meters, depending on track curvature. The capacity of one train is 800–1200 passengers.

Figure 7. A metro train of the Berlin metro (U-Bahn), series HK, on the U2 line in September 2010. One train unit consists of four carriages, with a continuous passenger section from one carriage to another. The length of one unit is 51.6 meters and the trains consist of two units.

3.1.4 Tram-train

A tram-train is a tram which operates on at least two power systems. Tram-trains were taken into use in Karlsruhe, Germany, in 1992 so that the same carriages moved both on the tram tracks and railway tracks. A tram-train can use at least two catenary voltages and its wheel set can be adapted to both tram and railroad switches.

Figure 8. A tram-train on the Paris tram line T4 in June 2010. The Siemens-built Avanto S7 is composed of five units, with a total length of 36.5 meters.

3.1.5 Hybrid tram

A hybrid tram is a tram-train that operates both on electricity and on fuel. A hybrid tram contains an engine-generator, which feeds the tram with electricity when a catenary is not available. As the engine-generator is dimensioned according to the carriage motor power requirements, a hybrid tram has the same performance with or without a catenary.

Figure 9. A hybrid tram on an unelectrified railroad track in Sweden in 2007. The Regio Citadis tram is built by Alstom for the city traffic in Kassel. Photo by Alstom.

3.1.6 Battery electric coach

Battery electric coach is an electric vehicle that uses energy stored in battery packs. Battery electric coaches were in use in the early 1900s, but combustion engine carriages proved more economical for operating on unelectrified railroad track parts. In the beginning of 2000s battery electric trams have been taken into use in tram transport, when historically valuable locations have been wanted to spare from the overhead lines. When battery packs are used only during some parts of the route and they can be recharged while driving on a rail equipped with overhead lines, the mass and cost of battery packs remain reasonable.

3.1.7 Personal rapid transit

Personal rapid transit is a Demand Responsive Transport (DRT) system of vehicles running on tracks or on equivalent fixed guideways, vehicles typically carrying only a small group of passengers, passenger load ranging from a few persons to 20 persons. It is often called also People Mover or PRT, the latter term being used especially when the vehicle's passenger load is equivalent to that of a passenger car and when the system operating principle is that the carriage is hired for the individual route of the passenger. The German term for it is Cabinenbahn.

The operation of the system is based on driverless service which is how the system competes with the costs of normal taxi system. Since vehicles are driverless, the system has to be isolated completely from the rest of traffic. Generally the planned systems and the few operational systems actually built are elevated railways which are a way to avoid the disruptive effect in community structure and the high cost of underground construction. The natural propulsion power for track-based DRT systems is electricity.

The idea of PRT dates back to the 1960s, when the automation required became technically possible. The largest exisiting PRT system is probably the Morgantown PRT, opened in 1975, that services West Virginia University. Track length is 13.2 km, there are five stations and only one route. Although there are several plans for networklike PRT systems, no such systems have been built anywhere. The probable reason for this is on the one hand unwillingness to start building a solution of which there is no experience and on the other hand the high cost of the plans with respect to benefits and demand.

A recent and fairly far executed large PRT system plan is the system planned in 2009 for Uppsala, comprising of 125 kilometres of track and 162 stations. The population of Uppsala is 145 000 and according to prognosis it will grow to 196 000 in 2030 (Gustafsson 2009).

3.2 Buses

3.2.1 Trolleybus

Trolleybus is so far the only electric bus that has been taken in large commercial use.

The first trolleybus line was introduced in 1910 in Bradford, UK. Nevertheless, trolleybuses became common only during 1930s. Power supply is based on overhead wires built along the bus route. The bus draws constantly electricity from the wires and there is no need for vehicle-specific driving energy supply.

Trolleybuses have been similar in design to internal combustion engine buses, the only difference being the power source. Inexpensive overhead wire structure allows a maximum speed of 50 km/h. Two-wire structure allows reliably a maximum speed of 80 km/h, but costs approximately twice as much as the one-wire structure.

In the late 1900s, hybrid models of trolleybuses equipped with combustion engine aggregates started to become more common. Trolleybus routes could be designed to work so that the bus was powered by the aggregate for a part of the route instead of using the aggregate merely as an auxiliary power source for emergencies. Trolleybus hybrid design is a series hybrid in which the aggregate feeds electricity to the power control of trolleybus instead of trolley poles.

In the 1990s, several systems were introduced where the trolleybus were force-guided for a part of the route or the whole route. The purpose of force-guiding is to decrease the lane width required by the bus. The first large force-guided system existed as far back as in the 1980s in Essen, where force-guidance was implemented by using guidance panels along the sides of trackage and guide-wheels protruding at the axles (kerb guided bus). Later applications have used a rail in the middle of the lane and groove wheels under the bus. The most common power supply method is using two overhead wires, but one-wire designs where the guidance rail is the return conductor are used as well. In this setup a particular problem is ensuring proper grounding of the vehicle and situations where the pantograph touches the overhead wire but no grounding connection exists.

In Essen the force-guided trolleybus was structurally similar to a diesel bus, and the trolleybuses were replaced with corresponding diesel buses during the 1990's. Newer trolleybuses have used separate suspension, wheel-specific traction motors and multiple swivel wheels.

At the beginning of the 20th century trolleybuses were deemed to be a more modern solution that would replace trams. In the 1930s trams in several European cities were equipped with two axles and had a capacity of 30–60 passengers. Both trams and trolleybuses could use a trailer that doubled the capacity. Thus trolleybuses were approximately as large as trams, but cheaper as an initial investment in regard to stock and route.

Many trolleybus systems were nevertheless short-lived, lasting only one or two stock generations. The price development of diesel motors, gearboxes, clutches, torque converters and oil made diesel bus a cheaper and easier solution than trolleybus. Trolleybuses remained a significant means of transport in socialist countries where the lack of western diesel bus technology probably contributed to this. In western countries trolleybuses have remained in use in cities where the terrain is challenging for combustion engine buses. In recent decades, the interest in trolleybuses has been growing for environmental reasons.

The size and capacity of trolleybus are restricted by the road transport regulations and conditions in the same manner as with combustion engine buses. Capacity has been increased by introducing double-deck designs and by lengthening the bus with articulated structure. Trolleybus is structurally slightly more flexible than combustion engine bus, since there is no need to reserve room for combustion engine and mechanical transmission. Traction and acceleration can be increased in articulated trolleybuses by equipping the bus with several drive axles.

The longest articulated trolleybuses are 25 metres long and have a capacity of 150 passengers, of which 50 passengers are seated.

Figure 10. Articulated trolleybus in Solingen, Germany, in July 2003.

3.2.2 Battery electric bus

Lead-acid batteries have a too low capacity-to-weight ratio to be used as the power source of bus. Battery electric buses reached commercial stage only in late 1900s, when new battery technologies developed in connection with electronics became available.

Battery electric buses have been in large-scale use in China at least during the Beijing Olympics and Shanghai World Expo. The technical solution adopted in Beijing was to exchange drained batteries with fully charged batteries. The performance of buses was equal to that of a normal bus, and buses were the same size as normal 2-axle city buses. The cost of batteries is the disadvantage of battery electric bus in the same way as with electric passenger cars.

The future of battery electric buses is tied to the general development of electric car technology. When an investment on a bus is in proportion more effective than on a passenger car, battery electric buses can be expected to become common faster than battery-electric passenger cars.

The capacity of battery electric buses does not generally differ from the capacity of other buses. If the batteries weigh a lot, this may limit the payload and thus in practice limit the number of standing passengers.

3.2.3 Gyrobus

In gyrobuses energy is stored into the flywheel rotating in the bus. The flywheel is accelerated at passenger stops, and the bus is driven as an electric bus that gets electricity from the generator used by the flywheel. First gyrobuses were in use in the 1950s. In the late 1900s, the principle of gyrobus was re-examined in the light of advanced electrical engineering. Gyrobus does not require as massive energy storage as battery electric bus, and the charging of the flywheel can be accomplished very fast. Compared with trolleybus, gyrobus removes the need to build overhead wire networks constantly and can be rerouted for short distances when needed in emergencies.

The capacity of gyrobus does not differ from that of other buses.

3.2.4 Hybrid electric bus

Hybrid electric bus, introduced in the beginning of 2000s, is a parallel hybrid bus. It is equipped with an internal combustion engine that has a small-capacity battery or supercapacitors as an auxiliary system and an electric motor working as generator connected to the diesel-electric powertrain. Main source of energy is liquid fuel, and electric system stores braking energy that is used to facilitate starting the bus. In practical applications the internal combustion engine is constantly running, but the performance required can be reached with lower power and therefore a smaller motor is sufficient.

The benefits and disadvantages of parallel hybrid buses are similar to those of parallel hybrid passenger cars. However, hybrid solutions are relatively more useful in buses than in passenger cars, since buses have to stop due to their passenger stops more frequently than passenger cars.

Parallel hybrid bus is primarily a combustion engine bus, because its main source of energy and powertrain are the same as in a combustion engine bus. The design of parallel hybrid bus is not suitable for rechargeable battery use or overhead line power feeding.

In practice, the technical parts of parallel hybrid buses are located in the roof and the motor generator in the connection with the gearbox. The equipment does not limit the capacity of bus in terms of space or weight.

In series hybrid solutions, internal combustion engine powers the generator and power control and powertrain are electrical. The principle is the same as with the diesel-electric locomotive commonly used in rail traffic. The benefits of electric transmission include independence of the torque given by the internal combustion engine and the torque at the wheel, simplified mechanical structures, and axle- or wheel-specific drive motors. The design of series hybrid is equivalent to that of trolleybus or battery electric bus.

Figure 11. Articulated series hybrid bus with 2 pivoting joints, manufactured by Hess, in road test at Pitäjänmäki in May 2010. The bus is a modification of trolleybus; it has no trolley poles but there is an aggregate in the rear and supercapacitors on the roof. Diesel engine is constantly running during operation.

3.2.5 Fuel cell bus

Fuel cell bus is an electric bus which uses a fuel cell as its power source. Fuel cell can be regarded as a means of storing electricity in hydrogen form, when electrically produced hydrogen is used for fuelling the cell. Compared with batteries, fuel cells have the advantage of facilitating a fast feeding of power to the vehicle. On the other hand, the disadvantages include the difficulties and risks of handling hydrogen. Fuel cell buses have been in trial use for instance in the European Union's CUTE project. The results of the trial established that the environmental load of fuel cell bus manufacture was twice as much as that of a diesel buss and that the energy consumption of fuel cell buses was greater than that of diesel buses.

3.3 Passenger cars

3.3.1 Plug-in electric car

Plug-in electric car, in other words plug-in, is a battery-equipped car that has merely electric propulsion system. The design of a plug-in model is not tied to the basic solutions used in combustion engine cars. Car can have wheel-specific motors, and batteries can be located apart from each other, thus causing their mass to be shared equally among all wheels. Therefore, motor and transmission do not determine the car design, but passenger seats and cargo compartments can be placed freely in the vehicle.

The technical limitation of a plug-in model is the battery technology's weak ratio of energy, volume and mass. Due to this, the operating range of a plug-in similar to a present-day internal combustion engine car is not equal to the operating range of an internal combustion engine car, but only about a third of it, in other words, 150–170 kilometres. Another problem associated with battery technology is the slow charging speed of batteries, being normally a few hours instead of a few minutes. Quick charging is possible, but it shortens the battery lifetime, which is not desirable due to the high price of batteries. One solution for this dilemma is to replace drained batteries with fully charged batteries. In that case, cars will have to have standardized battery solutions.

Plug-in cars cannot be heated with waste heat like internal combustion engine cars. During short trips, plug-ins can be heated with mains current. In long-time use, heating the vehicle either shortens the operating range or makes the use of a fuel-powered heating apparatus necessary. In that case the plug-in model is partly fuel-powered.

3.3.2 Modified internal combustion engine car

A modification of an internal combustion engine car is a car designed to be powered by an internal combustion engine whose internal combustion engine technology is replaced with electric power technology. For instance, Finnish Elcat van is a modification, the result of a process where Japanese-made serially produced cars were industrially built into electrically powered models. Sähköautot-Nyt community offers the consumers a chance to modify individual cars into electrically powered ones by using serially produced components.

In the modification all other car parts except for motor, exhaust system and fuel tank, remain as they are. The car is driven like a normal internal combustion engine car. A separate liquid-fuel powered heater is used for heating the vehicle.

The mass of battery is equivalent to the mass of internal combustion engine. Therefore the carrying capacity of a modified electric car is almost the same as that of an internal combustion engine car's. Mass change can decrease the payload of the car, which in turn decreases the maximum allowed mass of cargo.

3.3.3 Combustion engine hybrid

Combustion engine hybrid car is a passenger car powered by internal combustion engine where both the unused power of the engine and braking energy are stored in batteries or supercapacitors. Electricity is used for starting the car as the only source of power or as an auxiliary power source to an internal combustion engine. Internal combustion engine can be turned off when the car is at halt, and it starts automatically when charge is beginning to be low or electric propulsion is not sufficient anymore.

The goal of combustion engine hybrid is to increase the total efficiency of fuel use. Internal combustion engine is used in the operating range of good efficiency, and kinetic energy is converted back to electricity. Hybrid achieves with a smaller combustion engine the same performance as a larger combustion engine.

3.3.4 Electric quadricycle

Quadricycle (mopoauto) is a four-wheeled class L6e vehicle fulfilling the requirements defined in the EU directive 2002/24/EY (overrules the directive 92/61/ETY). The allowed maximum unladen mass of a quadricycle is 350 kg, not including the mass of batteries in electric quadricycles. Allowed maximum speed is 45 km/h, and the power of a diesel engine or electric motor may not exceed 4 kW. A quadricycle is registered for two persons.

The most significant property of a quadricycle is that in Finland a person over 15 years with a class M driver’s license (in other words, "moped license") is allowed to drive it. Diesel-powered or electric quadricycles are also exempt from automobile tax and propulsion tax.

The quadricycles sold in Finland are practically all equipped with diesel engines. Their EU-regulated fuel consumption is 3–4 litres per 100 kilometres. Due to small numbers of manufactured quadricycles, they are expensive in comparison to normal cars, new quadricycles costing as much as 10 000–15 000 euros.

Electric quadricycles have been sold in Finland for around 14 000 euros. The unladen mass of electric Microcar quadricycle, manufactured by French Ligier, is 540 kg without batteries. Battery capacity is 9.2 kWh, and operating range is 110 km, energy consumption therefore being about 0.1 kWh/km. The vehicle contains a heater powered by diesel oil (Geitel 2009).

Taxation policy cannot be used to influence converting quadricycles into electrically powered vehicles, since quadricycles are already exempt from special taxes.

Figure 12. Electric quadricycle Elo, photo taken in summer 2010 in Helsinki. There is a moped insurance plate on the vehicle instead of normal registration plate.

3.4 Personal electric vehicles

3.4.1 Electric bicycle

Bicycles equipped with an electric motor can either be electrically-powered mopeds or electrically-assisted bicycles (pedelecs). The essential difference between these is that a pedelec is not considered a motor vehicle but a bicycle according to the paragraph 19 of Finnish Vehicle Law and it does not require traffic insurance, nor does its owner need a driving license. A pedelec may have an electric motor with a maximum power of 250 W that functions as an auxiliary motor and switches off at the speed of 25 km/h at the latest.

Electric bicycle is thus a bicycle equipped with an auxiliary motor that is mainly propelled by muscle power. Electrical assist makes pedaling easier, for instance when going uphill. Batteries can be charged by going downhill and braking. Electric bicycle does not have limited operating range, since the bicycle is always powered by muscle power. When operating on electric power alone, the operating range is 50–70 kilometres with a battery capacity of 0.2–0.35 kWh. If the bicycle is equipped with regenerative braking, the operating range of battery use increases to 180 kilometres, according to the manufacturer. Battery charging time is 4–6 hours.

There are two kinds of auxiliary motor solutions on the market. The auxiliary motor with its battery can be located with the pedal shaft, or a separate auxiliary motor is located at the front or back wheel hub. Battery can be located on the pannier rack. The power of auxiliary motor is adjustable by the user. An operational electric bicycle with a lithium-ion battery weighs under 30 kg. A bicycle with a lead acid battery weighs about 40 kg.

Recently, electric bicycles have become more popular to such a degree that the annual sold amount was 300 000 bicycles in Japan (TM 2009). In Europe, 500 000 electric bicycles were sold in 2008 (Electricbikee 2009). In China, 20–120 million electric bikes are in use after the sales picked up in 2006 (Goodman 2009, CO_2 report 2010). In China electric bikes have no speed limit like in Finland. In Finland electric bikes are used throughout the year for delivering mail. Finnish electric bicycle brands include Helkama and Tunturi. The prices of electric bicycles range from 1000 to 2000 euros in Finland.

3.4.2 Electric scooter

Electric scooter is an electrically-powered scooter equivalent to a scooter powered by an internal combustion engine. Motor power range is 500–800 W, maximum speed is about 50 km/h, and operating range approximately 50 km. Scooters weigh about 100 kg.

There is large-scale manufacture of electric scooters in China and India. BSA, a British company that used to manufacture motorcycles, opened in 2009 an electric scooter factory in India. The initial output of the factory is 150 scooters per day, and the factory can double its production rate. Japanese Yamaha started producing an electric scooter aimed for Asian markets in autumn 2009. The lack of electricity feeding infrastructure prevents Yamaha from entering European markets (Electricbikee 2010).

3.4.3 Hanidcapped carriages

There are battery-powered 3- and 4-wheeled vehicles offered for persons with limited mobility. These carriages are generally meant for both indoors and outdoors use, so that they are of use also to those who are completely disabled physically. Due to carriage's purpose of use, its size has been minimized so that it is as close as possible to that of the seat itself. The aim is to facilitate the use of carriages in all public spaces, also indoors.

Carriages can be equipped with various controls according to the user's motor, for instance so that it is possible to use the carriage even when both feet and hands and fingers are completely disabled. Carriages are equipped with a cargo transport feature so that they can be used for carrying out personal business and for errands.

They are manufactured for various degrees of physical disability. For instance, elderly people may acquire a carriage only because they find it too cumbersome to walk long distances. In that case, the carriage is the personal vehicle of a basically healthy person.

According to the 2nd paragraph of Vehicle Act, invalid carriages are not vehicles in the sense meant by the law, when motor power is 1 kW at maximum and maximum speed attained is 15 km/h.

3.4.4 Segway

Segway is a two-wheeled, one-axled personal vehicle that is driven standing up. The operation of the device is based on gyroscopic sensors and wheel-specific motors that keep the device and the user upright. The first Segways were introduced in 2001.

Segways have a maximum speed on 20 km/h and, according to the manufacturer, an operating range of 26–39 km (16–24 miles) in street traffic. The offroad version's operating range has been reported to be 19 km. Segway's lithium-ion batteries have a capacity of 1.04 kWh and their charging time is 8–10 hours. According to the manufacturer, the average consumption is 0.033 kWh/km (0.052 kWh/miles) calculated from the energy used for charging (Heinzmann & Taylor 2009). The minimum operating temperature of the batteries reported by the manufacturer is -10°C. Segway weighs about 50 kg.

Segway does not fit any vehicle category defined in Finnish legislation. Its performance is similar to moped's, but the equipment of the device does not fulfill the requirements stipulated in Vehicle Act. Thus, Segways cannot be registered in Finland and no traffic insurance can be obtained for them, which leads to that they are not allowed for use in public roads. Nevertheless, Segways are in use in the EU, even though the device has no EU qualification approval. In Germany, mailmen use Segways; in Stockholm Segways are rented to tourists (Peutere 2005). In the UK, a law amendment was started in January 2010 to legalize vehicles like Segways (DfT 2010).

Figure 13. Segway users in Tallinn, May 2008.

3.5 Electric cargo transport vehicles

Cargo transport in Europe is based on using diesel trucks and vans. Electricity is used in rail traffic. Electric vehicles have occasionally been used for making deliveries in cities. In the UK, for instance, electric vehicles have been used for milk deliveries in the morning to avoid causing noise. Domestically manufactured Elcat electric vans have been in use in Finland.

To some extent, tramways and trolleybus networks have been used until the mid-1900s for cargo transport. During wartime and after war the reason for this was the lack of internal combustion engine vehicles and fuel. Nowadays such applications are rare.

Since January 2001, a five-carriage cargo tram has been in use in Dresden, shuttling between the Friedrichstadt logistics centre and Volkswagen car factory with one-hour run interval and passing through Dresden downtown. The tram length is 59.4 metres, its carrying capacity is 60 tons and floor area is 214 m^2.

In Zurich, a tram has been used since 2003 to collect recyclable waste. Two old tram chassis have been converted for cargo transport, and they visit the designated collection centres according to their monthly schedule. Collection centres are located at sidetracks and railway sidings where the carriages can halt without disturbing other rail traffic. For the arrangement, one track has been built for unloading the carriage to serve the local recycling centre.

In 2007 city of Amsterdam started a pilot project for a city-wide delivery system where cargo trams transported goods to local delivery centres, from where electric delivery trucks delivered the goods to their final destinations. The pilot effort led to starting of the project, and it was supposed to complete in 2012. Due to financing difficulties, the project was halted in 2009. The objective is to decrease the emissions of delivery traffic, to remove delivery trucks and the traffic congestion caused by them from the city centre, to make delivery more efficient and to extend the delivery operating hours from the limits set to trucks.

Wien tried in 2005 to implement cargo transport on tramway network. The system was to be used for transporting goods between industrial plants, among other things. Transport would have taken place at night, when halted carriages would not have disturbed passenger traffic.

Electrical cargo transport solutions are in general use in terminals and enclosed spaces where poisonous fumes pose a problem. Electricity is a common power source for forklifts. Battery-powered vehicles used at railway station platforms were common in the late 1900s, and battery-powered vehicles are used at large airports for indoor transport. In all the applications described above, gas-powered combustion engine is a rival to electricity as a power source.

4 Energy sources of electric transport

Electricity is not primary energy, in other words, it does not naturally occur in a form usable by man. Therefore, electricity must be produced by converting primary energy into electricity, which means that electricity is a means for transmitting power. Converting primary energy into electricity is useful also because electricity is a form of energy that can be utilized in versatile manner.

The oldest methods for producing electricity are hydroelectric and fuel-powered power plants. In addition to these methods, a significant part of electricity is nowadays produced by using nuclear power plants (Figure 14). Nuclear power plants and the majority of fuel power plants are turbine-based thermal power plants. In thermal power plants the fuel is generally solid, eg. coal or bio-mass, which are difficult to use in other containers than in immobile boilers. Liquid and gas fuels are also used in combustion engine power plants and combustion turbine power plants.

Wind and solar power plants are new methods of electricity production. In wind power plants, the movement of air is converted by wind turbines or propellers into movement that rotates a generator. Solar electricity is produced mainly through a photovoltaic reaction where the light energy is converted into electricity by a chemical process. A steam turbine process has also been planned for large-scale solar energy.

According to the laws of thermodynamics, heat-based methods for producing electricity can reach the efficiency coefficient of approximately 45 % in regard to the energy content of the primary energy source. The primary energy of a thermal power plant can be utilized best if there is a use for the waste heat. This is the prevailing situation in industrial processes and district heating. In that case, the proportion of primary energy converted into electricity decreases to less than 30 %, even though the plant’s total energy efficiency is 85 %.

The energy efficiency of a hydropower plant is at best 90 per cent of the potential energy of water. Depending on the turbine model, adjustability may also be good. When a Pelton turbine is used, efficiency starts to decrease only when input power decreases so that it is under half of the nominal power.

The downside of wind and solar power is the production’s dependency of natural conditions. For that reason the average output power is only a quarter of the nominal power. Despite the fact that primary energy is free, production costs are at the moment (2010) considerably higher than with other energy production methods.

From electric transport’s viewpoint, it is germane to note that in regard to primary energy electric vehicles are a reasonable solution, if primary energy cannot be used as such in vehicles. Primary energy in liquid and gas form is most advantageous to use directly in vehicles, because in this way losses in electric power transmission and storage can be avoided and it is possible to utilize waste heat.

Electrifying transportation does not change the community's need for energy as such, but it changes the form of primary energy required. Instead of liquid fuels and gas, any other primary energy can be acquired, since all primary energy can be converted into electricity. Transportation will also be more flexible in regard to environmental load, since electric transportation's need for energy is easier to meet with sustainable and emissionless energy forms than when using combustion engine powered solutions.

The economic efficiency of electric transportation is dependent on the techno-economic development of technology required. The energy for electric transportation can at the moment (2010) be produced more cheaply than liquid fuels and gas, but vehicle technology is presently (2010) more expensive than combustion engine technology.

4.1 Current state of electricity production

In Finland electricity production is based on fuel-powered steam power plants and nuclear power plants. About a quarter of the electricity required is produced by nuclear power plants (Figure 14). About a third of electricity is produced in connection with heat production both in industry (12.8 %) and in district heating production (19.9 %). Another third of electric power need is fulfilled by implementing separate electricity production in condensate power plants (15.4 %) and by using hydropower plants (14.6 %). Both of these solutions are used for regulating production in order to adjust to electricity consumption variation (Figure 15).

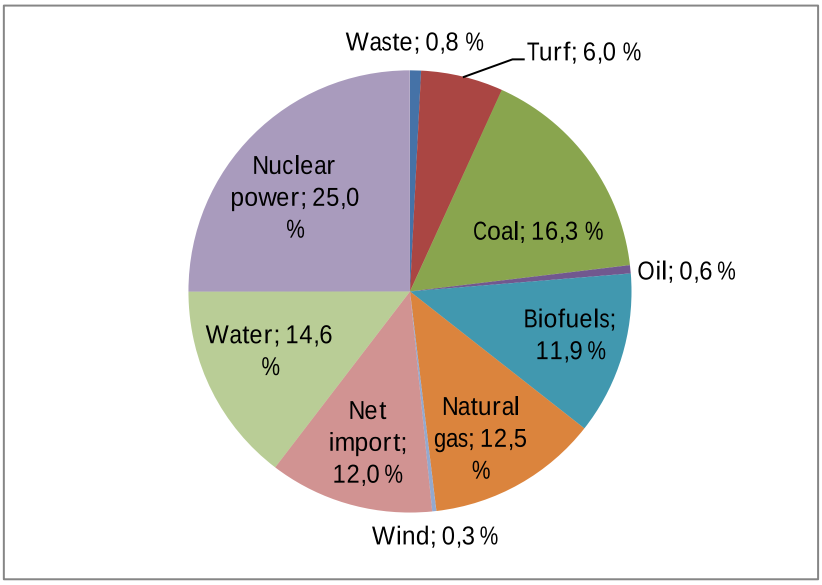

Figure 14. Electricity generation by production methods in Finland in 2010. The total amount of electricity consumed in 2010 was 87.5 TWh. The amount of electricity produced in Finland was 77.0 TWh. The proportion of renewable production methods in electricity generation in Finland was 31 % and the proportion of CO_2 neutral methods was 59 % (Finnish Energy Industries 2011).

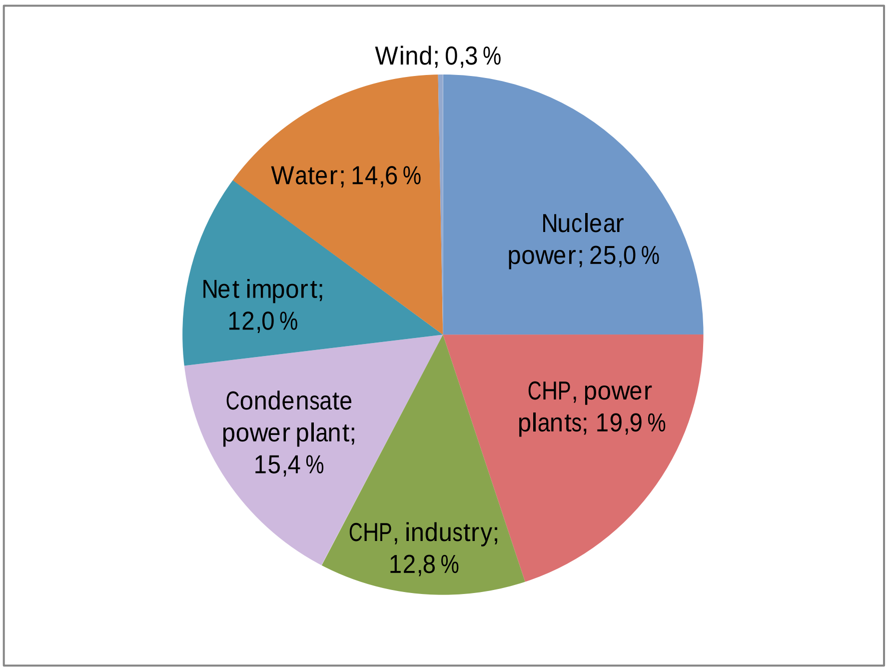

Figure 15. Net generation of electricity in 2010 by power plant technologies (Finnish Energy Industries 2011).

Electricity generation is guided by both purchase contracts directed towards certain production and by production costs of power plants.

Renewable electricity generation’s proportion of Finnish electricity consumption, 26.8 per cent, is large by European standards. This is due to the large role of forest industry in Finland’s energy economy. However, the recent structural changes in forest industry and reductions of production capacity have decreased both industry's need for power and electricity production. The small role of solar and wind power in Finland is explained by the fact that both of the production methods are for geographical reasons far less efficient here than in more southern countries or in countries located along the Atlantic coast.

Net imports of electricity include hydropower from Norway and Sweden and nuclear power from Russia. Electricity imported from Russia makes up about a half of the importation. Electricity produced in Norway and Sweden is bought through the Nord Pool.

Government's decision to build two new nuclear power plants in Finland will change power production structure. It has been publicly assessed that when both new plants are operating, Finland's electricity production capacity will be larger than consumption, which means that Finland will be a net exporter of electricity. Decreasing other electricity production so that it would be replaced with nuclear power is not feasible, since electricity is produced in combined power plants especially during heating period. In addition, load following power plants are permanently required due to the weak or missing load following capability of nuclear power plants (Figure 16). For these reasons new nuclear power plants will not replace present-day coal power plants as such. The emissions of those plants can be reduced only by converting them so that they are fired by renewable fuels.

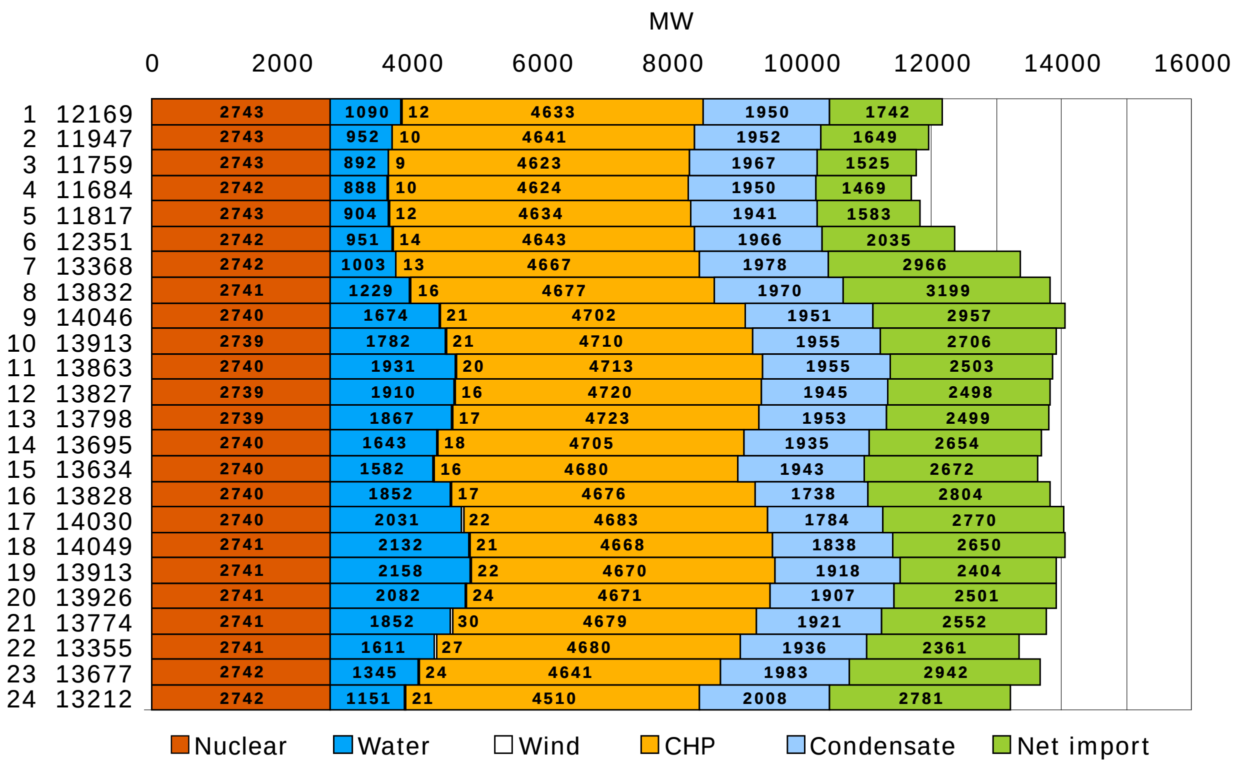

Figure 16. Electricity generation by the hour at the peak load day 29.11.2010 in winter 2010–2011 (statistics prior to 31.12.2010). Load following according to need was implemented mainly by using hydropower and secondarily by adjusting electricity imports (Finnish Energy Industries 2010).

4.2 Transportation's need for electricity and production possibilities

4.2.1 Electricity demand of vehicle motion

The energy consumption of transportation based on internal combustion engines is the energy contained in the fuel used in the vehicles. The energy that can be used for moving the vehicle is 15-18 % of the energy contained in the fuel (tank-to-wheel efficiency). The corresponding figure for a plug-in vehicle is 70–80 %. This means that the energy requirements for an electric vehicle fleet is significantly lower than the energy content in fuel consumed by traffic (Kronström 2009).

The combustion engine of a passenger car consumes 7-8 L/100 km, which corresponds to an energy consumption of 0.63–0.72 kWh/km. The energy consumption of electrically powered passenger cars is estimated to be 0.15–0.25 kWh/km, not including heating or ventilation but including utilization of braking energy. (Kronström 2009). The electricity consumption of electric passenger cars is thus about 25 % of the energy content contained in the fuel consumed by the combustion engines in passenger cars. The Finnish passenger car fleet would thus consume, assuming current transportation habits and cars similar to those currently in operation, yearly about 9.2 TWh, which is about 12 % of the current electricity consumption of 90 TWh.

Finnish heavy traffic is responsible for 30–40 % of the 3.9 million tons of fuel consumed by road traffic, With current technology it is difficult to replace the combustion engine with electric power in long-range cargo and passenger vehicles. Storing energy in batteries leads to an unacceptably low payload. Fuel cells offer a better energy storage in respect to mass and volume, but the energy efficiency from fuel production onwards is low and the technical difficulties are significant (Romana 2010).

Currently it seems that the easiest way for heavy traffic to transition to renewable energy is by using biofuels. Neste Oil operates a commercial process, which produces a fuel that can fully replace petroleum-based diesel fuel. Neste Oil's process uses bio greases, such as oil plants. The carbon emissions from the process are about 40 % compared to the use of petroleum-based diesel fuel, when oil palm farming is taken into account. Chempolis Oy operates a commercial process which produces alcohol from various biomasses, such as farming waste. The process does not require the use of plant parts usable as food. However, alcohol is not a suitable fuel for current diesel engines. The process is self-sufficient in regards to energy, so the emissions over the lifespan consist of building the processing plant and transporting the raw materials. If the energy production is based on wood mass, CO_2-emissions are 1–2 g/kWh.

If heavy traffic's energy concerns are solved with bio fuels, these energy needs need not be accounted for in the electricity production structure. Heavy road traffic's energy need of approximately 14 TWh does however compete with electricity production for renewable resources. According to Rintala (2007), the bio mass potential of Finnish forests would be about 100 TWh. Since fossil fuels account for 115 TWh of electricity production, heavy road traffic would require a significant share of biomass.

4.2.2 Heating and air conditioning of electric vehicles

The need for heating varies according to the time of year. Depending on vehicle design, heating is generally required when outdoor temperature is under +10°C. Besides heating, window dehumidifying is also required in vehicles. In passenger cars this is accomplished by using strong ventilation. Ventilation is avoided in public transport by using double-glazed windows. Air conditioning is required in summer when temperature is around +15°C or over and it is sunny.

Electric vehicles used for public transport have direct electric heating. Braking energy can be used for heating. Nonetheless, this does not mean that heating would not increase the amount of energy used by the system. Instead of heating, some braking energy has been returned to overhead wires, which means accomplishing about 30 per cent savings in driving electricity. Admittedly, the feasibility of returning electricity to overhead lines depends on whether electrical substation can return electricity to distribution network and whether the same overhead line feeding sequence has other vehicles to power as well. Using braking energy directly for air conditioning in carriage is more difficult than using it for heating. Air conditioner cannot convert electricity into cooling effect momentarily at great efficiency and cannot store coldness as resistors can store heat in heat production.

Heating of passenger cars has been based on using internal combustion engine's waste heat that is available in infinite amounts in comparison with the degree of needed heating. Car mantle's thermal insulation has not affected heat usage critically, since heat is leaked out of the car along the heated up ventilation air. Equalizing heating in different parts of car has also been based on blowing air around, not on keeping still air warm. Blowing dries up air, which is necessary for keeping single-glazed windows free from frosting or misting up.

When car locomotion is achieved with about 10–15 kW, using several kilowatts of power just to heat and ventilate the car is not an acceptable solution, when the operating range is small even with the consumption of mere driving energy. According to Kronström (2009), the waste heat of electric appliances contained in electric cars is approximately 10 per cent, and this heat is both hard to utilize and, moreover, insufficient.

Constant heating can be accomplished by using a fuel-powered heater. Heating appliances are nowadays available with power of 2–5 kW, and they are used for stand heating of trucks as well as in machinery and boats. Fuel consumption is at maximum power 0.3–0.7 L/h, and usable fuels are petrol or diesel. Using fuel oil or other tax-free oil for mere heating of vehicles has to be clarified with the tax authorities. If the heater uses fossil fuel, a plug-in model produces CO_2 emissions during operation.

Heating needs of a moving car are greater than those of a standing car. In practice, daily winter use consists of short trips that last 15–45 minutes. A separate fuel heater would probably be used at maximum power for the most part. Thanks to charging arrangement, heating up the vehicle before starting is a natural solution. Preheating can be accomplished in the normal fashion by using an indoor heater plugged into mains current, which eliminates the need for fuel and vehicle battery capacity. In principle, the use of an indoor heater does not affect the present power network load, since heaters are already in general use. In cities the need for heating is lower, partly because of parking halls and caves, where the car keeps warmer than outdoors.

In addition to car interior, also the batteries of an electric car need to be heated up. Low temperatures decrease the battery discharge and charge ability. The effect is significant with current battery technologies commonly in use.

The fuel consumption of a fuel-fired heater is approximately 10 per cent of the consumption of combustion engine car. If electric cars commonly used fuel heaters, the annual fuel need of electric cars would be, taking into consideration the periodical need for heating, approximately 5 per cent of the consumption of current car stock. This amount could be reasonably produced in the form of liquid biofuels. The acceptable prices could even be clearly higher than the current price level of liquid transportation fuels, since the price would affect the total costs of the consumer fairly little, due to the modest need. If the annual drive-kilometres amounted to 18 000 km, the annual costs of heating fuel would amount to 100–150 € with the current consumer prices of liquid transportation fuels (1.4 €/L in 2010).

Cars' air conditioners work on the mechanical energy given by combustion engine. Separate air conditioners, used for instance in caravans and campers, have an electric motor of their own. The cooling efficiency of equipment currently on the market ranges from 0.8 to 3 kW, and input power is about half of this. Usually the equipment is made to use mains current, which is available at campsites. Battery use requires an inverter. Commonly sold air conditioning products are often combinations of an inverter and a battery charger, which also track the battery state-of-charge, for instance to ensure that the engine of the caravan can be started. Like preheating, air conditioning can be arranged to operate on mains current before starting the vehicle.

Air conditioner can also be used as a heat pump. This nearly halves the amount of electricity needed for heating.

An appropriate solution is to aim to decrease the need for heating and air conditioning in electric cars. There has been no need to decrease the heating needs of engine combustion cars, and thermal insulation and window defrosting technologies have been developed for public transport purposes only.

Improving thermal insulation adds to the mass of the vehicle, which is not desirable. This dilemma can be solved partly by optimizing energy consumption, partly by using and developing unconventional materials. Double-glazed side windows are a fairly feasible solution, but double-glazing a windshield would be challenging because of its size and shape. This means that avoiding blowing as the primary method for defrosting a windshield is difficult. However, electrically heated windshields are nowadays available. Need for heating can be reduced by wearing warm clothing, even though this has probably little significance during short daily journeys. The need for heating and air conditioning can also be reduced by cutting down outblowing of air. The need for outblowing air can probably be influenced by drying air.

Keeping the car in garage or parking hall reduces the need for heating and air conditioning during short trips. Nevertheless, from the viewpoint of total energy consumption, a warmed garage is a poor solution. The outdoor cooling off of the car is compensated as the need for heating up the garage. Underground parking does not require heating. Keeping vehicle indoors is good for the batteries, whose charge and discharge ability is strongly dependent on temperature. A simple and cost-effective solution for reducing need for air conditioning is to provide a roof or a canopy to shelter the car from the sun. This solution does not consume energy, either.

4.2.3 Transportation electricity production

The electricity consumption of passenger cars has generally been assessed as the electricity need of the whole car stock and with the assumption that cars weigh about 1400 kg and are also in other aspects like present-day passenger cars. In reality, car stock will not be electrified all at once. In Finland the renewal of car stock has taken 19 years, and the annual amount of new cars sold is slightly over 100,000, among which the proportion of plug-ins is insignificant for the time being.

In the car markets it appears that western automotive industry is not overly enthusiastic about adopting electric cars. In the USA, the growth in hybrid and electric car sales is predicted to be quite moderate (Figure 17). The earnings logic of automotive industry is largely based on post-sales business, which electric cars will diminish. The development time of new car models is several years, and product family life time is 5–7 years. For these reasons, it can be postulated that within the frame of the prevailing techno-economic conditions western automotive industry might migrate to electric car production in 10–15 years.

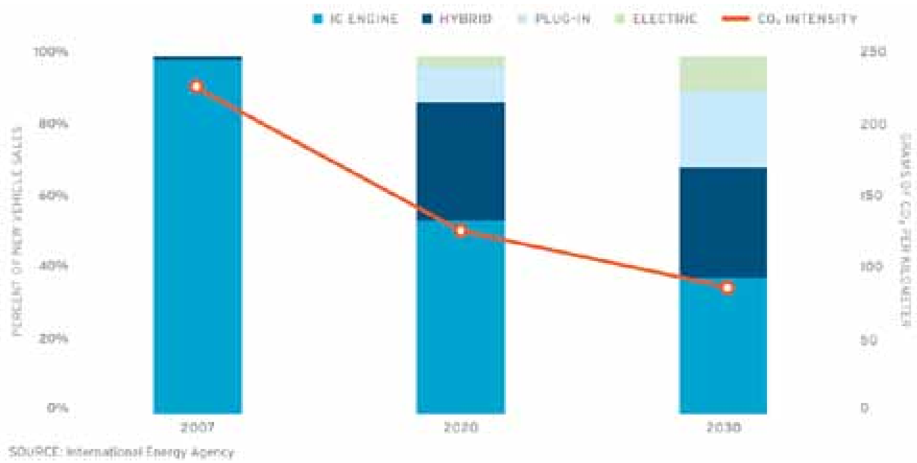

Figure 17. The percentage of various technologies of new vehicle sales in the USA and the development trend of CO_2 emissions (Electrification Coalition 2009).

With regard to the car sales numbers and the life time of car stock in Finland, the electrification of car stock can be assessed on the basis of the fact that annual car sales amount to 150,000 cars. If automotive industry would migrate to electric car production as fast as possible, the proportion of electric cars of new car sales could grow to 100 per cent in 12 years. The growth in passenger car traffic's electricity consumption adheres then to the diagram presented in Figure 18. This means that at first the electricity consumption of cars is insignificant in respect to electricity production and transmission in Finland. From the moment when a significant number of plug-ins will be available on the market, seven more years will pass, during which time the electricity consumption of cars is less than one per cent of the electricity consumption of Finland. The renewal of car stock will be addressed further in Chapter 5.6.

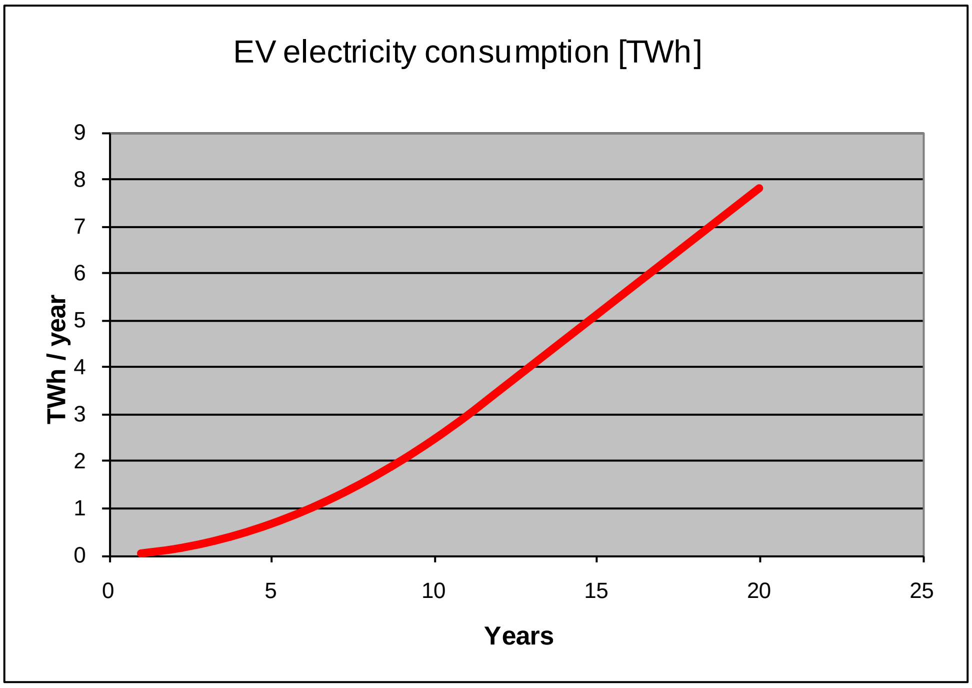

Figure 18. The growth in energy consumption of plug-ins from the moment the cars are released for sale. The diagram assumes that the annual car sales are 150,000 cars and that electric car sales grow in 12 years steadily so that all new cars are plug-ins.

It is possible that the renewal of car stock into electric vehicles will be expedited by authority actions, but, based on the present-day car's technical life time, the renewal time of car stock will probably not be less than 15 years. Furthermore, the renewal seems to start slowly due to weak supply.

It is also possible that, besides plug-ins, some other significant vehicle solutions using renewable energy will be made available (Figure 19). One reason for this are the estimates that claim that the world-wide production capacity of lithium-ion batteries is limited. The proportion of plug-in models sold could make up over half of the car sales, but pure plug-ins requiring large battery capacity would make up only a quarter of the sales at most. Large batteries are needed also in plug-in hybrids, but battery capacity can be 25–30 % of a full plug-in's battery capacity.

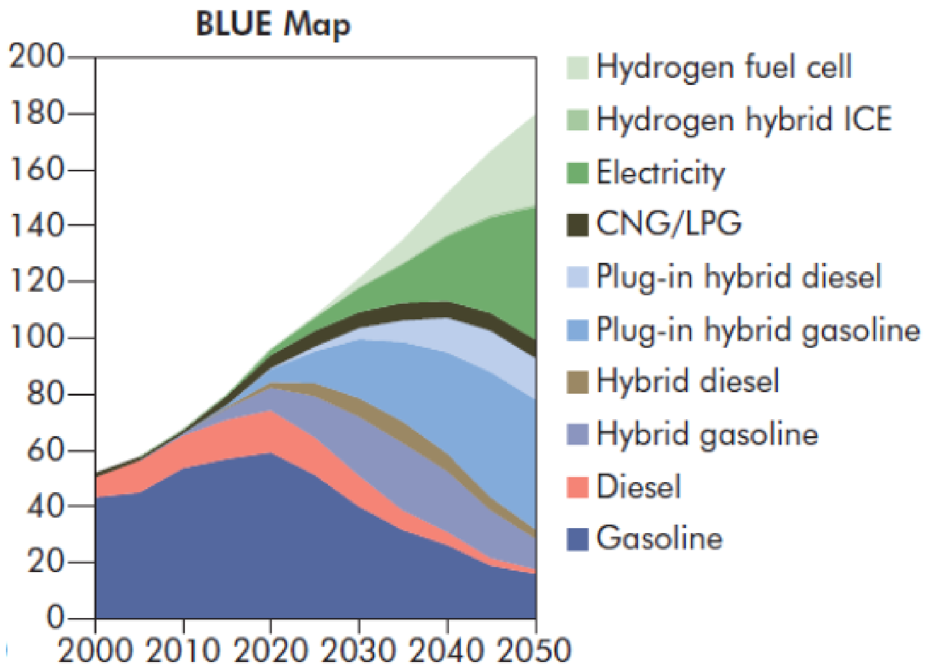

Figure 19. Various passenger car energy solution trends in car sales till 2050. The proportion of plug-ins and large-capacity battery models (dark green) is small compared to the whole (Cazzola 2010).

Kronström (2009) has estimated that the quantitative growth in electricity consumption caused by electric passenger car traffic, 9.2 TWh or 10 per cent, does not require more electricity production capacity, but the growth can be dealt with by implementing intelligent charging of the batteries of car stock. This means that the batteries are recharged at night, when daily variation lowers electricity consumption. This presupposes that the cars or their charging stations converse with the electric net and the system ensures, that the electricity production capacity is not exceeded.

From the car operator's perspective this system means that not all users can control the recharging themselves and thus can not necessarily know how the battery is charged. If bypassing this smart charging system is possible, there is a risk that this bypassing is used 'just in case'. This behavior can be controlled by the pricing of the fast or 'secure' recharging or by extending the operational range, in which case the consumer is more likely to accept that the batteries are not fully charged when the vehicle is taken into use. Intelligent recharging balancing thus means in practice that the operational range of the recharged car is reduced.

Intelligent recharging also means that car batteries can not be recharged during the workday, as the load would coincide with peak electricity consumption. For the consumer this means that the required range for the car in commuting use is doubled. With the current range of 150 kilometers for electric cars and the statistical average commuting length of 15 kilometers, this should not pose a problem.

Kronström assesses only the relationship between electricity production capacity and car stock's need for energy. The growth of plug-in car stock might pose a problem to the power transmission network, even though production capacity was sufficient. This is due to the fact that recharging causes more load in residential mid-range and low voltage transmission networks, which the current daytime peak load does not strain. Problems can occur in overhead power line networks with a voltage of 10–20 kV used for dispersed settlements, in underground cables in cities and in residential connection networks with a voltage of <1 kV. Nowadays, even the load caused by block heaters has proved problematic locally. Intelligent charging can adjust the load in these network parts.

A separate electricity production and grid load problem can be caused when parked cars are heated up with mains current at morning before starting them. Per car, the load caused by this heating up is equal to the current load caused by a block heater, but, due to the operating range and battery operation of an electric car, heating up a parked car may be necessary and more frequent than current use of block heaters. The combined power of the internal and block heaters is currently 2 kW. This equals the night-time charge power of cars, and it is needed both in the morning and afternoon for cars parked outdoors. At worst, the heating up of parked cars forms load peaks, which require the extra electricity production capacity that was avoided with intelligent charging.

In electricity production the operating order of power plants is determined by both production costs and environmental risks. The basic electricity production for the grid is accomplished by nuclear power plants, and hydropower plants are used as load following plants. During heating period, the basic power left over the electricity production of nuclear power plants and industry consists of co-generated electricity. Coal power plants are used for dealing with load peaks, but, despite its eco-friendliness and price, hydropower is used as the primary load following solution, since it is easiest to adjust hydropower production (Figure 20).

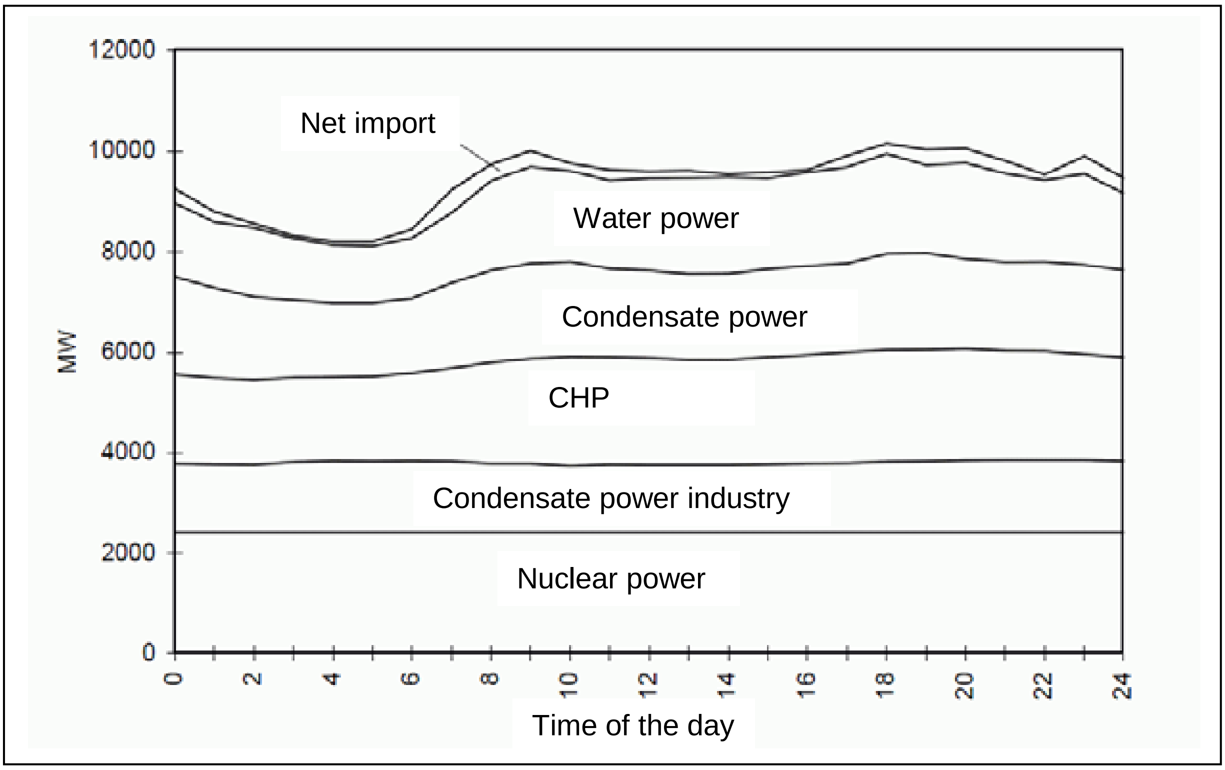

Figure 20. Electricity production methods during 16.1.1997 (Pirilä et al. 1997, page 26)

Intelligent charging system evens daily variation, but the marginal cost of required electricity is higher than the average production cost. With the current electricity production structure, the energy of electric cars is the most costly and most emission-rich form of energy; in the worst case, the energy consumed by electric cars is produced in coal power plants. How much of the night-time charging of batteries is powered by coal or hydropower is probably dependent on the desired hydropower load following margin, both short-term and annually, in relation to the amount of water available.

As the specific emissions of coal-produced electricity is 850 g/kWh, the specific emission of an electric car is 176 g/km without heating (Kronström 2009). The average specific emission of night-time charging would be half of this, if half of the charging energy was produced by coal and half by hydropower. From an environmental standpoint this is not very effective, as a hybrid car achieves the same emission level, with heating included. A gasoline-powered Toyota Prius -hybrid is said to have a consumption of 4.3 L/100 km and CO_2-emissions of 104 g/km. For example, if a hybrid car has a fuel consumption of 3 L/100 km and the specific CO_2-emission is 2,66 kg/litre, the specific emission of a hybrid car is 80 g/km.

Even if the total conversion of the current passenger car fleet to rechargeable electric cars would not require additional power plants, the reduction in car emissions requires that coal power, which is currently used as load-following, is converted from fossil fuels to CO_2-neutral power generation. Night-time recharging will not remove the current need for electricity production adjustability, even if it balances the nocturnal electric power drop either by volume, temporally or both. This issue limits the future power plant solutions, as they have to be adjustable also during car recharging times. This is because there is variation in the car fleet, so the nocturnal loading demand varies weekly as well as seasonally. Adjustable solutions currently in use are hydro power and biomass.

If the requirement is set at CO_2-free electricity production, CO_2-free solar and wind power can be used instead of load-following night-time recharging. Then the batteries could be recharged at any time of day. However, unlike in load-following power, this means investments in new production capacity to satisfy transportation's energy needs.

4.2.4 Wind power in transportation energy production

If wind power is used for recharging the batteries, wind power does not require load-following, unlike wind power fed into the electricity grid. Wind power can not alone provide all reloading capacity, as windless or low-wind periods can last for several nights (see picture in 4.2.6). According to Matilainen (2008), Finland could produce 2000 MW of wind power by 2020, when the technical maximum is at most 9500 MW. Current (2008) wind power production is 128 MW. With 2.7 million electric cars attached to 16 ampere connectors, the maximum required power is 9720 MW and the time to feed 81 GWh into totally empty batteries would be 8.3 hours. The daily average of annual 9.2 TWh consumption is 25.2 GWh, so the required minimum charging time would be 2.6 hours with 9720 MW power. When privately used passenger cars are unused at least 20 hours per day, the production power needed for providing daily charging is 1270 MW, in other words less than the planned wind power of 2000 MW.

When the 90 per cent reliable wind power is 6 per cent of nominal power, according to Matilainen (2008), the amount of reliable wind power available in 2020 would be 120 MW. Even at technical maximum, reliable wind power available would amount to 570 MW. Nevertheless, the charge need of electric cars is a flexible load, and the load criteria of general grid do not need to be applied to it. Charging need is flexible in the sense that a single car can operate without charging for 3 days and the car stock in average for 1.5 days, when the batteries of cars work as a load-following energy source. The car stock would need other electricity production capacity only during the second windless day in a row, when the free load-following capacity would be available to the car stock at nighttime.

It is essential to examine the total production of wind power capacity. According to Holttinen et al. (1996, pages 38–39), a wind farm produces annually 25 per cent and monthly at least 20 per cent of the nominal power production. 2000 MW of wind power capacity would therefore produce annually 4.4 TWh, which is less than half of the energy need of car stock. 2000 MW of wind power capacity built as car stock energy source would thus be an emission-free energy source meeting only half of the energy need, but this wind power capacity level would not require building reserve power plants.

4.2.5 Solar power in car energy production

The specific capacity of solar panels, considering the efficiency coefficient of charging regulator and inverter, is about 100 W/m^2. According to panel manufacturers, the annual average production of a panel in Finland is 15 per cent of the maximum power, which is reached at the maximum solar radiation of 1000 W/ m^2. In this case, providing the amount of energy consumed annually by a single electric car requires 28 m^2 of solar panels, if the car batteries are connected to the panel whenever the panel is producing electricity.

A car with fixed batteries is mainly used during daylight hours, so efficient production time of the panel is lost. Furthermore, the average production capacity of the panel is only 2 per cent of the summertime capacity from October to January (Figure 21). 90 per cent of the panel production is achieved during the time period from March to September. If the car is used in equal amount during every month of the year, the monthly energy need is 300 kWh. As shown in the figure below (Figure 21), a single 100 W panel produces about 9 kWh in March and September. If this is set as the criterion for the amount of electricity, 34 m^2 of solar panels are needed for a single electric car. From April to August the panels produce about 2 MWh of surplus electricity, but during winter months the car has to get 1.2 MWh electricity from other sources. Net surplus is 0.8 MWh.

If the need for solar panels is 34 m^2/car, Finland's car stock of 2.8 million cars requires in total 95 km^2 of solar panels. In other words, a square field of solar panels, the sides of the square measuring 10 kilometres, is sufficient to produce the electricity required by the car stock. There is 118 km^2 of roof area and 34 km^2 of facade area suited for installing solar panels (Solpros 2001, p. 6), which is more than would be required for producing the needed electricity for the cars.

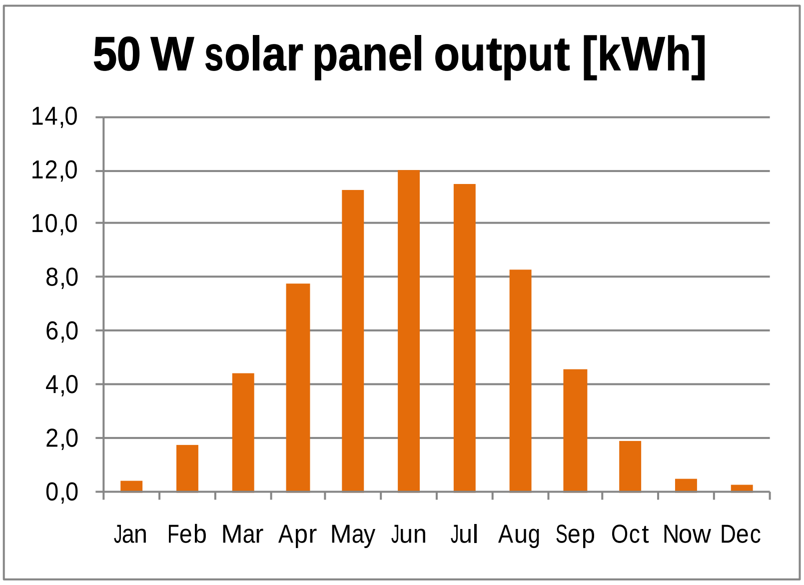

Figure 21. The energy produced by a solar panel in Varkaus, Finland by the month, when the panel's maximum capacity is 50 W (Savonia 2010).

Because of their yearly variation, solar panels are suited for compensating the yearly cogeneration (combined heat and power, CHP) variation (see Chapter 4.3). During winter, there is CHP electricity available for cars. It is not profitable to produce CHP electricity in summer, when there is an oversupply of solar power for transportation needs. Still, the dilemma concerning the fact that solar power is produced in the daytime, but the need for electricity is greatest at dusk, remains. Solar power must therefore be perceived as a daytime substitute for other load following energy. Another possibility is to compensate solar power production with car batteries. This will be discussed in the following chapter.

4.2.6 Using plug-in vehicle batteries for solar and wind power storage

Batteries of plug-in electric cars have been considered as a feasible means of storing solar and wind power. The idea is that solar panels and wind farms could always produce electricity at maximum capacity in good weather conditions, even though the grid had not enough load.

In order to use batteries for storing electricity, the average charge state of batteries must constantly be less than full charge. From the viewpoint of car use only, the batteries of cars in the grid are full in the mornings, when the cars are disconnected from the power grid. By 9 am most of the cars have returned to the grid and the battery charge state has been lowered. At this point, about 5–15 % of the charge for 150 km operating range has been consumed, according to the transport habit statistics. If batteries are not charged during the day to avoid overloading the power grid, the charge state of batteries will be about 15–45 % less than full charge at 8 pm when cars are back at home after commuting and other personal trips.

The load balancing needs of solar panels and wind farms differ from each other (Table 2). From the viewpoint of load-balancing use of car batteries, the most essential factor is the daily variation (in other words hourly variation) or the compensatory effect achieved within a couple of days at most. Batteries are not a feasible solution for load balancing in the case of significant annual power variation.

Table 2. The variation in the production of solar and wind power during different time periods in relation to nominal production

Balancing period	**Solar power**	**Wind power**
Annual variation	98–100 %	70–110 % [2)]
Monthly variation	2–100 %	51–157 % [4)]
Daily variation	0–100 %	0–100 %
Hourly variation	30–100 % [7)]	0–100 % [8)]

2) Korsnäs wind farm, Holttinen et al. (1996), p. 18

4) According to south coast wind statistics, Holttinen et al. (1996), p. 28

7) Variation in TKK Lighting Demonstration Building production on a partly clouded day. Schneider (2009) p. 32

8) Wind mill has to be stoppable in case the wind speed gets too high.

Solar power is regular in the sense that production is always at zero at night and that nominal power is achieved during all seasons in the sunshine. At annual level, variation is caused by the variation in the length of daylight hours, in the incidence angle of sunlight and in temperatures. Of these factors, temperature is affected by randomness. Short-time randomness is caused by clouds which reduce amount of light and decrease electricity generation. Periods of cloudiness can vary from minutes to days (Figures 22 and 23).

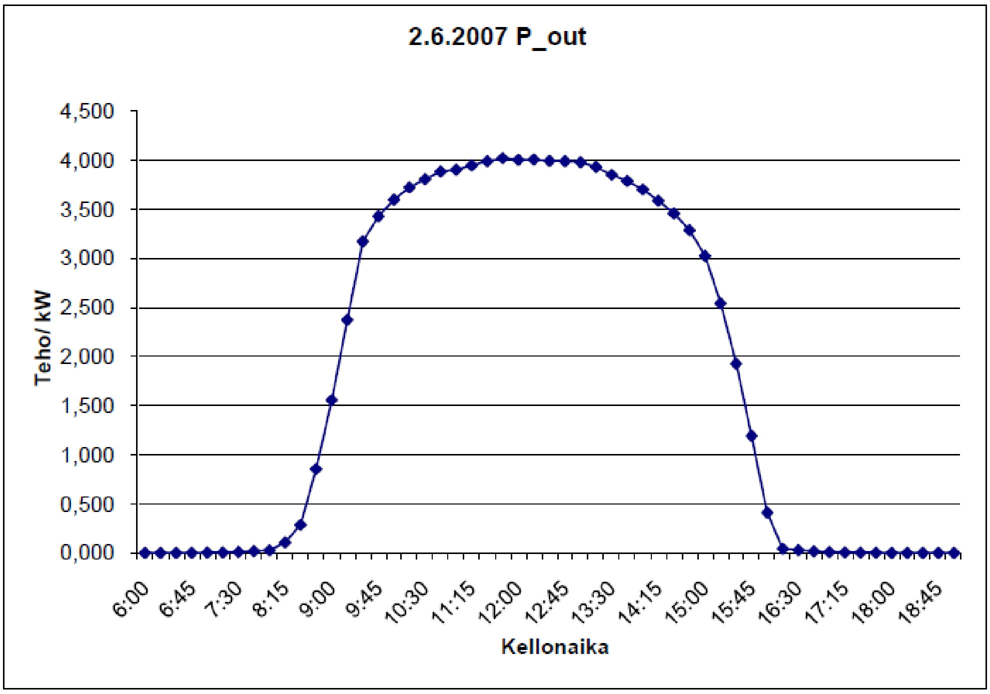

Figure 22. The power output of solar panels on a cloudless day at TKK Lighting Demonstration Building in Otaniemi (Schneider 2009). [Teho / kW = Power / kW, Kellonaika = Time of the day]

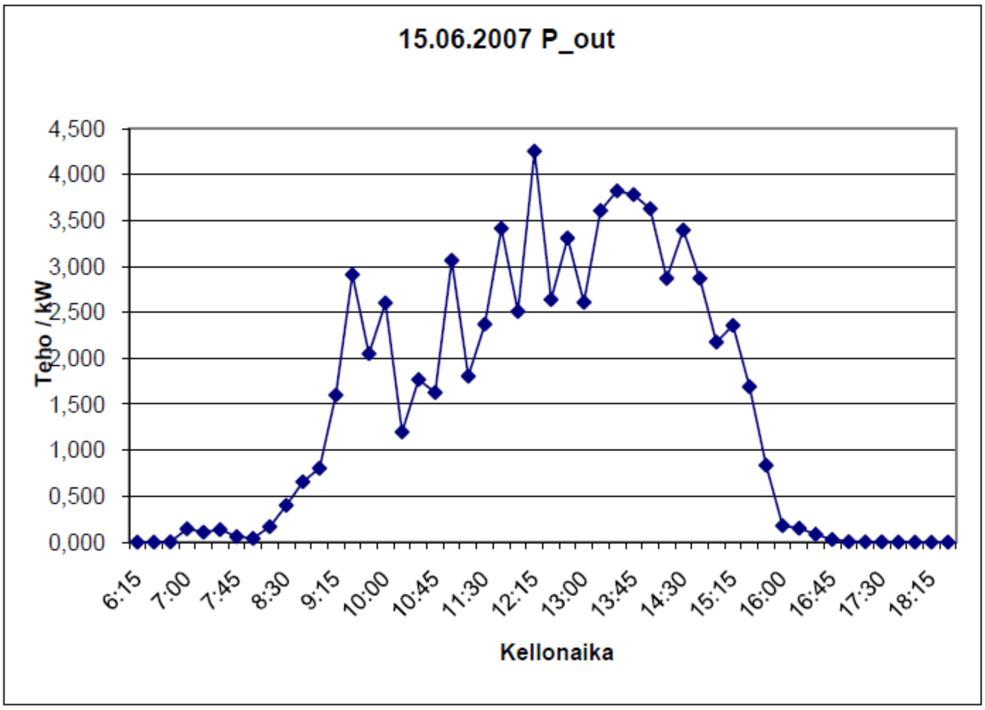

Figure 23. The power output of solar panels on a partly clouded day at TKK Lighting Demonstration Building in Otaniemi (Schneider 2009). [Teho / kW = Power / kW, Kellonaika = Time of the day]

The variation in wind power output is more random than in solar power. The 90 % reliable output of wind power is considered to be 6 per cent of nominal output (Matilainen 2008 p. 9). The system has to allow meeting a 25 % load following need and stopping single wind farm operation during storms within one hour. Daily variation is 90 % (Matilainen 2008. p. 8). This variation is not regular daytime and night-time variation, like with solar power. Scattering wind farms evens out wind power output variation on national level (Figure 24).

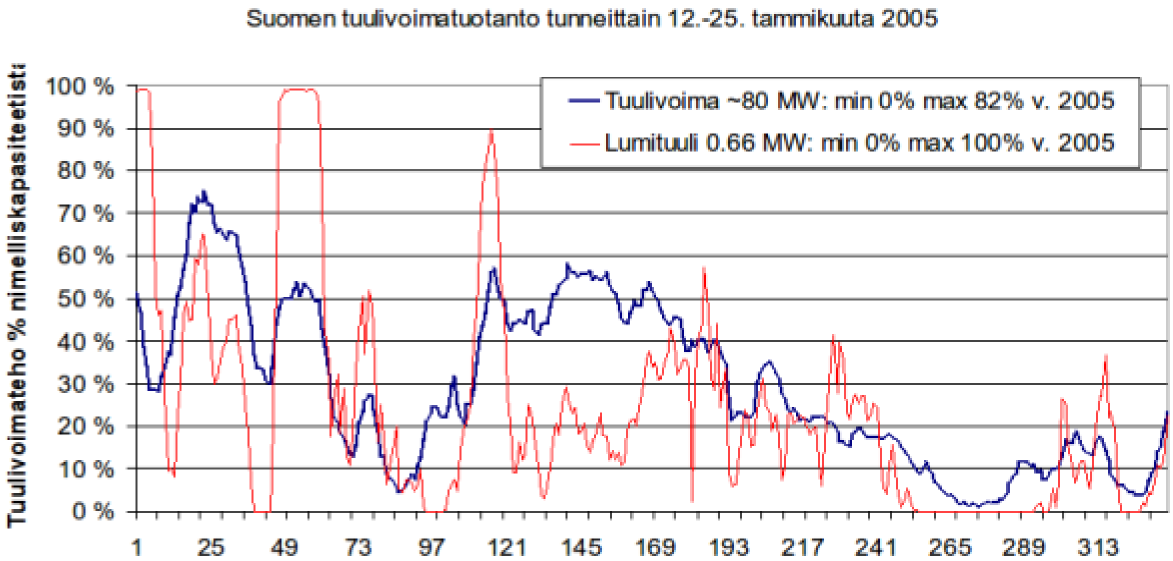

Figure 24. The variation in the wind power output of a single wind park (Lumituuli) and of all Finland during two weeks in January 2005. Source: Hannele Holttinen, 2007. Tuulivoima 2007 seminar. X-axle = hours, Y-axle = Wind power, share of nominal mill power. Tuulivoima = Wind power.

The electricity produced by solar panels and wind power plants should be charged into car batteries as near the production location as possible, so that this power transmission would not cause more load to an already-loaded grid.

From the viewpoint of a consumer, the use of car batteries for storage reduces the power capacity of batteries and therefore diminishes the operating range of the car. In order to be useful to the consumer, the car has to have a minimum operating range that is at least half of the daily drive-kilometres or at least equal to the longest continuous daily drive. According to the passenger traffic survey (HLT 2006 taulukko 6_31_tapa.xls/henkilöautoilun jakauma), 80.4 % of the trips performed as a driver of a passenger car were 20 km or less in length. On the grounds of this data, the reliable minimum operating range required can be considered to be approximately 40 km. The basis for this assessment is that the trip there and back is 20 km long, and the battery cannot be recharged at the destination. To ensure the reliability of the operating range, the charge state of the battery can be assumed to be equal to 50 km, for instance, which means that the operational reliability is 25 % in that case.

The minimum requirement for reliable operating range calculated above means that the consumer has to have at his disposal at least 10 KWh of battery capacity, which equals to 50 km operating range.

The technical operating range required currently from electric cars is at least 150 kilometres. This is equal to 30 kWh battery capacity. If the consumer accepts the daily operating range of 50 kilometres, he can hand over 20 kWh capacity for load following in electricity production. Intelligent charging system could work so that the consumer himself could choose how much and when he gives up some of his battery capacity for electricity production purposes.

If there is 20 kWh capacity available per car when plugged in the power grid, a single car would compensate for 3.3 kW of wind power (charging) or for 1.25 kW of wind power (discharging). For solar power, the corresponding figures are 2.35 kW of charging power and 1.8 kW of discharge power. The calculation has been based on the assumption that the wind power plant produces about 30 % of its maximum power output, which means that the wind power plan can be at a halt for 70 % of the time. A solar panel has been estimated to produce power on average for 10 hours per day. The calculations have taken into consideration the fact that cars are not plugged in the power grid at all times. In the case of solar panels, the time the car is disconnected from the grid has been evaluated separately for daylight and nighttime hours. Charging and discharging are supposed to take place within 24 hours. Using load balancing for cloudy days lowers discharge power in connection with solar panels.

The passenger car stock in Finland consists of roughly 2.8 million cars; in metropolitan area there are 430,000 passenger cars (statistical year 2009). According to the calculation above, they could compensate for 9.3 GW (charge) or 1.4 GW (discharge) in terms of wind power and 6.6 or 1.0 GW, respectively, in terms of solar power. For comparison's sake, it must be stated that Helsingin Energia's development project has planned for 1.3 GW wind power, the annual production of which is 28 % of continuous power output. The current electricity delivery power of Helsingin Energia is approximately 0.7 GW.

When the specific capacity of a solar panel, considering the efficiency coefficient of inverter and charging regulator, is about 100 W/m^2, a single car can compensate for the electricity production of a 24 m^2 area of solar panels. This area is equal to the area of a parking field per one parking space. Nevertheless, it must be noted that a solar panel's annual average output in Finland is 15 % of the panel's maximum output, which can be reached with 1000 W/m^2 solar radiation power. From November to January, the average output of a solar panel is only 2 % of the output achieved during the summer months.

Therefore, the battery capacity of plug-ins is of such magnitude that it can be a significant factor in compensating for the variations in electricity production and consumption. If batteries are permanently installed in the vehicles, this compensation would happen at the cost of effective battery capacity and, consequently, diminish the operating range of the car. It would also be detrimental to battery lifetime, since load-balancing usage increases the number of battery charge-discharge cycles.

The batteries of a plug-in model represent an essential part of the cost of the vehicle. The price of a lithium battery is 500–1000 €/kWh. The battery capacity reserved for power grid load-balancing forms therefore a significant part of an electric car's price. The lifetime of lithium phosphate batteries is about 10 years or about 3000 charge/discharge cycles, when residual charge is 20 %. The yearly cost of a 10 kWh battery with 5 % interest rate is thus 650–1300 €, or the daily price of a charge-discharge cycle with interest is 2.2–4.3 €. If car batteries are used in power grid, a price must be fixed for their use in order to ensure fair treatment of consumers and in order to make consumers willing to plug the car in the grid.

If charging system is based on replacing drained batteries, the relationship between the consumer and the power grid and electricity production administrator is different. The batteries inside the cars are not constantly plugged in the power grid, unlike the batteries at the charging stations. In principle, the required number of existing batteries is double the number of batteries charged in cars. Therefore there are as many batteries plugged in the power grid as when using batteries that are permanently installed in cars, but batteries are plugged in the grid also during the time cars are being driven.

Fully charged batteries should be available at battery changing stations in order to ensure good consumer service. Providing fully charged batteries to consumers is easier to arrange when using replaceable battery solutions, since the battery charge state variation needed for grid load balancing can be accomplished by adjusting the number of fully charged batteries. If the system runs out of fully charged batteries, the inconvenience caused by a partly charged battery can be compensated to the consumers through pricing.

A replacement battery system is technically better for load balancing use of batteries than fixed battery system. When replacement batteries are used, pricing becomes also more simple and more clear-cut from the consumer’s point of view. Battery changing stations can buy and sell electricity in a more flexible manner than single consumers, and the load balancing of electricity production does not affect the operating range and operability of the cars. When selling and buying electricity is battery station’s business activity, it can be a part of the earnings logic of the station that also balances the price of the electricity sold to consumers. Consumers are also given the option to decide when to buy energy. In electricity market the trade price varies faster than in oil market, and therefore also the consumer price asked by a battery station can vary according to whether the station needs to acquire battery capacity from consumers even from partly empty batteries or whether it benefits the station more to sell more electricity to the power grid from the batteries the station has in the store.

Plugging the battery in the power grid and consequently charging and discharging the battery while it is installed in the car can be technically feasible even in battery replacement system. This might not be desirable for the business goals of battery stations, which means that the matter should be settled with a governmental decision. However, it would benefit the consumers to be able to charge the batteries even when the services of battery changing systems are not readily available due to distances or time of the day. From the viewpoint of power grid load balancing, however, consumer-available charge/discharge is less significant, since battery changing stations can be equipped with more efficient connections than single consumers.

For the benefit of consumers, battery renters, energy producers and public authorities, ie. taxation, it is necessary to ensure that all charging systems are intelligent in the sense that the source of electricity and the characteristics of charge/discharge cycles are known. This information is needed for the pricing of electricity and electricity transmission, for optimizing emissions, for pricing the use of batteries and for taxation.

4.3 Cost of transportation electricity

Electrifying transportation will mean about a 10 % increase in electricity demand compared with the present-day (2010) demand. The acquisition cost of this electricity amount is dependent on the national energy solutions. On the other hand, an increase of this magnitude must be taken into consideration in energy policy.

The basic economical principle of electricity production is to produce at first the electricity that can be produced as cheaply as possible. Therefore increasing electricity production means in principle that the cost of supplemental production is greater than the cost level before the increase. Another basic principle of transportation energy production has to be that the electricity needed by transportation is produced with methods that have less environmental impact than the current transportation energy consumption and in such a way that the carbon footprint of transportation decreases.

Technically and politically unacceptable production methods include using hydropower and using fossil fuels to fire power plants. Nuclear power cannot be regarded as an actual means for producing electricity for transportation, since nuclear power is not adjustable otherwise than negatively in the way the variable difference of consumption variation and fixed production output is sellable as an export. Acceptable production methods that are currently in large scale use include biofuels and solar and wind power.

The production cost of biofuels consists of the power plant investment and the production and freight costs of biomass. Finnish forest industry has experience about all production phases of biomass and their costs. However, this experience is based on energy production that happens as a spinoff of chemical or mechanical lumber industry. For instance, pulp mills produce surplus energy, and it has been profitable to sell electricity and heat at market prices in order to lower the production costs of wood pulp. The circumstances are the same with wood chips. Mechanical lumber industry produces waste mass that can be sold at market prices. The harvesting of pulpwood and sawtimber logging residue is a cost not covered by market prices, but the harvesting market works with the aid of state-provided environmental support.

In principle, mechanical biomass is burned in power plants that are similar to fossil fuel -fired plants. Consequently, the price difference between burning mechanical biomass and burning coal or oil consists of the price difference in the crude materials at the power plant. The market price of wood-based biomass in energy production use is not known, because wood growth is primarily used as a raw material for industry. Depending on the wood quality and purpose of use, industry pays for wood 10–25 €/MWh as calculated per wood thermal value. Compared with the price of coal at port, Finnish industry pays 1.5–3 times as much for wood energy.

Wood sales prices must cover the growing and harvesting costs. Since it takes a forest approximately 50 years to grow to meet the needs of industry, there is no forest in Finland that could have been grown specifically for energy production with cheaper methods than lumber. The price of pulpwood cannot be considered as a reliable price of energy wood, either, since the use and pricing of forests are based on the current market situation and on the relationship between the pulpwood and sawtimber demand. While sawtimber has the highest growth costs, the production costs of energy wood are hardly higher than those of sawtimber. Nevertheless, on a large scale those costs are probably not quite as low as those of pulpwood in the current market situation, since the growth of pulpwood uses the same resources as the growth of sawtimber.

The transportation of biomass is an essential part of the price formation of biomass, because forests grow on a large area and mainly far away from population centers and settlements (Figure 25). In order to utilize the heat produced by burning, the mass has to be transported near to the use location. When wood is used for fuel on a large scale, the average transportation distance can be several hundred kilometres, since the forest areas located nearest to population centres do not produce sufficient quantities of biomass to meet the demand.

The choice of energy transportation method is an optimization problem. The specific weight of a solid fuel, e.g. wood mass, should be increased in order to lower transportation costs. The target density is approximately 900 kg/m^3, which is enough to meet the cost minimum of car and train transport. The density of woodchips is 300 kg/m^3, a log pile has a density of 500 kg/m^3. It is recommendable to chip logging residue near the harvesting site. On the other hand, it is profitable to transport stemwood to be used as firewood as logs and chip the logs for burning at the use location.

There is little public information about production costs of transportation. The market price of truck transport is known. The production costs of rail transport have not been publicly available since the incorporation of Finnish state railways. There is also no market price for rail freight in Finland, since VR Group has so far no competitors in freight business, even though this would have been allowed by legislation since the beginning of 2007.

The production costs of rail freight can be estimated with the help of unit costs of rail transport by calculating the investment and maintenance costs of the equipment, personnel and energy costs and rail tax. According to this calculation and with the current energy demand of Finnish cities, an electrically-powered 300 km rail transport of woodchips costs about 1.5 €/MWh, and the corresponding truck transport costs 5.9 €/MWh. The calculation assumes that the required equipment is reserved for biomass transportation only. The costs of transporting the mass to the loading siding and reloading costs must also be included, when calculating rail transport costs. These should make up about 0.5 €/MWh. The costs outlined above do not include the transport company business profit, which means that they are equivalent to the energy company's transport costs as self-performed work.

Another noteworthy observation about rail and car transport is that rail transport can be either fully or partly powered by electricity. Truck transport is by necessity powered by liquid fuel. The energy consumption of rail transport is 3.4 kWh per one MWh of transported energy; in truck transport the amount of energy consumed is 3 litres or 30 kWh per one MWh of transported energy.

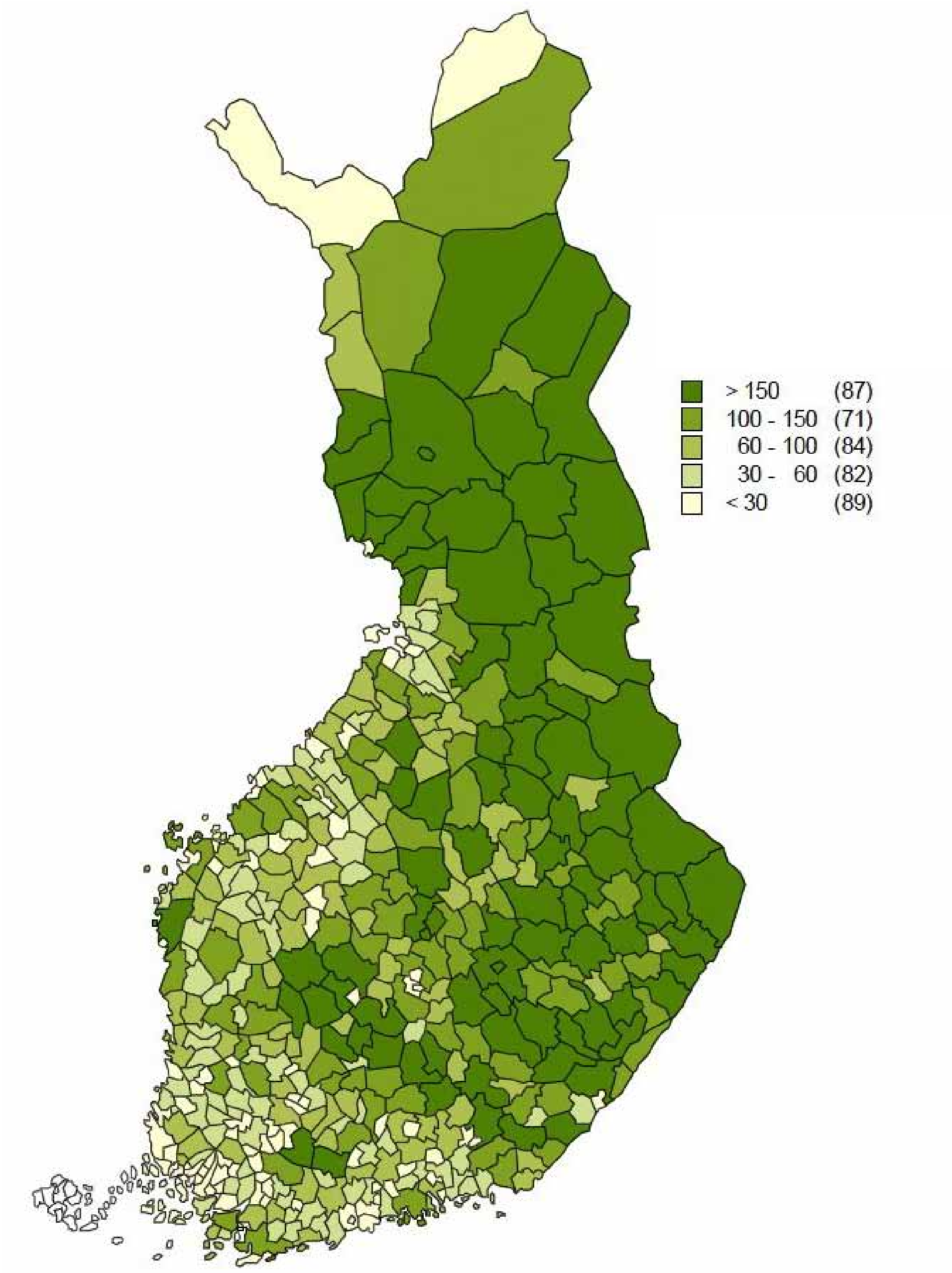

Figure 25. The regional supply potential of woodchips in 2015 measured in GWh per year (Iikkanen et al. 2009).

The cost of using biomass for transportation electricity production depends also on the degree to which biomass can be utilized in CHP production. The monthly variation in transportation energy demand is slight, but strong in heat demand (Figure 26). For instance, Helsinki reduces its electricity production considerably for summertime as the heat demand decreases, since it is more cost-effective to buy electricity than to get rid of power plant's heat by releasing condensation water into the sea. This procedure is performed in a situation where the Helsingin Energia CHP plants are fired by coal and natural gas.

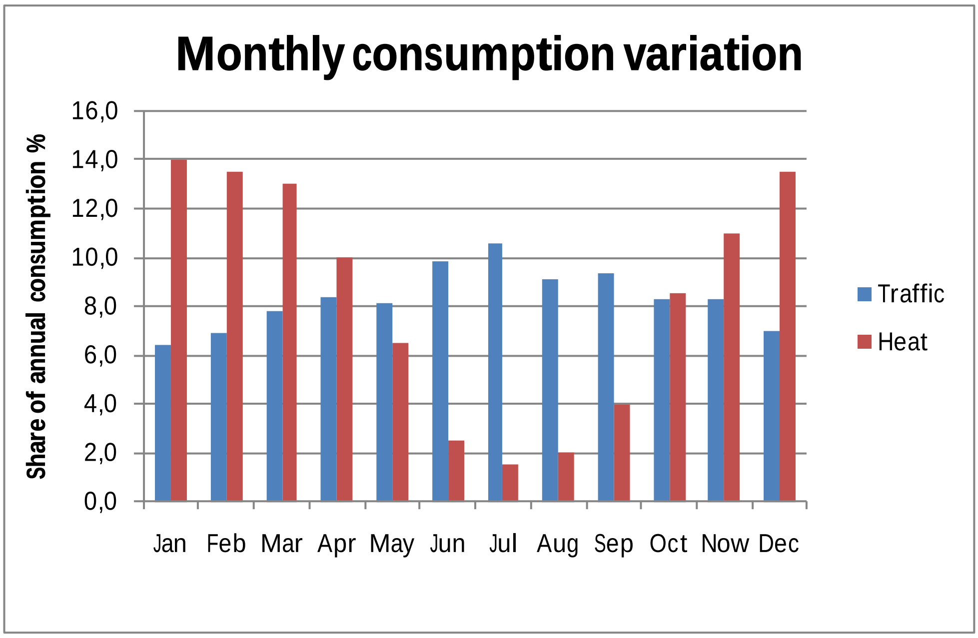

Figure 26. The monthly variation in domestic passenger car drive-kilometres and district heating consumption. (HLT 2006: http://hlt.fi/tulokset/ajalliset_vaihtelut.htm and HELEN 2009: http://www.energia.fi/fi/kaukolampo/kaukolampo/asiakkuus/kulutus)

Based on the above monthly distribution of traffic and heating needs the 9.2 TWh electricity production for traffic would require the use of 23 TWh worth of biomass, from which 7.0 TWh could be used as heating and 5.7 TWh would become thermal load for the environment, assuming a 5 % loss for the plant. On a yearly level the energy efficiency compared to the fuel's energy content is 70 %. If, based on the above, we calculate the price for the biomass to be 15 €/MWh when at a public road and a cost of 2 €/MWh for delivery to a railroad loading point and rail transport to the power plant, the raw material price for the energy at the power plant is 17 €/MWh. When the cost of the biomass is divided between electricity and heating, the raw material price for traffic electricity is 24 €/MWh.

If the biomass is to be used more effectively, e.g. using biomass only for CHP production, the heating needs dictate the amount of electricity produced. In this case 12.7 TWh of biomass is needed, and the cost for the energy becomes 18 €/MWh. But 4.1 TWh has to be produced by other means outside the heating season.

The price of wind energy consists mostly of investments and to a lesser degree of the windmill's maintenance costs. The market price for wind power is affected by the cost of the required spare capacity, when the wind power plant directly powers the electric grid. As has been stated before, wind power does not need a backup if, unlike in the case of direct load, the windmills are used to charge batteries, because the batteries will even out the fluctuation in produced power.

The price of a wind power plant is considered to be 3 €/W and a practical value for the produced electricity is 90 €/MWh. The price corresponds to a 25 year working life in Finnish wind conditions.

The price of a solar power plant in Europe is considered to be 3 €/W. It is suggested that in China the price of a solar power plant would rapidly fall to about 1 $/W, which would be the export price of these devices. If the working life of a solar power plant and it's peripheral devices is considered to be 25 years, and using the weather conditions in central Finland, which equates to a yield of 15 % compared to nominal power, the price for solar power is 160 €/MWh with European costs, but 45 €/MWh with Chinese export costs.

Wind or solar energy does not appear to be profitable when compared to biomass only. However, both have the potential to complement biomass use in the summer, outside of the heating season, when the CHP production of biomass does not produce enough electricity. Such a combination with solar power is presented in the picture below (Figure 27).

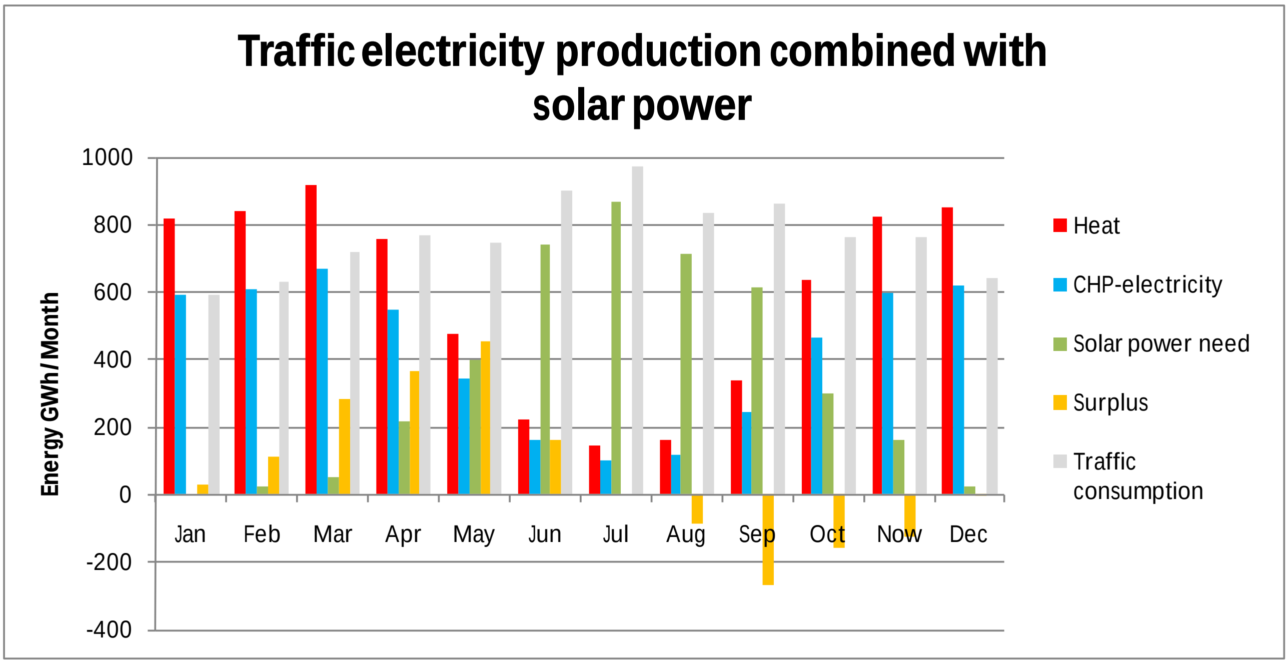

Figure 27. Transportation energy production solution that combines biomass-based CHP production and solar power -based electricity production. Surplus means the difference between the electricity produced jointly by CHP process and solar panels and the transportation's need for electricity. A positive surplus in the beginning of the year means excess production. Negative surplus means that during those months transportation had to get electricity from other sources.

Even though biomass alone would be a cost-effective solution for producing all transportation electricity, it might not be feasible because it is not appropriate to use biomass in condensate electricity production during summer months. The amount of biomass wasted is almost as great as the heat produced, and the thermal load in water systems is also an environmental hazard.

The basis of combination solution is the demand for heat. Heat is produced at a CHP plant which produces electricity at the output level that is technically possible in connection with heat production without condensation. The heat output of the plant has been scaled according to the transportation electricity need in January. The difference between the transportation electricity need and the electricity produced in cogeneration with heat is produced by solar power. The solar power output has been scaled according to transportation's maximum need of electricity, in other words according to July, when the production output of CHP electricity is at its lowest.

The arrangement produces surplus electricity 1.4 TWh in spring (Figure 27, orange column), but in autumn there is 0.64 TWh undersupply in the system. The net result is that the system surplus is 0.76 TWh.

The solution's cost for electricity needed by transportation is 90 €/MWh, which is equal to using wind power alone, when the cost of biopower is 18 €/MWh and the cost of solar power is 160 €/MWh and the estimated market price of surplus electricity is 50 €/MWh. Transportation electricity has a market price of 50 €/MWh, if the cost of solar power is 85 €/MWh or about 2 €/W. The calculation assumes that heat is sold at fuel price 18 €/MWh.

It is obvious that the proposed combination solution is not as cost-effective as any other solution based on market electricity, if the price of market electricity is lower than solar power's calculated price, ie. less than 160 €/MWh.

Combination solution can be implemented by using wind power as well, if wind power surpluses and deficiencies can be balanced with the price of market electricity. Due to smaller monthly variation in wind power, the balancing need of the system keeps growing during year. When the amount of wind power is dimensioned so that it covers the amount of electricity missing from CHP production during year, transportation requires at maximum 0.53 TWh of load-balancing power in July. During winter months the solution provides surplus electricity, at maximum 0,34 TWh in January. With the prices stated above, the price of transportation electricity will be 50 €/MWh (Figure 28).

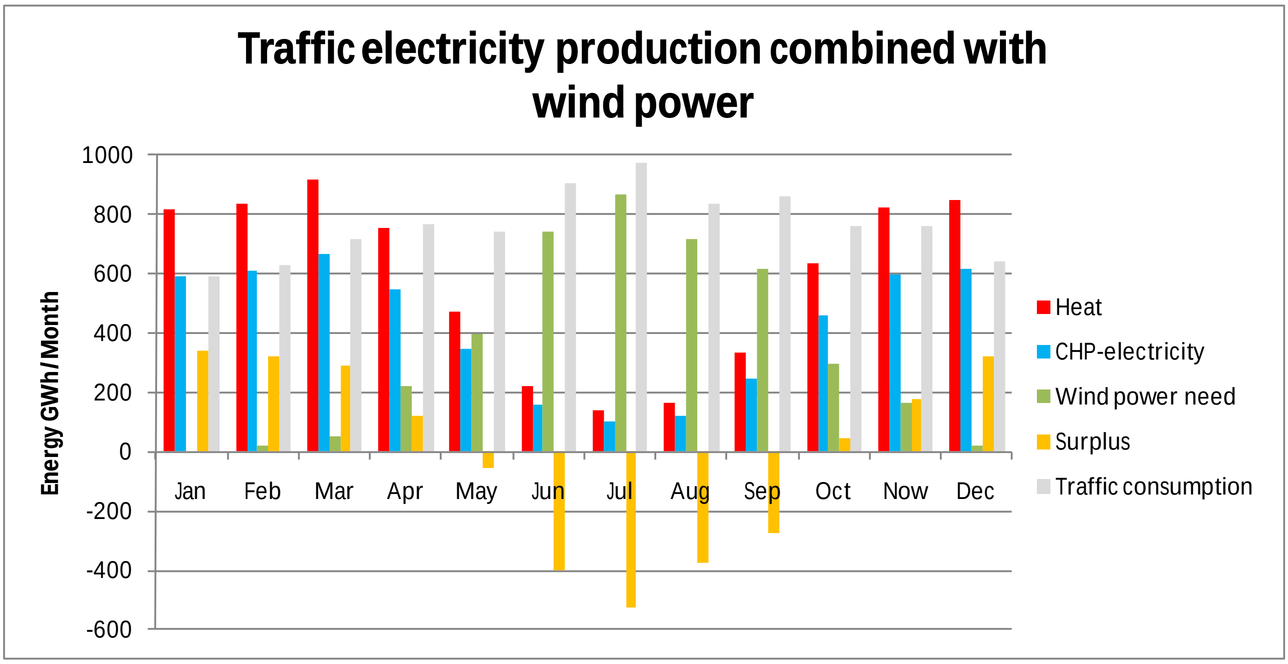

Figure 28. Transportation energy production solution that combines biomass-based CHP production and windpower-based electricity production. (Henkilöautosuoritteen kuukausijakauma.xls)

From the viewpoint of electricity production, wind power solution is worse than solar power solution, because load balancing will not compensate the general balancing need connected with CHP production, but increases it. The crucial factor in terms of cost-effectiveness is the market price of wind power load balancing. If selling prices and purchase prices differ from each other, it affects the price of transportation electricity. Nevertheless, this combination solution is as a whole more cost-effective than the solution based on mere wind power.

The amount of electricity needed by transportation is so great that it probably has a significant effect on the price level of electricity in Finland. It can also affect the production costs of electricity in Finland. Evaluating this requires making assumptions about the future development of energy markets both in Finland and worldwide. Energy production in Finland is dependent on global markets concerning fossil fuels and uranium and nuclear power plants, and the market price of electricity is dependent on the solutions adopted in the electricity markets of neighbouring areas and countries.

4.4 Pricing of transportation electricity

Reducing the proportion of oil as a transportation energy source is not meant to change the consumer price of transportation, but the consumer price change can promote migration from fossil fuels to electricity. Governmental guidance can affect the taxation of both vehicles and energy. The acquisition of electric vehicles has also been subvented by some countries. The guidance possibilities concerning vehicle taxation are slight or nonexistent, because even tax-free electric cars are in the initial phase more expensive than combustion engine cars, which is largely due to battery costs. However, energy taxation offers a significant guidance possibility.

Transportation energy in the form of liquid fuels costs currently (2010) approximately 0.16 €/kWh in Finland and Europe. This means a price of 0.11 €/km for passenger cars. Since the price of household electricity in Finland is 0.13 €/kWh, with electricity distribution and taxes included, the consumer price of a plug-in car will be 0.026 €/km, about a quarter of the energy price of a liquid fuel -driven car. The consumer price of fuels includes several taxes, the proportion of which is about 60 % of the petrol (not gas oil for diesel engines) price in Finland. This includes the fuel tax which is about 40 % of the consumer price. The tax-free price of fuel is therefore 0.044 €/km. The consumer price of electricity contains considerably fewer taxes. In addition to vehicle tax, the price includes electricity tax, 1.07726 cent/kWh, which is about 8 % of the consumer price of electricity in spring 2010. In total, about 27 % of consumer electricity price consists of taxes, and the tax-free consumer price of electricity distribution is 0.017 €/km.

Transportation taxation is primarily fiscal, which means that the tax is collected for the governmental expenditure. From the viewpoint of public economy, transportation should be taxed equally regardless of the energy solutions adopted in transport. The current liquid fuel tax is 0.066 €/km. In order to get the same tax revenue from electric cars as from combustion engine cars, transportation electricity price should be set at about 0,085 €/km (Figure 29). Then the consumer price benefit of using an electric car would be 0.025 €/km, in other words, 23 % less than the current price of driving energy. Based on the average annual drive-kilometres, 18 000 km, the consumers benefit about 450 € in a year.

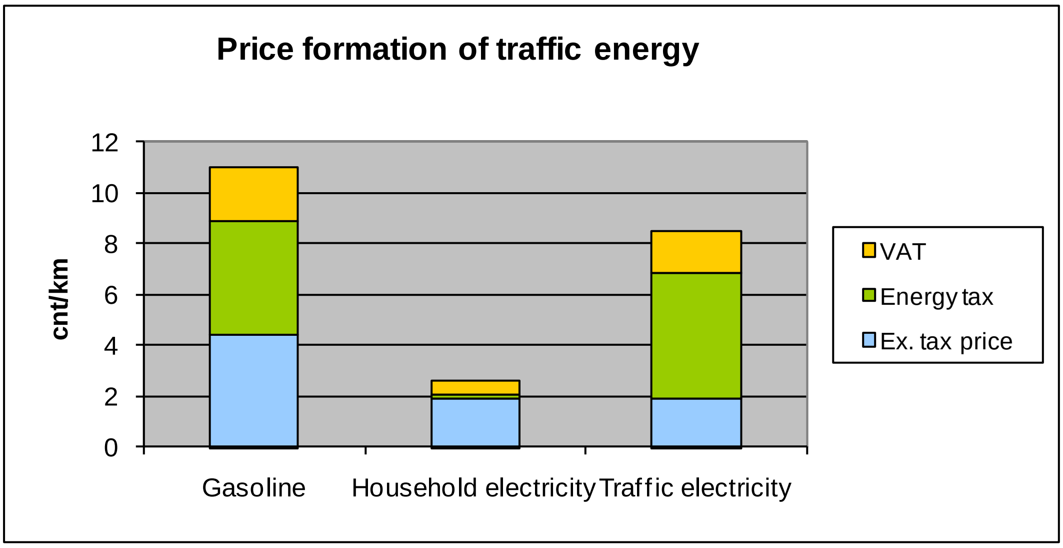

Figure 29. The price formation of transportation energy. The tax revenue from transportation electricity is the same as the present-day revenue from liquid fuel.

The energy tax revenue accrued per car is now 1 190 € per year. When an electric car is charged with household electricity, the accrued tax is 126 € per year. This means that the state will subsidize electric motoring for an average of 1 060 euros per car in a year. When the yearly benefit of 450 € caused by lower energy price is included, the total benefit to consumers is 1 510 €/year.

The cost benefit of electric motoring to consumers is 8 600 €, based on a solution lifetime of 19 years, if government tax for transportation energy will be the same as the current liquid fuel tax. The current value of this consumer benefit, discounted with a 5 % interest rate, is 5 470 €. If government stopped taxing transportation energy completely, for instance by removing the tax from the first electric car the consumer buys in order to subsidize the adoption of electric cars, the consumer benefit for 19 years would be 18 270 €. The current discounted value of this is 11 680 €.

When the price of an electric car is formed roughly so that a car without any batteries costs about the same as a combustion engine car, the battery cost can be considered to be a part of the energy cost. When the price difference between liquid fuel and electricity is 450 €/year, a battery that lasts for 10 years or 3000 charges may cost with 5 % interest rate 3 500 €. At the price of household electricity, the benefit for the consumers is equal to batteries worth 11 700 €. In reality, the batteries of a passenger car cannot be acquired through energy cost benefit in either case, since the 30 kWh batteries needed for a 150 km operating range cost at the moment 15 000–30 000 €.

According to analyst prognoses about battery price development in subcontractor markets, the prices will be 300–400 $/kWh in 2015 and 200–300 $/kWh in 2025 (Figure 30), so the battery prices are going down. However, even the lowest predicted price will not be low enough for the current price difference between liquid fuel and electricity to cover the costs of sufficient batteries, if transportation electricity tax remains equal to the euro amount of liquid fuel tax. When a 30 kWh battery pack is used, the energy cost of one kilometer is 15 cents, whereas with liquid fuel the cost is 11 cent/km (Figure 31).

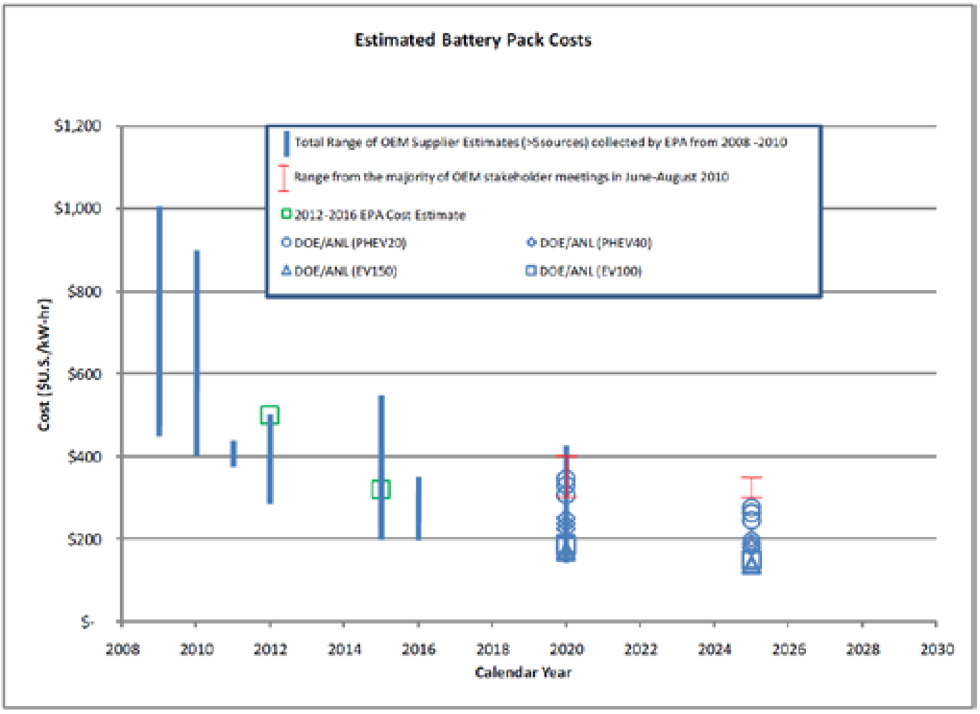

Figure 30. The predicted price development of lithium batteries (EPA 2010).

The energy costs of a plug-in can be estimated so that initially a plug-in's household electricity will not contain transportation energy tax, but batteries are expensive. In the future transportation energy will be taxed as presently, but batteries will be cheaper. The costs for the consumers will remain about the same as now, about 13 cent/km, when the car's battery capacity is 20 kWh. Based on this, the consumers should at first content themselves with a small battery capacity and short operating range and lengthen the operating range only when the prices of batteries go down. Even though transportation electricity taxation would rise to the current level of transport energy taxation, the cheapening of batteries will compensate for the total cost of energy paid by consumers (Figure 31).

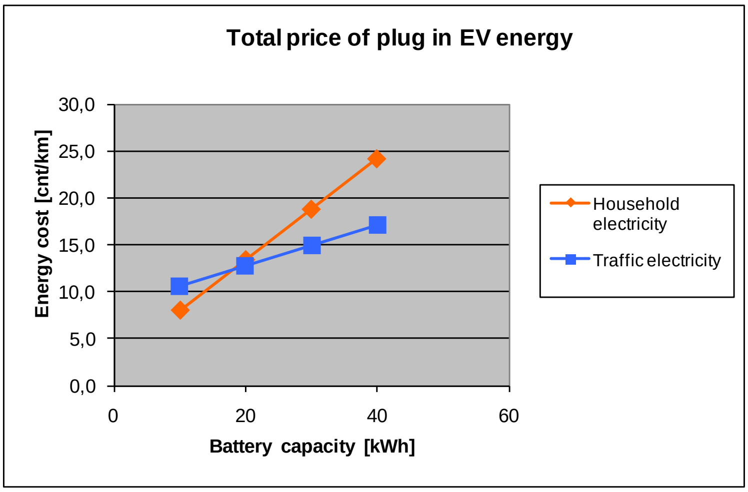

Figure 31. The total price of energy for a plug-in car, including energy costs and the paying off of battery. The tax-free price of energy is the current 1.9 cent/km. Household electricity includes the current household electricity taxes, 0.7 cent/km, and the specific price of battery is 750 €/kWh. Transportation energy tax is the same as the current liquid fuel tax (presented in euros), 6.6 cent/km and the specific price of battery is 300 €/kWh. Battery lifetime is 10 years and interest rate 5 %.

If the lifetime of electric cars remains the same as that of present-day cars, 19 years, each car will need two batteries during its lifetime. The first set of batteries bought in the near future will be more expensive than the second set of batteries, so the energy cost of a plug-in will decrease in terms of batteries. Nevertheless, it is possible that a known phenomenon affecting other battery-operated devices could affect car markets as well. The lifetime of battery itself has turned out to be also the lifetime of several battery-operated devices, since the cost of acquiring a new battery is high compared with the cost of acquiring a completely new and more advanced device. Even though electric cars are more simple and more robust in design than combustion engine cars, the limited lifetime and permanently high price of batteries in relation to car price may lead to cars having shorter useful life cycle, at least for the first rudimentary electric cars.

In the current legislative situation, the battery charging system has an impact on the taxation of electric motoring in Finland. When batteries are a fixed part of an electric car, vehicle tax is applied to them. If batteries are replacable, their taxation falls under energy taxation, if electric cars are sold without batteries and a rent is paid for the batteries to the energy seller as a part of the energy price. At the moment (2010), it is more profitable for the consumer to buy the batteries with the car, since 40 % of the consumer price of car and 60 % of the consumer energy price is made of taxes.

Buying cars without batteries helps to make electric cars more common. The price image in the consumer’s mind is formed more by the sales price than lifetime use costs that cannot be predicted reliably. A new electric car sold without batteries would probably have a lower consumer price than combustion engine car, even if car tax would be the same for combustion engine cars and electric cars. In the long run, it is also probable that the production costs of electric cars will be lower than those of combustion engine cars, due to the simple design of electric cars.

Energy production has to be taken into consideration as well, when pricing the energy used by electric cars. The current price of electricity and the previous estimate based on that price are dependent on the current production structure, and on the Nord Pool market price in Finland. If electricity is produced at night with the load-following capacity that has been freed as other electricity consumption has gone down, electricity used by transportation is produced on the average with a more costly production method than other electricity in the market. In that case, it would probably be fair to set the part of the price that covers transportation electricity production costs higher than for other electricity. Otherwise the rise in average unit price in electricity production is paid equally by all electricity consumers, which means a transfer of income from electricity users to motorists.

A similar principle should be followed if new capacity is constructed for the benefit of traffic. Based on assessments in the spring of 2010, a sizeable additional construction of wind power means, that the production cost of wind power is three times that of the current electricity market price. If wind power is constructed for the benefit of traffic, then this traffic electricity should be priced according to the actual production costs of wind power. The same applies to solar power. To further make the treatment of traffic electricity consumers and other consumers fair, traffic electricity consumers should also be reimbursed, if the batteries in the traffic electricity system benefits other electricity production by, for example, reducing the need for expensive and polluting load-following capacity.

Considering the above it is clear, that a separate pricing of traffic electricity from other electricity requires an intelligent charging system. Otherwise it is impossible to know how much electricity is consumed in recharging cars and how this recharging affects the production and acquisition of electricity. The pricing examples above also show, that without an intelligent charging system the government would automatically support electric cars with tax breaks without an explicit support decision.

The question about whether it is desirable to support the proliferation of electric cars with tax breaks should be decided as a political question, based also on the external effects, which follow from using electricity instead of fuel to provide energy for traffic. One possible external effect is the use of car batteries in load balancing of electricity production. Especially with a battery replacement system, the compensatory effect on the network load and electricity production can be a financially significant factor in determining the price of electricity for vehicles.

It should also be decided how long it is appropriate to subsidize adoption of electric cars with tax regulations. In the beginning, tax regulations do not have a great impact, but six years after the appearance of electric cars on the market, the tax exemption of traffic electricity exceeds a 10 % share of the income from the passenger car energy tax, provided that electric cars come into common use as described in chapter 4.2.3 (Figure 32). The international tax status of fossil fuels as part of emission trade and the consumer price development of petroleum products may very well lead to a situation where electric cars are competitive enough even without tax reliefs.

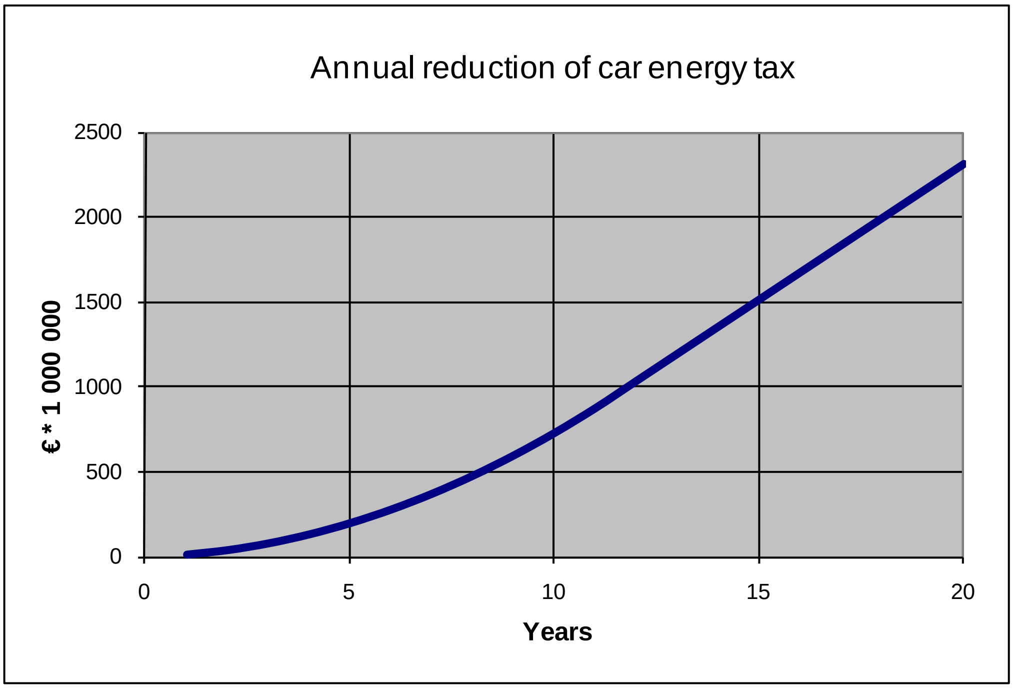

Figure 32. The reduction in tax revenue from passenger car energy, when the annual sales of plug-ins rise in 12 years to 150 000 cars and when the tax applied to the electricity used by the cars is equal to household electricity tax.

5 Electric transportation and the future of traffic

5.1 Development possibilities of vehicle technology

Vehicle energy consumption has not changed significantly after the current technologies became commonplace. This is probably explained by describing a vehicle's energy consumption with the Davis formula or its modifications, which separate a vehicle's energy consumption to a fixed part and parts consisting of mass, velocity and the square of velocity. A vehicle's mass is the main factor in energy consumption, and in passenger traffic the share of payload is very small, approximately 10 %.

Since the basic innovations in combustion and electric engine technology, the efficiency of both technologies has improved due to more accurate production and control technology. On the other hand, consumption has increased due to other features. Air conditioning has been one of the latest reasons for increased energy consumption. A significant increase has been due to the image associated with cars. For image reasons, the size and mass of cars increase and consumers are fond of image solutions that increase energy consumption. This applies to equipment in general, but especially to large engines and wide tyres.

The developments in the energy consumption of cars seems to have been directed mostly by the price of energy. For instance, the sales of SUVs, which formerly were popular in the USA, fell rapidly as the price of fuel rose in conjunction with the US economic crisis at the end of the first decade of the 21st century. A good single example is the fate of the Hummer H1, a civilian version of the military HMMWV. When consumers wanted to buy the military vehicle for civilian use, a separate civilian version was produced. The sales of this very masculine model dried up and its production was ended in 2006 after fuel prices went up. The brand owner, General Motors, ran into financial difficulties and did not allocate funds to make the car, which weighed 2500 kg and consumed 25 liters per 100 kilometers, conform to the environmental standards set for cars in the USA.

In the case of electric vehicles, the price of energy is unlikely to affect development, since for technical reasons electricity will always be cheaper than fuel. The impetus to reduce electricity consumption comes from the need to increase range and reduce the capital tied up in batteries. If we consider the typical range of a modern electric car, 150 km, then halving energy consumption doubles this range and reduction to a third makes the range comparable to that of a modern combustion engine car. Reducing energy consumption is most likely easier than improving battery technology so that capacity is increased 2-3-fold in respect to volume, mass and price.

As an electric car is absolutely simpler to construct and cheaper to produce than a combustion engine car, the real price of vehicles will most likely be less than for current cars. The markets for technical devices have often developed so that a drop in real prices leads to a wider variation in models and properties, so that consumers acquire several different models instead of just one meant to cover all usage needs. In respect to cars this would mean, that a household would have more than one vehicle for each active, licenced driver. The vehicles would be different and each person would use them for different purposes.

The benefits of an electric vehicle design include mechanical simplicity and a good power and function relation to volume and mass. Compared to combustion engines, the performance of the energy storage is poorer than for a fuel tank. In improving the energy efficiency, the low mass characteristic of electric technology provides a basis for reducing the mass of the vehicle. The simplicity of the design and the attendant low costs of production make it commercially viable to design light vehicles in such a manner that a reduction in transportation capacity is acceptable to the consumers. In other words, the carrying capacity and production costs are linked more closely to each other than in the case of combustion engine cars (Figure 33).

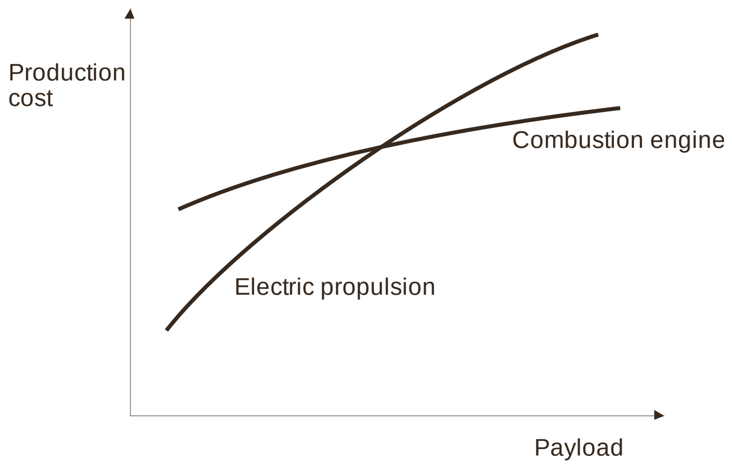

Figure 33. Principle of the relation between the manufacturing cost and payload of a combustion engine vehicle and EV.

5.2 The energy requirement of transportation

The energy requirement for transportation can be evaluated either by measurements or theoretically with the Davis formula, which describes the movement resistance of a vehicle. The Davis formula was developed in early 20th century based on experiences with railway traffic energy consumption, but the four-term structure of the equation is still used for example in evaluating the energy consumption of rolling stock. The basic form of the Davis formula is:

{1} $F = A + B \times m + C \times V + D \times V^2$

where:
A = static movement resistance, caused by the vehicle’s construction, such as losses in the engine and transmission
B = resistance to motion, caused by the vehicle’s mass, which affect such factors as the rolling friction in wheels and axle bearings
C = resistance to motion caused by velocity, for instance in rolling stock the resistance caused by the sinusoidal movement of the wheel set on the track and air friction.
D = resistance to motion caused by drag, composed of cross-section, drag coefficient and half of the density of air

For cars, often only the second and fourth term are used in resistance calculations. Bypassing the first term eliminates the internal resistances in the engine and power train, which are assumed to be included in the general efficiency of the car. Bypassing the third term for road traffic is based on the fact that in the contact between a tire and the road’s surface there are no effects similar to those between a flanged wheel and a track or other significant effects which would alter the rolling resistance as velocity changes. Air friction is included in the overall drag coefficient as the length of the vehicle is constant.

Next we describe the energy consumption of movement for various passenger traffic vehicles, whose statistics are presented in Table 3. This examination includes various passenger car concepts in addition to the common 5-person passenger car. Public transport is represented by the bus, tram and metro train. The statistics for the bus are those of an average Helsinki metropolitan area public transport vehicle. The tram is a typical European tram with a length of about 30 meters. The metro train statistics are from the Helsinki metro, and they can be used also for local trains. The payload of public transport is calculated from actual usage percentages in Helsinki traffic, defined as the relation of used and offered passenger kilometers.

Table 3. The payload percentage, mass and payload for various vehicles.

Vehicle	**Payload percentage**	**Mass [kg]**	**Payload [kg]**
Bicycle	75 %	25	75 kg
Pedelec	68 %	35	75 kg
Segway	60 %	50	75 kg
Scooter	44 %	95	75 kg
Microcar KR-200	25 %	230	75 kg
Quadricycle	18 %	350	75 kg
Quadricycle, electric	12 %	560	75 kg
Mini (1959)	11 %	650	75 kg
Smart	9 %	730	75 kg
Private car	5 %	1450	75 kg
Bus	8 %	12.000	14 x 75 kg
Tram	6 %	41.000	35 x 75 kg
Metro coach (HKL)	7 %	32.000	34 x 75 kg

By the end of the 20th century, increasing attention has been paid to the drag coefficient. The exterior design of passenger cars has led to an average value of 0.3, which is a measured value, thus incorporating the effect of the space between the chassis and the road surface. The drag coefficients of bicycles depend on the riding position and are close to one. Motorcycles and scooters also have a drag coefficient that is close to one, but still lower than bicycles due to design.

According to the Davis formula, at a constant speed the energy need for a person kilometer is highest for the various passenger cars, when the actual public transport utilization percentage of 20 % is used and compared to the driver of the passenger car. Light passenger cars, such as Smart or the original 1959 Mini, have results close to the bus. A quadricycle has approximately the same need for energy as a bus. Rail traffic and personal vehicles such as scooters, bicycles and Segways are in the same class; however, as the velocity increases, rail traffic has a significantly lower energy consumption than personal vehicles (Figure 34).

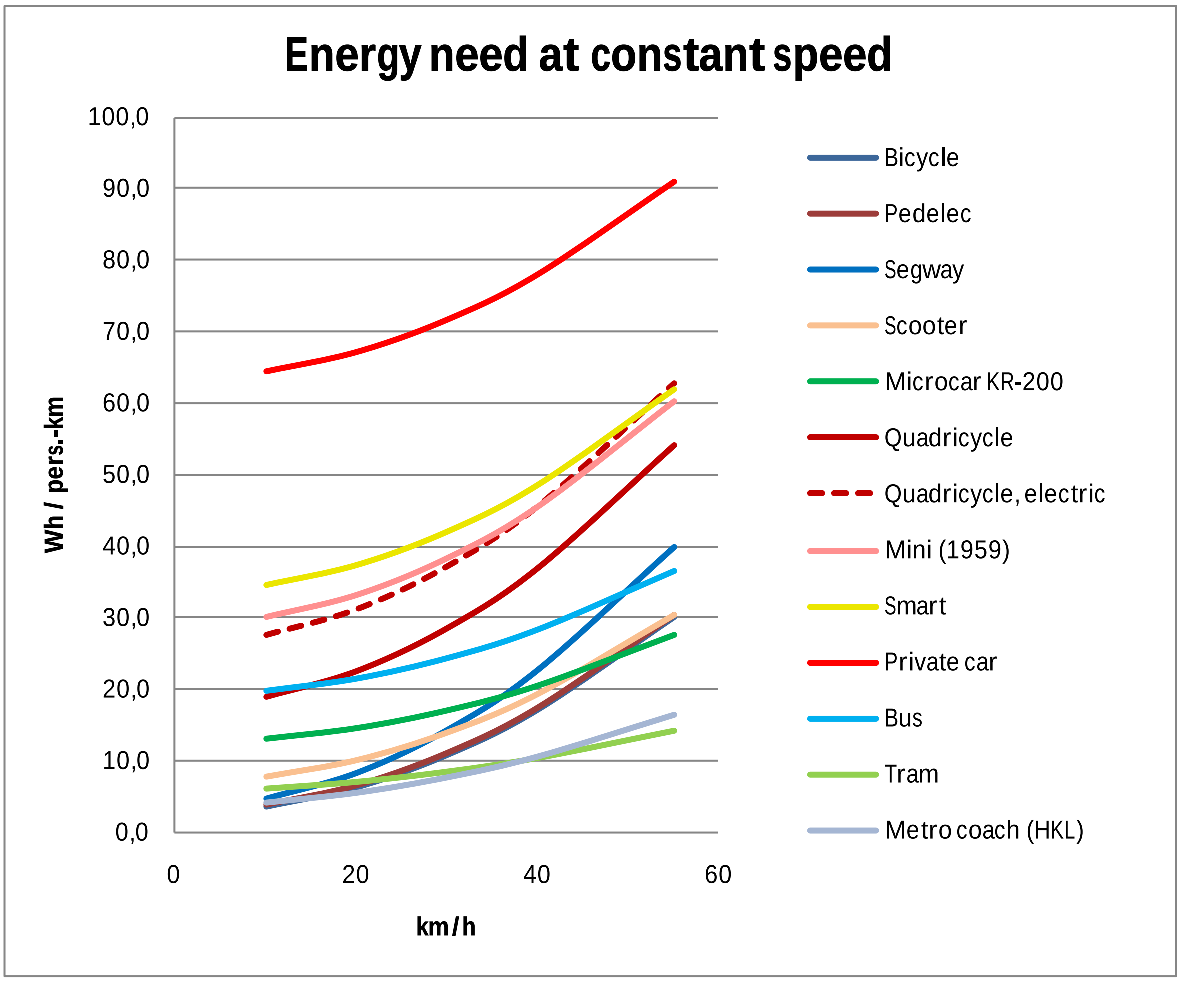

Figure 34. Energy need of various vehicles at constant speed. The utilization rate of public transport is 20 % of the offered seating kilometers. Masses and drag coefficients are typical values. The statistics regarding quadricycles are based on an Axim model, which is also manufactured as an electric version. (Ajoneuvojen energiankulutus.xls)

In urban conditions, actual utilization percentage is 20 % and speed 25–35 km/h, in which case rail vehicles used for public transport and personal vehicles need approximately 10 Wh/person km of energy. That is 1/7 of the energy need of a passenger car and 2/5 of the energy need of a bus. At the practical maximum speeds of about 55 km/h, drag increases the energy need of personal vehicles to a value of 30 Wh/person km. At the same speed level, the maximum energy need is approximately 90 Wh/person km for cars and 15 Wh/person km for rail traffic.

Energy need is dependent on traffic conditions, as standardized practices of measuring car energy consumption have shown. Compared with the values calculated above, the proven consumption of a plug-in, 0.2 h/km, is over double the amount calculated here. A statistic measured in electric public transport of Helsinki region is 0.11 kWh/person-km, in other words, about 10 times as much as when compared with the constant speed calculated here. The greater difference in the case of public transport compared with cars is explained by the fact that rail traffic consumes energy mostly during acceleration, whereas cars consume also significant amounts of energy in order to maintain the desired speed. The empiric energy consumption value of public transport includes also lighting and air conditioning. The consumption of an electrically-powered passenger car does not include air conditioning.

The diagram below (Figure 35) demonstrates the effect that kinetic energy used for accelerations has on energy consumption, when the speed between accelerations is 30 km/h. The efficiency coefficient during the acceleration is disregarded in the calculation, but on the other hand the calculation also disregards the change in velocity during acceleration and deceleration in the Davis formula. The effect that stopping the vehicle has on energy need has been calculated with the Davis formula and with calculatory kinetic energy.

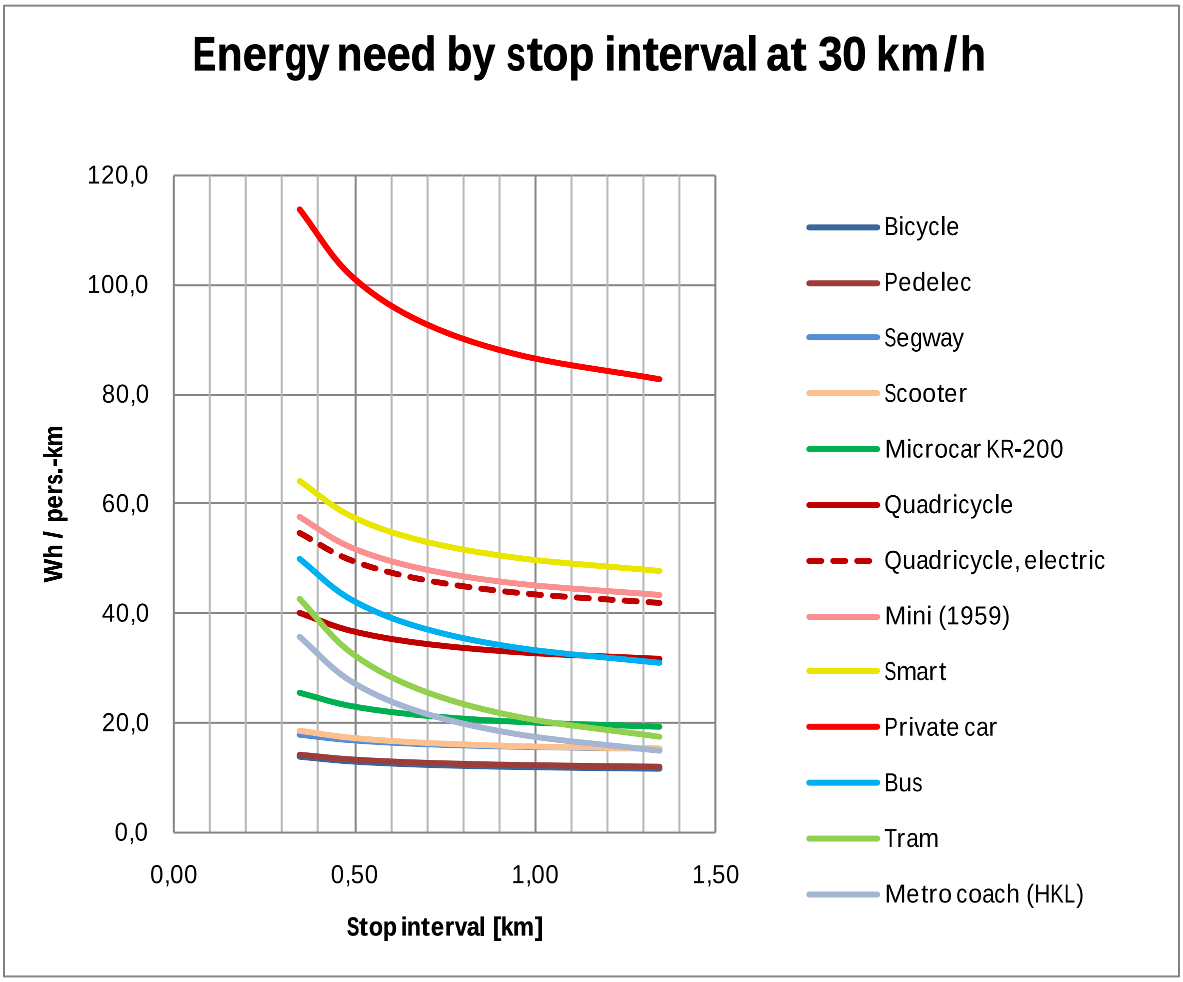

Figure 35. The energy need of various vehicles per used passenger-kilometre, when stop interval changes and the constant speed is 30 km/h. Braking energy is not utilized.

Figure 35 shows the impact that vehicle stops have on energy consumption both in public transport and in the case of passenger cars, the payload percentage of all those being clearly under 10 %. The shortest stop interval described in the diagram is 350 metres which is approximately the same as the stop interval defined for city traffic in the ECE 15 emission procedure in the EU. In Europe the public transport stop intervals are approximately 500 metres, when public transport is given preferential treatment. Consequently, in urban traffic the energy consumption of public transport with a 500-metre stop interval should be compared with private transport with a 350-metre stop interval.

A normal characteristic of electrical propulsion systems of passenger cars is to convert kinetic energy back into electricity during braking. In public transport, this regenerative braking has been a characteristic of electrical systems since the 1980s, but there has not always been an option to utilize it. Utilization has been limited by the fact that feeding stations have not been able to function as load and to return energy back into the power grid. This has been necessary for the reason that other acceleration and deceleration phases of vehicles in the same feeding sequence do not occur at the same moment temporally.

In battery solutions, batteries always act as the load, and with the current technology, at best as much as 70 % of kinetic energy can be converted into electricity. The diagram in Figure 36 describes the energy need of transport, when vehicles stopping at intervals use kinetic energy recuperation.

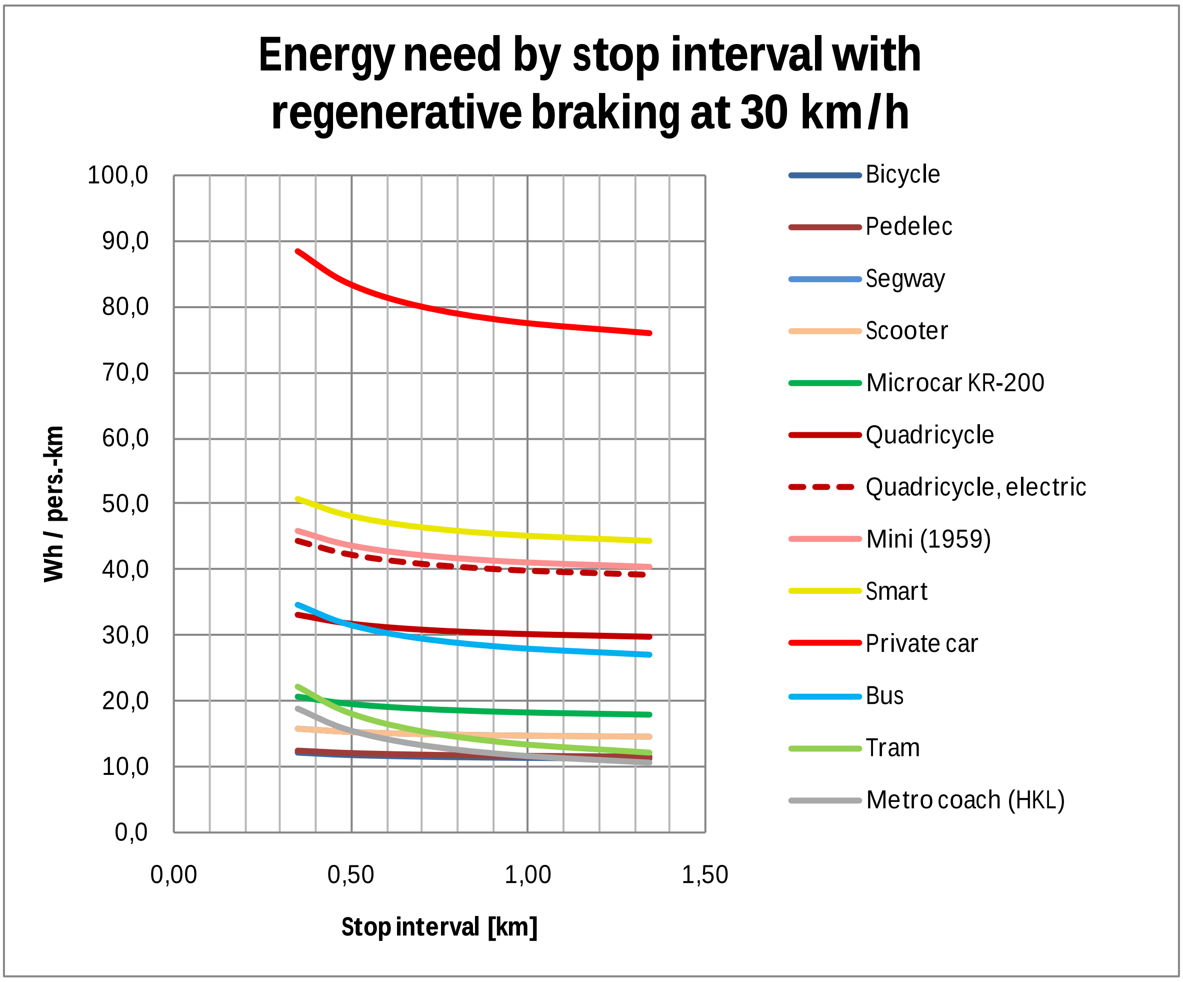

Figure 36. The energy need of various vehicles per used passenger-kilometre, when stop interval changes and the constant speed is 30 km/h. Of braking energy, 60 % of kinetic energy can be converted back into electricity.

In relative sense, regenerative braking reduces the need for energy most efficiently in the cases where payload is poor, in other words, in the case of passenger cars and public transport. However, the energy need of various cars is still greater than in public transport, but a bus and a quadricycle with an unladen mass of 350 kg have an almost equal need of energy as public transport.

The characteristics of a present-day passenger car combine a large drag and great unladen mass and therefore a small payload, which is even smaller than that of heavy rail traffic. Comparing an electric quadricycle with a combustion engine one shows that electrifying a car is not reasonable in the cases where the mass of the car grows substantially due to electrification. Consequently, when aiming to decrease the energy consumption of transportation, it is not appropriate to build electric vehicles according to the same design as the present-day passenger cars. The objective should be to reduce the unladen mass of vehicle and therefore to increase the proportion of useful load. The impact that stops have on energy consumption proves that using regenerative braking is a substantial method for improving energy economy, but it will not remove the significance that a passenger car's great unladen mass and small payload have on economy.

5.3 Improving the energy use efficiency of mobilty

The energy use efficiency of mobility means in this context reducing the amount of energy required for a person's locomotion per the distance travelled. This work does not address the amount of personal movement and the need to reduce movement. Reducing the need for movement improves the efficiency of movement in relation people’s needs. This issue is dealt with in Chapter 5.9 Development of community structure and movement habits.

As we have seen, a major way to improve the energy efficiency of human movement is to improve the payload percentage of the vehicle. In principle, the vehicle stock should correspond to movement needs so that vehicles do not offer useless transportation capacity by carting around the vehicle's unladen mass corresponding to that useless capacity.

We have previously established (Kronström 2008), that the energy needed by electric cars to perform the drive-kilometers of the current vehicle stock would be 9.2 TWh per year. According to the passenger traffic survey (HLT 2006), 55 % of passenger car traffic has only one person, the driver, as the load and in 18.5 % of the traffic the car contains more than 2 persons, which requires a modern-type car with a rear seat. When calculated as distance the corresponding shares are 63 % for driver only and 12.3 % for more than two persons.

Approximately 80 % of passenger car drive-kilometers could be performed with a two-seat vehicle, much smaller than current, about 1.5-ton passenger cars. If the unladen mass of such a vehicle would be about 400 kg, the energy requirement of electric passenger car traffic could be 3–4 TWh, or 33–42 %, less than with heavy cars similar to the current vehicle stock, provided the relation between the theoretical energy need and actual consumption is the same for a light electric vehicle as for a heavy electric vehicle.

The previously calculated 9.2 TWh energy need of the electric vehicle stock is based on a technology, where approximately 60 % of braking energy is fed back to the vehicle’s batteries. The estimate does not contain the energy consumption of the vehicle’s heating and air conditioning systems.

A great deal of effort in vehicle development has lately been directed into reducing drag, and there has been a marked reduction in the drag coefficient due to car design. However, drag does not play a large part in urban traffic. Previously the energy need for a passenger car with 350 meter stop intervals and a velocity of 30 km/h was calculate to be 89 Wh/km with regenerative braking, while the energy need for a constant 30 km/h velocity is 72 Wh/km.

In highway traffic drag has a larger effect. At a velocity of 80 km/h the energy need of a 1450 kg passenger car is 122 Wh/km and the energy need of a 400 kg vehicle with the same drag coefficient is 68 Wh/km, when it is assumed that the lighter vehicle has a 17 % smaller frontal area than the passenger car. The reduction in mass and vehicle size have an effect of 44 %. At a velocity of 80 km/h, the potential reduction in the energy need of the lighter and smaller vehicle is in the same class as in urban traffic.

It should also be noted that the energy need of collective traffic in relation to other vehicles is significantly less as velocity increases. In rail traffic the energy need is less than 30 Wh/km/person and for buses 56 Wh/km/person, both with a 20 % utilization of passenger kilometers.

5.4 Energy-efficient vehicles

Based on the above, energy-efficient personal vehicles must be small. Small vehicles aka microcars were manufactured in 1950s and 1960s and partly until 1980s especially in France and Germany. The main purpose of these microcars was to help in conducting daily personal business, although some sports models were also built for consumers. Some of the most popular models were manufactured in tens of thousands. About 200,000 Goggomobil series cars were produced in Germany.

The manufacture of microcars in the 1950s was based on the high price of passenger cars and legislative limitations. Since the vehicles had 3 wheels or limited performance, they could be registered as non-cars, which meant that no driver’s licence or reaching the driving age was needed and that the vehicle tax was lower than normal car tax. Fuel consumption was often small compared to cars, but during an era when oil was cheap this had no great significance. For weight and cost reasons microcars often had a two-stroke engine. The noise and exhaust fumes caused by it proved detrimental to the image of microcars in the 1960s.

The basic design of microcars met often even the present-day requirements of an energy-efficient vehicles suitable for winter conditions. Vehicle provides shelter from weather, and its performance is sufficient for conducting daily personal business in urban traffic conditions, when the daily use is mainly by one user. At least three wheels keep the vehicle upright and make it possible to drive on slippery roads. The most popular 3-wheeled models, such as Isetta and Messerschmitt, have a design based on a broad front axle that ensures good stability in curves. Isetta was 3-wheeled only in those countries where the number of wheels was limited by legislation, though. The basic version had a short rear axle (Figure 37).

Microcars with a roof weighed usually about 300–400 kg, but the lightest vehicles weighed unladen only a bit over 100 kg Engine power was about 10 kW. Microcars were often under 3 metres in length and had a width and height of about 1.4 metres.

Figure 37. Microcars were common in the 1950s and 1960s when they were produced especially in France and Germany. Several models were 3-wheeled. However, the Isetta 250 model in the photo has 4 wheels, even though the gauge of rear axle is narrower than that of front axle. Photo 16.6.2010 A. Alku.

The demand for microcars dried up probably because vehicles registered as small cars arrived on the market at the end of 1950s. For example, the Fiat 600 (from year 1955) and 500 (from year 1957) and BMC Mini (from year 1959) were almost the same size as microcars, but they had room for four persons, and Fiat 600 and Mini had a 4-stroke engine and the performance of a "real car". These small cars were also competitive in price in comparison to microcars. The success of these cars is proven by the fact that the model versions were around for over 20 years and they were sold in millions.

Microcars were reintroduced in Europe, when EU approved a "quadricycle", a light 4-wheeled vehicle, in 2002. According to the directive 2002/24/EY (revoked the directive 92/61/ETY), a class L6e vehicle may weigh 350 kg without batteries, the maximum allowed power of its diesel or electric engine is 4 kW, the maximum cylinder capacity od petrol engine is 50 cm^3, the vehicle can be registered for two persons at most, and its maximum allowed speed is 45 km/h. Quadricycles can be driven with a moped license, which means that the driver can be as young as 15 years old. Consequently, a quadricycle is a reprise of a microcar in the sense that limitations imposed by regulations have resulted in the creation of a vehicle class that does not require a driver's license to use and that has no car tax. Unlike cars, there are no environmental regulations regarding quadricycles, and electrical use brings no benefit to the consumers.

There are very few or no vehicles on the market that aim to reduce the energy consumption of personal transportation, in other words, that aim to replace combustion engine passenger cars. For example, a quadricycle is not meant to be an environmentally friendly and energy-efficient vehicle. When the target group consists of consumers that are too young to get driver's license and whose alternative methods of transportation include cycling, using public transport or mopeds, a quadricycle increases the energy consumption of these traveller groups and therefore also the environmental load.

3-wheeled commercial versions have been developed from the basic design of mopeds and scooters. These products can stand on their own at traffic lights and at parking spaces. The carrying capacity of these vehicles is similar to that of 2-wheeled versions. Roofing the vehicles fully or partially is possible.

According to the test drive performed by Tekniikan Maailma magazine (Lehtonen 2007), the 3-wheeled Piaggio model (Figure 38) is stable and safer than a 2-wheeler both on asphalt covered with loose gravel and on gravel roads. The experiences suggest that the vehicle could be driven in winter conditions as well.

Figure 38. The 3-wheeled Piaggio scooter. The model has been parked with the help of a kick-stand, even though the front suspension can be locked into standing position for parking.

British motorcycle manufacturer BSA patented the design of a 3-wheeled vehicle in 1966 and manufactured in the 1970s a 3-wheeled moped called Ariel-3 that had two rear wheels. The patent of BSA ended up in the possession of Japanese Honda that had been producing a similar moped of its own mainly for Japanese markets since 1981. The Gyro model introduced in 1982 (Figure 39) is still in production. Chinese Xingyu Industry manufactures a partly-roofed model based on the same design, the XY150ZK (Figure 40). An electric version of it has been planned among other development possibilities. The XY150ZK model has been for sale in Finland as well for about 2500 €.

Figure 39. The Canopy model of Honda's Gyro moped was taken into production in 1990. The device includes a windshield, roof and a 62-litre cargo compartment. The engine, transmission and rear axle form a unit, which as a whole is fastened with a hinge to the chassis, which can tilt to the side while turning. Photo source: Wikipedia Commons.

Figure 40. XY150ZK, the 3-wheeled partly roofed scooter manufactured by Xingyu. The vehicle can seat 2 persons, and there is also a small cargo compartment behind the seat rest. The vehicle is 2.2 metres long and 0.67 metres wide, unladen mass is 160 kg. Photo source: Xingyu.

There are several light vehicles in development and prototype phase. French Sidam has been planning a 3-wheeled vehicle with one seat and cargo compartment (Figure 41). This vehicle is meant for light deliveries. There is a prototype model of Segway, Puma, that has 2 seats and can be equipped with a roof (Figures 42 and 43). Puma offers shelter from weather and carrying capacity either for another passenger or for goods instead of the second passenger. Peugeot Plus (Figure 44) is an example of roofed 3-wheeled vehicles that have been suggested as a viable solution for the personal vehicles of the future. The basic design is the same as with the few currently sold 3-wheeled motorcycles and with the microcars of the 1960s, the front axle having 2 wheels and rear axle having one drive wheel.

Figure 41. Sidam Xnovo is a 3-wheeler with one seat and cargo compartment. Photo source: Sidam.

Figure 42. A version with two seats and one axle, based on Segway technology. Photo source: www.scientificamerican.com

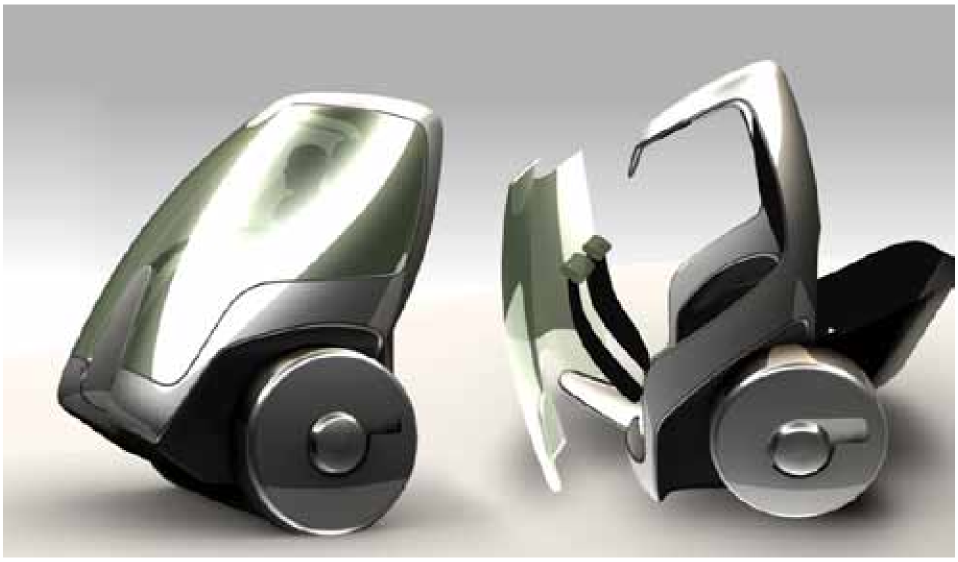

Figure 43. Design study of Segway Puma. Photo source: General Motors.

Figure 44. A design study called Peugeot plus, by David Vargas, for the Peugeot Design Competition 2007. There is room for two passengers. The length of the vehicle is 2.2 metres and the width is 1.2 metres. Photo source: http://psipunk.com/peugeot-brings-three-wheeled-eco-vehicles-to-style/

Based on the vehicles on the market and the designs still in the planning stage, the workable minimum dimensions of personal vehicles can be estimated to be the following: length 2 metres, width 0.7 metres and height 1.7 metres. This volume can fit 1–2 persons and 60–100 litres of goods. When the vehicle needs to offer protection from weather, it is recommendable to design it as enclosed, which minimizes the drag. Based on the drag values of geometric shapes, the estimated drag coefficient is 0.2.

Realistic unladen mass without batteries is probably 100–150 kg. The mass of batteries depends on the usage of the vehicle and the charging possibilities offered by the use environment. The energy consumption of a vehicle outlined here is about 15 Wh/km with a stop interval of 350 metres. When the actual consumption of charged electricity is assumed to be equivalent to that of an electric passenger car, the real consumption would be 30 Wh/km. A 100-km operating range requires 3 kWh of battery capacity. With the current lithium-ion battery technology this means a mass of 15 kg and capacity of 6 litres, ie. in practice a device resembling the startup battery of a combustion engine car.

5.5 Cargo transport need

About a third of passenger car trips are made for shopping and personal business, which means that transporting goods forms a significant part of the passenger car usage. The required cargo transport capacity is illustrated by the size of car cargo compartments as well as by the volume of shopping carts in the stores. Based on these, a volume of 100–200 litres should be reserved for cargo transport.

A vehicle's cargo transport need is tied to the transport habits and the service structure of community. A shopping mall culture based on the use of passenger cars decreases the number of shopping trips and increases the amount of goods transported per one trip, when the physical accessibility of the shop decreases as the distances and the time used for shopping lengthen. The difference can be seen in the shopping behaviour witnessed in downtown and suburban commercial centres: an one-off purchase is clearly larger in suburban malls than in downtown shops. Consumers travel to malls by passenger cars and to downtown shops by foot and public transport. The cargo transport need of a shopper visiting a shop located in downtown or near his place of residence is illustrated by the size of the shopping basket, about 15 litres.

If vehicles are lighter than the present-day passenger cars, their need for cargo transport capacity depends on the moving and shopping habits prevalent with the users of light vehicles. An example of this is Amsterdam, where cycling is a very common method of transport. Bicycles equipped with 50-litre cargo boxes are common in Amsterdam (Figure 45). Another example is Japan, and the 3-wheeled Honda Gyro mopeds (Figure 39) common there, that have a 60-litre cargo compartment. In Finland, bicycles are commonly equipped with 10–15 litre basket for transporting goods.

Figure 45. A bicycle equipped with a cargo box typical in Amsterdam. The version in the picture is a pedelec having the electric motor in the front wheel. Photo A. Alku 26.3.2011.

According to a residential environment study conducted in Finland, consumers of all ages wish for shop services located nearby and independency of passenger cars and shopping malls (Koistinen and Tuorila 2008). Based on this, a possible development is that when personal vehicles meeting the needs of consumers are available and common, consumers will do their shopping in the shops near them and visit those shops frequently. In this case, the amount of one-off purchases decreases, which means that the cargo transport need of a vehicle is reduced.

Most likely, the amount of cargo transport capacity needed is determined by the actual volume of some often transported goods package. Largest packages of daily consumer goods include paper towels, toilet papers and diaper packages. Consequently, the actual minimum need is probably one large package and one large bag of other goods. This equals a carrying capacity of about 50 litres.

As with passenger cars, consumers value versatility also in personal vehicles. Therefore the capacity for carrying goods could be combined with a possibility to transport another person. In that case, the carrying capacity available could be considerable greater than 50 litres. For example, the seats of current passenger cars are roomy enough for transporting domestic appliances in their packages, even though the packages do not fit in the trunk.

5.6 Renewal of vehicle stock

In Finland, the useful lifetime of passenger cars is 19 years on the average (HLT 2006). Of public transport vehicles, combustion engine buses have the shortest lifetime. Buses have also resale markets in the way that buses are transferred from big cities to smaller towns in Finland. In small towns, the utilization rate of buses is often lower than in big cities. In cities buses have a useful lifetime of 12–15 years. Some of the used buses are sold abroad. Trolleybuses last longer than combustion engine buses, and their lifetime is internationally considered to be 15–20 years, when the trolleybus is overhauled once during its lifetime.

In reality, the renewal of vehicle stock is affected by the price of new cars and the developments in operating costs. Consumers' willingness to acquire a new car depends on the cost of the change and on the changes in operation costs. At today's market prices, electricity is cheap compared with liquid fuels. Annual fuel costs are about 1.800 €, when the average annual amount of drive-kilometres is 17.300 km (HLT 2006). The annual energy cost of an electric car with household electricity would be about 450 €. This cost difference is equal to the 3-year financing cost of a cash payment of about 5.000 €. If an electric car is charged with household electricity, the car user gets from the state a tax break equal to the fuel tax, in which case the low operating costs of electric cars compared with combustion engine cars would probably have a significant effect on the willingness of consumers to buy new passenger cars.

Even though energy costs may decrease, the initial cost of an electric car should not be significantly higher than the current price level of cars. Nevertheless, at the start the price will probably be considerably higher than the current price level of cars due to new technology, small production numbers, and especially due to the costliness of batteries.

The renewal of car stock is also hindered by technical and productional obstacles. So far there is no product ripe enough for the markets, so renewal cannot start yet. When commercially ripe products enter the markets, their production will most probably be limited and their price will be high as well. The machinery of automotive industry is suited for manufacturing combustion engines. Battery production is by nature totally different from the production of current cars, so migrating from producing combustion engines to producing batteries and electric motors cannot be implemented in a short time. Especially in the case of batteries, it seems that a significant part of the car value will be removed from the hands of car factories, which will not make current automotive industry more keen to start producing electric cars.

A quick renewal of car stock means that the need for the total car production capacity grows temporarily very fast. This is not desirable from the viewpoint of automotive industry. Increasing capacity requires investments which would be left underused after the quick renewal phase was over and the demand had gone down. The result would be that the age structure of car stock would become homogeneous, which might affect the future so that car markets would experience a periodic recurring variation in demand when the first-generation electric cars reached the age for renewal. Therefore it is entirely possible that automotive industry does not even want to adjust to quick electrification of car stock, since that would make the markets unstable.

Experiences about the automotive industry's ability to keep up with strong market changes were gained during the economic crisis of 2009. Both USA and Europe ended up subsidizing automotive industry with public funds in order to avoid bankruptcies and causing job losses for automotive industry workers.

One possible unpredictable factor is formed by the automotive industry in India and China. In both of these countries, industry is in strong growth phase and, due to this growth, has both the ability and possibility to adjust to a new kind of production. However, it is possible that growing industry does not have sufficient resources to grow for both western export markets and domestic markets. Political pressure may cause the domestic markets to become the primary growth target, since export income must benefit the growth of material living standard in home country. In that case, the export potential would be limited in order to keep enough capacity for meeting also the domestic demand.

Consequently, if there arises a situation where the world's automotive industry cannot produce electric cars, national attempts to renew the car stock will be futile. They would only lead to tax revenue losses and of distortion of competition without benefiting the quick renewal of car stock in the hoped way.

From the viewpoint of automotive industry, a better development path is to advance toward a combustion engine hybrid in the initial phase. The old machinery will still be needed then and the volume need of the new kind of production is lower. New components, especially batteries, are not as critical for the product's operation as with plug-ins.

5.7 Technical possibilities of vehicles

Using electricity as a source of energy for vehicles gives more versatility to the technical solutions compared with the current vehicles. Especially car technology is dominated by the basic structure of the automobile, established at the beginning of the 20th century. In this design, the automobile has one power source producing mechanical power and a mechanical power transmission to the wheels. In passenger cars only two basic solutions are used, front- and rear-wheel drive. In public transport electricity has been used as propulsion power from the end of the 19th century, so the technical solutions in public transport vehicles can not be said to be constrained by the fact that electricity was not a viable power source.

It is typical to the basic structure of a passenger car, that the combustion engine and mechanical power transmission dominate the structure (Figure 46). The engine and transmission take up the space of about one person and weigh 100–200 kg. Other necessary components, i.e. wheels, axles, suspension and chassis weigh together at least 250–400 kg. This means that the unladen mass of a passenger car is as much as 1500 kg, which is so much that it dominates the dimensioning the car's performance, meaning that it is not really practical or profitable to produce cars for less than four passengers. This then dictates the main dimensions of a car. The width of the passenger compartment must be at least one metre and its length must be 1.8 metres. This in turn means that cars are at their shortest at least three meters long.

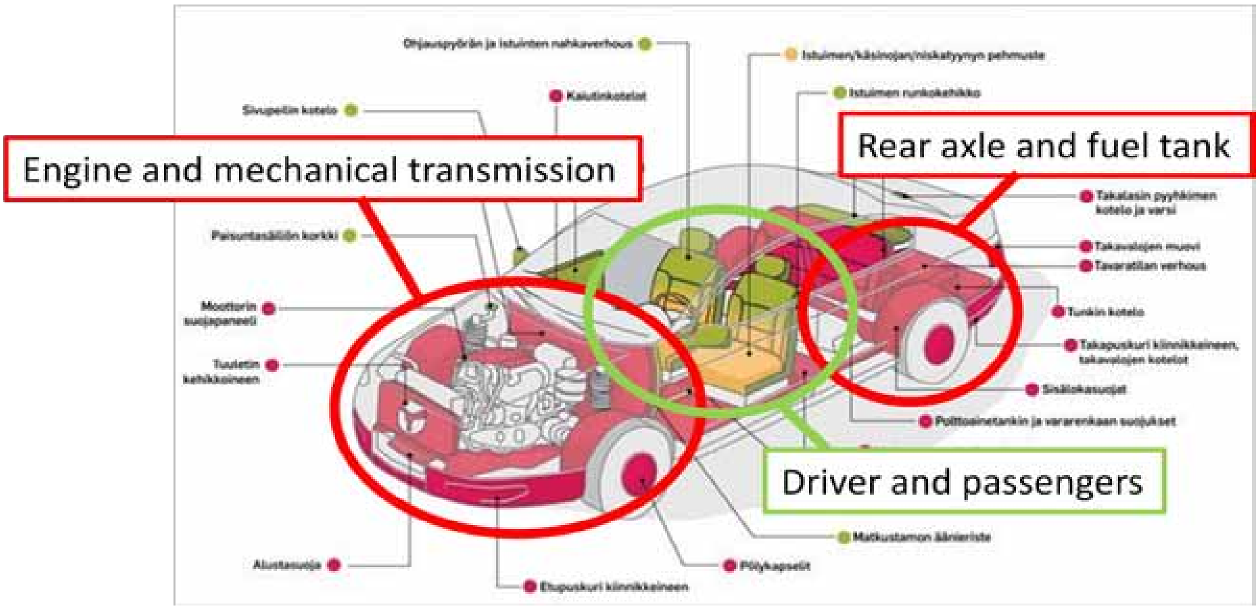

Figure 46. The basic structure of a combustion-engine passenger car. The picture depicts a front-wheel drive, common in modern cars.

Vehicle design has implications for the usability of the vehicle as well for the environmental impacts caused by the vehicle. The space required by a passenger car has been discussed in more detail in Chapter 2.1. The space required by a moving passenger car is dictated by the safety distances and the width of the roadway lane, in which case the size of the car is not relevant. The actual space needed by the street network depends on the structure of the network, such as the amount of crossings and the way in vehicles leave the network for parking. The space required by car parking is dependent on the size of the car. The size of parking squares and the size of parking facility drive lanes are both based on car size.

The length of a parking square in Finland is 5 metres, and the distance between opposing squares is 6.5 meters. A driver sitting and operating pedals requires lengthwise about 1.2 meters of room, so the length of a parking square is quite long compared to effective length. A common short passenger car, the two-seat Smart for 2 was in its initial version 2.5 meters long, but the new chassis model introduced in 2006 was 2.7 meters long. Lightly constructed two-seat quadricycles, commonly thought of as small, are 3–3.2 meters long. The British Mini, introduced as early as in 1959 and produced until 2000, was 3.05 meters long, but it could seat four people. The body of a Mini would, however, not be compliant with the current structural requirements for collision behaviour.

Based on the aforementioned, it could be estimated that parking slots and their attendant drive lanes could have their area reduced by at least 40 %, if the production and sale of two-seat vehicles was feasible. Then the area needed by a vehicle in field parking would be 12–15 m^2. In parking facilities the reduction would not be proportionally as large, as the length of a car has no effect on the space needed by the drive ramps between floors. The practical problem in space saving is that not all cars would be smaller. With different sized cars in traffic, parking is still needed for large cars, and the roadways and lanes have to be dimensioned according to the largest vehicles.

Electrically powered vehicles do not have the same transmission-related limitations as combustion-engine vehicles. The electric drive scales according to the purpose of the vehicle and does not limit structural solutions. An electric drive has a better potential to reduce a vehicle’s unladen mass and volume than a combustion engine. However, electric drive does not affect the structures required for protecting the driver and passengers.

It is easier to create personal vehicles with electric propulsion than with combustion engines, as is controlling the prime mover, which means it is easier to use electric motors than a mechanical power system in controlling the vehicle.

As a whole, electrically powered vehicles enable the breaking off from the concepts of current vehicles. In principle, the electric drive with its attendant features makes any sort of vehicle physically possible. An example of this is the Segway, which would not have been possible with a combustion engine and without modern computer and sensor technology. As a starting point for unbounded thinking one could imagine a vehicle with feet instead of wheels, in which case the vehicle does not need an even surface, as wheels do.

In Chapter 5.2, The energy requirement of transportation, it was shown that the energy needed to transport people increases as the share of the payload decreases. From the 120 Wh/km energy requirement of a modern passenger car in city traffic, it would be possible to come down to 20–40 Wh/km energy requirement, when the mass of the vehicle corresponds to the transportation need of one person and not, as in current passenger cars, of five persons and 400 litres of goods.

The theoretical energy need of personal lightweight vehicles is 20–35 % of the energy need of a passenger car. In actual combustion engine vehicles the ratio is not as good, but the fuel consumption is 30–50 % of the consumption of a passenger car. However, electric drives could be expected to come closer to the theoretical ratios due to a better structural efficiency and due to the possibility of utilizing braking energy.

With current transportation habits, only 20 % of passenger car drive-kilometers require a carrying capacity of more than two persons. If we assume that electric vehicle technology would make it possible that 80 % of passenger car drive-kilometers would consume half of the energy consumption of “heavy” five-seat passenger cars, the consumption of the entire passenger car fleet would be 40 % less than the initially assumed 9.2 TWh annually. With the current specific emission of electricity production and passenger car drive-kilometers this would equal to 47 g/km. The average emissions of the passenger car fleet would be 28 g/km, when the drive-kilometers of the passenger cars would be the same as now, but 80 % of the cars would consume only half as much energy as current passenger cars.

In the year 1990, which is the comparison year for environmental goals, the Finnish passenger car fleet produced 33.4 billion drive-kilometers and in 2009 46.0 billion drive-kilometers (Liikennevirasto 2010). Drive-kilometers have thus increased 37.5 %. With a current average emission of the passenger car stock of 180 g/km, the desired emission reduction is 85 % and an average emission goal is 26 g/km, assuming drive-kilometers stay the same and do not increase. For the past 15 years, the yearly growth of road traffic has been 2 %. If growth continues at 1 % annually, the drive-kilometers will grow to 1.5-fold by 2050. Then the specific emissions should be reduced by over 90 % from the present, ie. to an average value of 17.5 g/km for the passenger car stock, to fulfill emission goals (Table 4).

This means that the technical possibilities offered to vehicles by the electrification of passenger cars will not be enough to achieve emission goals. In addition to technical measures, what is needed are means to significantly either reduce electricity production emissions or to change movement habits and thus community structure, or both.

Table 4. Means to reduce traffic emissions. The average target emission for the passenger car stock is 18 g/km in 2050, if passenger car drive-kilometers increase by 1 % annually. The target emission for passenger cars in 2050 has been estimated as 1.2 billion kilograms annually.

Means	**Average emission CO_2 g/km**	**Total emissions Gkg/year**	
		Current drive-kilometers	**1 % growth to year 2050**
Current passenger car traffic	180	8,3	12,4
Heavy electric cars	47	2,2	3,2
Personal vehicles 80 %	28	1,3	1,9
Target for 2050	17,5	0,8	1,2

To summarize, electric technology improves the possibilities to make personal vehicles and to improve payload ratio. Reducing vehicle size has a minor impact on community structure space saving, since the traffic network has to be dimensioned according to large vehicles, and in the direction of movement the deciding factor is velocity and not vehicle size. The reduction of a vehicle’s total mass has a significant effect on energy consumption and thus on emissions. The emission target set in the EU, 80 % of the emissions level in 1990, can not be achieved solely by vehicle technology solutions. Changes have to be made also in transportation habits and electricity production emissions.

5.8 New vehicles and transportation habits

The general assumption when discussing the electrification of transportation is the replacement of the combustion engine with an electric engine without changing the basic structures of vehicles and the traffic environment. By scrutinizing the technology breakthroughs in other fields, we can see that it has been typical to first imitate existing product concepts with the new technology. Once the new technology has become familiar and cheap, a change in product concepts follows.

An example of this development is the modern smartphone, which combines the previously separate phones, cameras, televisions and record players (Figure 47). All these devices were first developed as electric and digital versions, but they were still separate devices and were used for only one purpose. Once the technology behind these devices was similar, they could be combined into one single device that has all the features of the original devices plus new features that would have been impossible in the original devices.

Figure 47. An example of a technological breakthrough, which has caused a total change in product concepts. Phones, cameras, televisions and record players were first turned into electronic and digital versions of the previous separate devices. Once their technology had become similar, they evolved into a new product concept, the smartphone. This evolution has reduced both the mass and the energy need of these devices.

Transportation and the vehicle industry can well be compared to phones, cameras, televisions and record players. Except for the television, the basic technology was invented at the early phases of industrialization. The television is about 50 years younger, but it also remained much the same until the end of the 20th century. The current passenger car has about the same structure and design as in the beginning of the 20th century, the combustion engine and mechanical power transmission being the dominating features, as described in Chapter 5.7.

Just as with the smartphone and the devices integrated in it, a similar total change in production and consuming habits could happen with transportation. The creators and manufacturers of smartphones are not former phone, camera, television or record player manufacturers. The most interesting and significant new products of recent times have been introduced by computer and software companies. The production structure is entirely different from the ideology of the former device manufacturers, which centered on their own factories. Currently the owner of the brand just designs and manufactures products. Production is handled by subcontractors, and it utilizes the technological knowledge and skills of manufacturers that are specialized to produce various components.

Such development is already underway in transportation. The most interesting electric car products, both quantitatively and qualitatively, are produced by other companies than traditional car manufacturers. The rising economies in Asia have a strong grip on the markets, and they already control the market for light electric vehicles that imports electric bicycles and electric scooters to Europe.

Just like smartphones, the new electric products could partially solve the technical limitations inherent with traditional cars. If vehicles become lighter and their efficiency improves, smaller batteries are needed. Then the world's lithium production is sufficient for more vehicles than if large batteries were needed for heavy cars. A smaller battery is also cheaper, so that the battery is not such a big cost factor as it is at the moment and for vehicles similar to present-day passenger cars.

A distributed, subcontractor-based production, such as is used in computing and phone industry, is much more flexible for vehicle designers and retailers than the structure used by modern car manufacturers, which is based on heavy metal industry. In older car factories there is no impetus to change production quickly, but change comes only as machine tools and production lines are worn out and investments have been recouped. In a subcontractor-based production these limitations do not exist. A brand can migrate to electric cars quickly by replacing a subcontractor with another one who is able to produce electric cars.

It is likely that electric vehicle technology will offer vehicles, the likes of which do not yet exist. They can for example be lighter and easier to handle than current vehicles. They can for instance be applicable to the same use as bicycles, but be more versatile in transporting goods or be more suitable for longer journeys and poorer weather conditions as well as for persons whose health does not allow long bicycle journeys.

The space required by electric vehicles can be significantly less than that required by cars or even bicycles. The intelligence of electric vehicles may enable dense movement on a common lane or automatic parking after the driver exits the vehicle at the destination door. And the user can similarly order his own vehicle to the door when needed. This intelligence can also be utilized in route selection when reacting to disruptions in traffic. Such guidance can be used also in traffic network maintenance and repair by letting the vehicles know where their movement is restricted or blocked.

The threshold to move may be lowered, but also become different than with cars. It will be easier to travel in neighbouring areas outside walking range, but there will be less interest to travel distances of several kilometers as it is customary with passenger cars. Transferring from the vehicle to pedestrian movement may be significantly easier, when large parking spaces are not needed, and contact with the surrounding space is better than when enclosed in a car.

5.9 Development of community structure and movement habits

Transportation and movement in a built-up environment is possible only along traffic lanes. Traffic lanes have dominated and directed the formation of the built-up environment as well. Nothing is built in areas where traffic lanes are difficult or impossible to build. On the other hand, construction is drawn to areas where traffic lanes and roads already exist.

The effect of traffic development has been marginal in rural areas. In rural societies, placement was dictated by nature, such as waterways and terrain suitable for farming and grazing. In cities, traffic plays a central role. In urban development history, the importance of water transport can clearly be seen, as well as the effect of mechanical road traffic, created during the industrialization era of the 19th century.

Until the end of the 20th century, it was common in western countries to renew cities by tearing down old buildings, at which point city plans were also redone. Technological development made taller buildings possible, and streets were widened to satisfy the needs of increasing traffic. During industrialization, there was a transfer from a pedestrian city to a communal traffic city, and starting from the 1950s, also to an automobile-based city in Europe. The automobile city created the urban sprawl, when the principles of functionalism and suburbanism led to a drive to separate the functions of a city and habitation was placed in forested suburbs, which were considered healthier than city blocks.

A scattered city structure increased travel and traffic. In Helsinki the amount of public transport trips per person has remained fairly constant, but the amount of trips by car has increased (Figure 48). This increase is due to people's free time becoming more active and distribution traffic being replaced by citizen collection traffic. The length of the trips has also increased. This is due to traffic being faster, as the time used for travelling has remained the same.

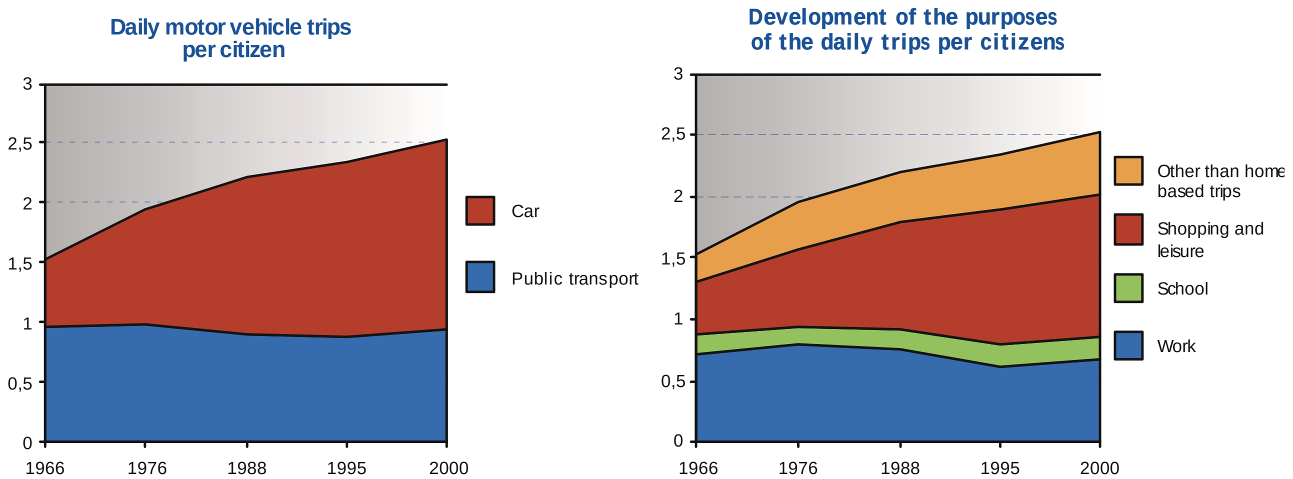

Figure 48. The development of travel means and purpose in Helsinki during 1966–2000 (Helsinki 2003).

There is a limit to the growth of motoring, however, caused by the filling of the capacity of the traffic grid and by urban economics. There is a connection between land value and the cost of transportation, which means land gets more and more valuable when used for construction rather than transportation purposes when approaching the downtown. In practice, this means that there is a land-use efficiency limit to how much transportation can be based on a modern-type car. A more effective land use requires less space-consuming traffic solutions.

In the late 1900s, a practical problem in European cities has proven to be the reaching of the limits of motoring growth, apparent as congested road networks. Previously, the chosen method of urban development would have been to tear down the unworkable city structure and replace it with new buildings and traffic networks. This is no longer considered politically feasible, but a more serious problem is that no one is willing to fund the renovation of the city structure. Previously the city structure renewal was funded by expanding building rights, i.e. increasing land use efficiency. Making more room for traffic means a decrease in land use efficiency, and no one is willing to pay for that.

In oldest city structures, the efficiency of land use has decreased naturally as occupancy rate has grown. However, this effect is minor, and the increase in real estate value may even reverse the effect. Consequently, it must be accepted nowadays that the community structure renews and adapts to technical development of transportation very slowly or not at all. The fastest way to change community structure is to change the purpose of the buildings. For example, in Helsinki a lack of office space in the 1970s led to a sizable conversion of residences into office space.

Purpose of use and traffic solutions also interact with each other. Stores fare best when the traffic space is adapted for pedestrian use. Congestion increases the environmental hazards of traffic, which reduces the willingness to reside or conduct business in the area. What remains are city functions, which get by with less traffic, or functions with low economical profit, which are more interested in low real estate costs than the quality of the environment. In the worst case, there remains no use for the area.

Typical for European cities is also a regional change in city structure where the industrial and traffic areas located near downtown, such as ports and other logistics functions, move or are moved elsewhere (Figure 49). These areas are more valuable when built for housing or office use than in their previous function. On the other hand, industrial and logistics areas that have become surrounded by dense city structure suffer from traffic connections that have become ill suited for their purposes.

Figure 49. Vacated storage field at the Jätkänsaari port in June 2010. The area will be converted into dense city structure, which will become the western extension of the inner city of Helsinki.

Figure 50. The town of Vantaa has plans for using driverless vehicles in the new suburbs due to be built in the Marja-Vantaa area. This transporter was tested in Tikkurila in a fenced-off area in May 2009.

Repurposing areas changes the city structure, but this change is slow. Cities can grow only at an annual rate of 1-2 %. New traffic solutions can be applied in the new areas (Figure 50), but they don't change the solutions in the old areas, although they can burden the old traffic system further. The traffic solutions in the new areas are also burdened by the requirement to be compatible with the old areas. Entirely new solutions can be applied solely for traffic inside the new areas and between adjacent new areas. Otherwise the solutions have to be designed so that they can be applied also in older city structures.

Electric vehicle technology can produce new traffic solutions, such as a transporter operating without human guidance or rails, with a low environmental impact and no local emissions (Figure 50) or a one-axle device that transports a standing person and requires only slightly more room than a person travelling in public transport vehicle (Figure 13). Such devices can create new movement habits, as they fill the functional gap between walking, cycling and car driving.

New mobility habits not only include travelling by one method, but the creation of more versatile travel chains. For example, the designers of Marja-Vantaa envisioned a driverless transporter solution for feeding heavy rail traffic, to make public transport enticing enough compared to moving by car. Even though the transport could not move faster than walking speed for safety reasons, it would require less effort than walking and would thus be applicable for longer connection distances than walking. The device’s movement environment could require less space than a normal street reserved for cars and could be more pleasant.

Movement habit is not just a technical solution, but a service product, which in addition to the vehicle consists of the lane and route, of the availability and usage rights of the vehicle and of the usage times, punctuality and other qualitative factors. The mixed usage of various movement methods becomes more common in urban environments (Voltti & Karasmaa 2006). The extension of the commuting zone leads to an increase in traffic between areas that are incompatible trafficwise, meaning that some of the trips have to be made with more than one transportation method. In this case, it becomes technically impossible for the passengers to own vehicles, as there is no room for long-term parking of the vehicles. Owning several vehicles is also expensive.

As is the case in Marja-Vantaa, in urban transportation service product the share of rented movement capacity in travelling increases and can take on new forms, such as light electrically-powered vehicled and smart vehicles. This development expands the possibility of movement both for the young and elderly and increases the quantitative accessibility of dense city structures. The granularity of the community structure may increase, as the increase in availability offered by simple and effortless movement increases the customer potential of shops and services, as use of traffic space becomes more efficient compared to car travel and service and availability distance increases compared to walking.

The important item is that these positive effects on people’s mobility and the increase in accessibility of community structure are only available when the electric vehicle technology is used in new kinds of vehicles and new kinds of services offered by these vehicles. Merely converting current passenger cars into electrically-powered ones will not improve the traffic system or the community structure.

5.10 The potential for reducing traffic emissions

The purpose of using electricity as an energy source for vehicles is to reduce the carbon footprint caused by traffic. In 2007, the EU formulated a goal of reducing greenhouse gas emissions by 60–80 % from the 1990 level by 2050. The Kioto protocol is in effect worldwide, and it calls for an 8 % reduction from the 1990 emission level by the year 2012. At the Copenhagen Climate Conference in December 2009 the EU countries announced their own goal to be a 30 % reduction from the 1990 emission level by the year 2020.

For electric vehicle research the most relevant goal year is 2050. 2020 is too soon for any changes to take place that would be significant enough to markedly increase electricity's share as an energy source for traffic, compared to the situation in 2010. This is because of the slow pace of renewing the vehicle fleet, as stated above, and because of the speed at which community structure can change. Year 2050 is almost 40 years away, so there is time both to renew the vehicle stock and to perform the necessary technical development and design work.

Next paragraphs present those requirements and opportunities possibly available with electric transportation in order for to fulfill the goal for year 2050 for the transportation. At the same time we evaluate progress paths and the possible situation at year 2020.

The production of electric energy for transportation was covered in Chapter 4, Energy sources of electric transportation. Based on those calculations, it can be maintained that the yearly increase of 9.2 TWh in electricity consumption required by the electrification of transportation can be covered by emissionless electricity production methods such as biomass, solar power and wind power use in various combinations. This means that if the profile of other electricity production methods remains the same, the specific emission of the entire electricity production will be reduced by the effect of an emissionless increase of 9.2 TWh. If the entire production of electricity is considered to be 90 TWh and the current specific CO_2 emission is 260 g/kWh, adding the emissionless production of electricity for transportation lowers the specific emission of the entire production to 236 g/kWh.

A significant change to this development might be brought by the building of the two nuclear power plants accepted by parliament during the scrutiny period. Most likely these power plants would be completed during a time when the electrification of the vehicle stock would still be ongoing.

As a whole, it cannot be supposed that the electrification of transportation means total elimination of traffic emissions, if the additional production required by traffic is emissionless. Electricity production as a whole needs to reduce emissions, and the means of emissionless electricity production are limited. In other words, other electricity production needs compete also about the same limited emissionless production resources as transportation.

A benefit for traffic can be considered to be that a properly implemented electric transportation enables storing of wind and solar power and thus brings about a practical increase in the production of both energy forms. Based on this, the electricity used by transportation could be considered as having a lower specific emission, since the battery storage capacity enables a lower specific emission for the entire production than would be the case without batteries. It is difficult to define this "reimbursement" fairly, however, and this reimbursement does not change the total emission amount. Therefore there are no calculations for a specific emission of transportation electricity, but rather the specific emission is that of the entire electricity production in the case, where emissionless production methods are used for producing the electricity used by transportation.

The specific CO_2 emissions of passenger cars in Finland, with the latest combustion engine technology, ie. with an EURO5 standard compliant engine, are currently 164 g/km. The emissions from the entire passenger car fleet are 180 g/km (Mäkelä 2009). When the electricity consumption of an electrically powered passenger car is 0.2 kWh/km and the specific emission of electricity is

236 g/kWh, the specific emission of an electric passenger car is 47 g/km. Just making all cars electric would thus lower car emissions by 74 % compared to the current situation. Since in the comparison year 1990 drive-kilometres were fewer than now, electrification alone is not sufficient to attain the 2050 emission goal.

The goal of reducing emissions by 80 % can not be achieved by transforming the passenger car fleet to electric cars. In addition, the following methods are to be used:

- Reducing passenger car drive-kilometers
- Increasing public transport utilization rate
- Other technical solutions in vehicles, such as improving payload ratio
- Lowering the specific emissions of electricity production

5.11 Ownership and control of vehicles

In Finland passenger cars are privately controlled and either owned by the operator or in personal use as company cars. Company cars are often leased so that the lease covers maintenance costs in addition to the car price. Leasing a car for private use is rare. In practice only one company, City Car Club, offers shared use of cars. This service is only available in the capital's city centre and its adjacent areas.

Until 2009, Helsinki operated a city bike system, where bikes could be borrowed without charge.

Taxi service is available everywhere in Finland. Taxis are used very rarely for everyday transport. During daytime taxis serve business travel, at evenings and nights they serve recreational passengers. The price of taxis is considered to be high compared to the use of passenger cars or public transport.

The vehicle ownership structure impedes using those travel chains that contain private transport segments elsewhere than when at starting a trip from home or ending a trip to home. Thus bicycle and car connections are possible only to those destinations that are accessible by public transport within walking distance. An exception is the metro in Helsinki, where transporting bicycles is allowed without extra charge and where there is so much surplus capacity that transporting bicycles does not detract from the service of transporting people.

The ownership structure also supports overcapacity in the vehicle stock. People who need a car relatively rarely buy one, because they feel renting a car or using a taxi is expensive. The cars obtained in this way are then used rarely or used even when using a car would not be necessary. But since the car is there and available, it is used. The average annual mileage of 18.000 drive-kilometers proves that the latter case is very common.

Changing vehicle ownership from consumer ownership toward renting could happen either similarly to current leasing practice or as use-specific renting. Use-specific renting can also be a part of a public transportation chain so that the ticket allows renting or a reduction in rent.

Leasing practices have very little influence on movement habits. Control of the vehicle is similar to the ownership, in which case the usability of the car is no different from that of an owned car. Therefore leasing will not reduce emissions by reducing usage. Emissions are reduced because the vehicle is serviced regularly and the technology is renewed, when the leasing company is the one making decisions about renewing vehicles. Combustion engine cars can be renewed faster and the consumers can get electric vehicles with less commitment than when purchasing a possibly costly vehicle. Leasing can thus speed up the transfer to electric vehicles, but it will not reduce car usage or the amount of traffic.

In use-specific renting the vehicle is not considered as owned. Usability might still be better than in owned or permanently rented cars. The consumer has at his disposal a suitable vehicle (two-wheeler, small passenger car, elegant passenger car, van) for each use occasion, possibly parked closer than at a permanently operated parking space. Using vehicles as parts of travel chains becomes possible in a very flexible way. The lack of a personal vehicle at the end of the journey does not limit public transport usage or cause additional costs on trips to other locations. The consumer does not have to pay for parking at the destination, either. For example, during a flight there is no need for a parking spot to hold an unused passenger car.

Use-specific renting is poorly suited to a loose community structure. The availability of vehicles could be compared to the availability of public transport stops. For instance, if in a one-family house area the demand is one vehicle for five households, on average a vehicle is available only at every fifth plot. A one-family house area is an area where demand is one-way and efficient usage of vehicles requires that the operator arranges a return drive. An alternate option would be a system of entirely driverless vehicles, in which case the vehicle can return on its own to pick up the next user.

Currently an owned passenger car can be acquired more cheaply than any sort of rented car, as long as the consumer agrees to use an older car and skimps on maintenance or maintains the car himself. This, in conjunction with the status values inherent in car ownership, is an important competitive factor with regards to renting and a major obstacle to making electric vehicles more common. Leasing costs can not be competitive to ownership, as the use of the vehicle is no more effective than in ownership. Use-specific renting can compete with ownership due to better utilization of the vehicle and parking space.

The electrification of the passenger car stock would benefit from competitively priced renting solutions. The benefit of leasing is that financing has been agreed beforehand and there is an option not to commit to a new and possibly unreliable technology. To improve the preconditions for the leasing business, leasing should perhaps be extended to cover older cars than currently offered, so that leasing could be a better option for consumers who settle for used cars. For the entrepreneurs, this will probably be a better business with electric cars than combustion engine cars, since electric cars are likely to have less faults and need less preventive maintenance as they get older.

In use-specific renting, it would probably also be advantageous to introduce products intended to compete with owning older cars. In other words, there would be cheap, older and lower quality vehicles available.

For both renting methods, it is necessary to maintain profitability to offer cheaper, older products, since technological progress will in the beginning lead to a rapid technical aging of the vehicles. Well-off customers demand new technologies frequently and it is quite possible that agreement term lengths would shorten. There should be some reasonable market for the older vehicle stock, for example a market for cheap renting.

Due to the high price of batteries, it would be beneficial for the proliferation of electric vehicles that purchase of batteries and vehicles was separated. In a battery replacement system, the consumer does not invest in a battery but only pays a rent for the battery. The battery capacity hooked up to the car at a time could be smaller than in a system of fixed batteries, since it is possible to transfer electricity into the car in a couple of minutes. It would also be possible for the consumer to select the amount of battery packs to be placed in the car. If the car is used in city traffic and for trips under 50 km in a day, investing in a smaller battery capacity is enough. Those using the car more would buy or rent batteries according to their individual needs.

The government should favour renting, as this would improve the proliferation of electric cars and improve the usage efficiency of the vehicle stock. Both issues would also benefit environmental goals. At the moment, renting batteries does not affect taxation. It would be more appropriate to collect the same amount of car tax in the price of a car without batteries and then the batteries themselves would be free of car and fuel tax.

6 Summary and conclusions

The aim of this work was to find out the opportunities electricity as the energy source of vehicles offers to the development of the vehicle technology, traffic system and community structure.

Electric propulsion technology is ready and at a commercial level to be used and set for sale in car industry. There are strategic interest in car industry to continue with oil based car technology in some companies when others, more pioneer-like companies and companies in far east seem to be more interested in EV-technology.

There is still much to develop in EV-tehcnology. The main problem still is the short operating distance with the current battery technology. There seem not to be any revolutionary technology available in coming 10 to 20 years to enhance the storage capacity. Another approach is to reduce the energy consumption of an EV. There the main focus must be to reduce the tare mass of the vehicle. This means in practice, that there must happen a transition in the concept of what we understand as a car today.

The size and mass of a current car is much a result of the combustion engine and mechanical drive train technology. The fundamental parts of a car, engine, transmission and axles, form the majority of the mass of a car. In an EV the main single mass is the battery, but it's mass may be reduced if the mass of the rest of the vehicle can be reduced. When the current payload of a car is near one person, one possible future is to go towards single or twin person EVs. In future, instead of two or more 5 person cars in a household, a household may own only one large car and more single or twin person vehicles.

In Finland there is a need to heat the saloon of an EV. The heating is still an unsolved question. There is no waste energy available for heating in EV. It is not economical nor environmental friendly to use electricity for heating the saloon, when electricity is generated in a power plant with lost excess heat. The current solution is to use a separate oil burning heater. It may be run with biofuel to reach CO_2-neutrality. The use of a heat pump may also be relevant alternative.

The current electricity production capacity in Finland may produce electric energy required for the cars as they are at the moment. But it means to use coal in balancing power plants, which is not an alternative to reduce CO_2-emissions. It is theoretically possible to add either solar or wind power to cover the electricity need of traffic. But based on the temporary nature of solar and wind power, the batteries of the EV's must be used to balance the overall electricity production.

If EVs would be simply electric versions of current cars, electric propulsion has no effect to the traffic system and community structure. Then the benefit is to reduce CO_2-emissions. But it seems to be impossible to meet the EU goals to year 2050 without altering the concept of a car and to reduce the need to travel using motorized traffic.

To what ever the concept of an EV will develop, shifting towards electric propulsion requires support and guidance from the authorities. EV's require charging infrastructure and the taxing scheme of the traffic is a strong tool to manage citizens interest to buy or lease an EV instead of a new oil based car. Though the future road with EVs is not yet clear, it is a good idea to start the evolution and to be prepared. This is also important when planning future traffic environments and city structure, and energy policy. Though it is not possible to have the benefits of electric traffic immediately, the development must not be prevented with solutions bound to current technologies.

The next phases of the project will deal charging infrastructure, environmental aspects and mobility management based on EV technologies. These coming reports will offer more practical points of view on how to implement EVs into the traffic system.

Summary of the statistics used

Battery capacity/weight –relation (Li-Ion) 0.202 kWh / 1 Kg
(http://www.batteryuniversity.com/parttwo-55.htm)
Battery capacity/weight –relation (Li-Ion) 1 kWh / 10 Kg (Haakana 2008)
Battery capacity/volume –relation (Li-Ion) 0.514 kWh / 1 L
(http://www.batteryuniversity.com/parttwo-55.htm)
Battery service life (lithium phosphate) 10 years (Battery manufacturer's specification)
Battery charge/discharge amount (lithium phosphate) 3000 (Battery manufacturer's specification)
Battery specific price for consumers 5.000-10.000 € / 10 kWh (European Batteries Oy)
Specific capacity of a solar panel, considering the efficiency coefficient of inverter and regulator, 100 W/m^2 (Savonia 2010)
The average capacity corresponding to the yearly yield of a solar panel in central Finland 15 W/m2 (Savonia 2010)
Length of a commute driven with a passenger car 15 km (average in the Helsinki area)
Average life cycle of a passenger car in Finland 19 years (HLT 2006)
The average usage of a passenger car in Finland 18.000 km/year (HLT 2006)
Average daily usage of a passenger car at 80 % probability at most 40 km (passenger car usage distribution in Henkilöliikennetutkimus (HLT 2006 6_31_tapa.xls))
Tax percentage in passenger car consumer price, about 40 %
Market price for coal in a port in Finland, price per thermal value, 8 €/MWh
Tax percentage in traffic fuel consumer price, about 60 %
(http://fi.wikipedia.org/wiki/Polttoainevero 8.4.2010 17:18)
Market price for traffic fuel, price per thermal value, 0,16 €/kWh
Density of wood chips 300 kg/m^3
Industry market price for wood, price per thermal value, 10–25 €/MWh
Density of wood logs when stacked 500 kg/m^3
Finnish passenger car stock 2.8 million cars (year statistics 2009)
The yearly energy consumption of an electric car stock in Finland 9,2 TWh (Kronström 2009)
Practical battery capacity of an electric car 30 kWh (150 km range)
Nominal drive energy consumption of an electric car (tank-to-wheel) 0.2 kWh/km (Kronström 2009)
Consumer price of electricity 0.13 €/kWh
(http://www.sahkonhinta.fi/summariesandgraphs 8.4.2010 17:12)
Specific emission of electricity production in Finland 260 g/kWh (Energiateollisuus 2010)
The average effect corresponding to a wind power plant's yearly production, as share of nominal power 25 % (Holttinen ym. 1996, pp. 38–39)
The planned total wind power to be constructed in Finland 2000 MW (Matilainen 2008)

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Figures

Figure 5 Motor coach ”Flirt”, i.e. series Sm5, operated by Pääkaupunkiseudun junakalusto Oy at the Leppävaara train station in April 2010. The train consists of four carriages, with a total length of 75.2 meters. File P1050616.JPG

Figure 6 Alstom Citadis 402 tram of Paris tram line T3 in June 2010. The tram has seven parts and its total length is 43.7 metres. File P1080208.JPG

Figure 7 A metro train of the Berlin metro (U-Bahn), series HK, on the U2 line in September 2010. One train unit consists of four carriages, with a continuous passenger section from one carriage to another. File P1100197.JPG. Data source http://de.wikipedia.org/wiki/BVG-Baureihe_HK 31.1.2011 11:01

Figure 8 A tram-train on the Paris tram line T4 in June 2010. The Siemens-built Avanto S7 is composed of five units, with a total length of 36.5 meters. File P1070818s.jpg

Figure 9 A hybrid tram on an unelectrified railroad track in Sweden in 2007. The Regio Citadis tram is built by Alstom for the city traffic in Kassel. File Citadis rannalla.jpg

Figure 10 Articulated trolleybus in Solingen, Germany, in July 2003. File DSCF0690.JPG

Figure 11 Articulated series hybrid bus with 2 pivoting joints, manufactured by Hess, in road test at Pitäjänmäki in May 2010. The bus is a modification of trolleybus; it has no trolley poles but there is an aggregate in the rear and supercapacitors on the roof. File P1050790.JPG

Figure 12 Electric quadricycle Elo, photo taken in summer 2010 in Helsinki. File P1090122.JPG

Figure 13 Segway users in Tallinn, May 2008. File P5242029.JPG

Figure 45 A bicycle equipped with a cargo box typical in Amsterdam. The version in the picture is a pedelec having the electric motor in the front wheel. Photo A. Alku 26.3.2011.File s19-s41.cdr

Figure 49 Vacated storage field at the Jätkänsaari port in June 2010. The area will be converted into dense city structure, which will become the western extension of the inner city of Helsinki. File P1060241.JPG

Figure 50 The town of Vantaa has plans for using driverless vehicles in the new suburbs due to be built in the Marja-Vantaa area.