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„Masterplan 100 % Climate Protection" – Frankfurt am Main

General Concept
Summarised version

Stadt Frankfurt am Main
Energiereferat > Die kommunale Klimaschutzagentur

STADT FRANKFURT AM MAIN

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„Masterplan 100 % Climate Protection“ – Frankfurt am Main – General Concept

Summarised version

Commissioned by
City of Frankfurt am Main
Municipal Energy Agency

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„MASTERPLAN 100 % CLIMATE PROTECTION“ – FRANKFURT AM MAIN – GENERAL CONCEPT

Content

1. Introduction

Frankfurt am Main is among the most built-up cities in Germany; the population rose to around 690,000 in 2013. In 2010, approximately 22,600 gigawatt hours (GWh) of final energy were consumed – just under 1 % of German's final energy consumption.

95 % of this energy was imported, i.e. generated outside of Frankfurt and, as a rule, outside of the region. Since the beginning of 2013, Frankfurt has developed the "Masterplan 100 % Climate Protection" – a vision of how the city can halve today's final energy consumption by the year 2050 and meet the remaining demand entirely from regenerative energies.

This is to go hand-in-hand with a 95 % reduction of carbon emissions. The process is financially supported by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The study by the Fraunhofer Institute for Building Physics (IBP) shows measures and ways of achieving these objectives. It identifies means by which the energy consumption and the associated emissions can be reduced through the development of predominantly local, regenerative energy generation and through efficiency measures.

A number of different studies and concepts have been incorporated into the Masterplan, including the "Regional Energy Concept Components Frankfurt/Rhine-Main 100 % efficient and renewable".

It also incorporates an hourly simulation of the regenerative energy generation in the year 2050 from the report on the findings of the Fraunhofer Institute for Solar Energy Systems, ISE. Also taken into consideration were the results of six workshops focusing on "Building, Living, City Planning", "Energy Supply" and "Mobility" held with Frankfurt's Climate Protection Council and representatives of municipal bodies. Finally, it also incorporates the suggestions of citizens of Frankfurt who were able to express their thoughts on the topic in a range of participatory events.
The numbering of the figures corresponds to the full version of the study.

2. Initial energy situation of the City of Frankfurt

In the Frankfurt metropolitan area, around 22,650 gigawatt hours (GWh) of final energy were consumed in 2010. Most of this was accounted for by heat, representing around 50 %, followed by electrical power with approximately 30 % and transport (just under 20 %).

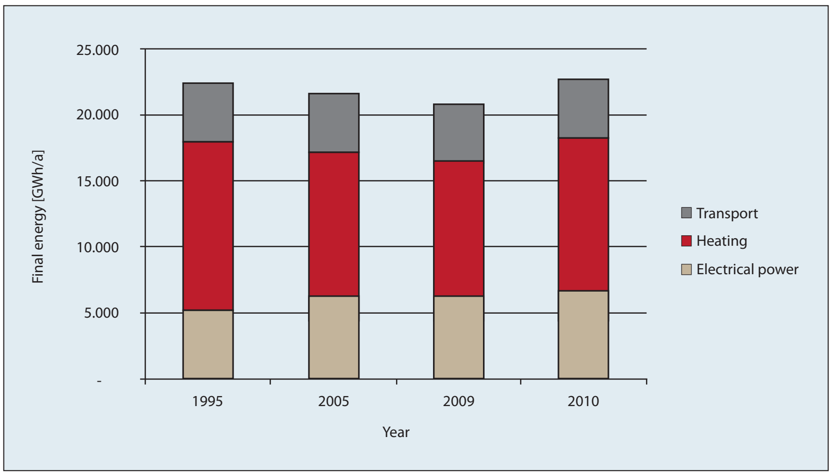

Fig. 3: Distribution of final energy by sectors, electrical power, heating and transport in the overall energy demand, own figures (IBP) according to updated data (ifeu 2011).

Categorised by types of use, the following picture emerges: The largest consumer is industry (30 %), closely followed by the tertiary sector, commerce, trades and services, with 29 %. Frankfurt's households consume 22 % of the final energy, with 19 % being accounted for by the transport sector.

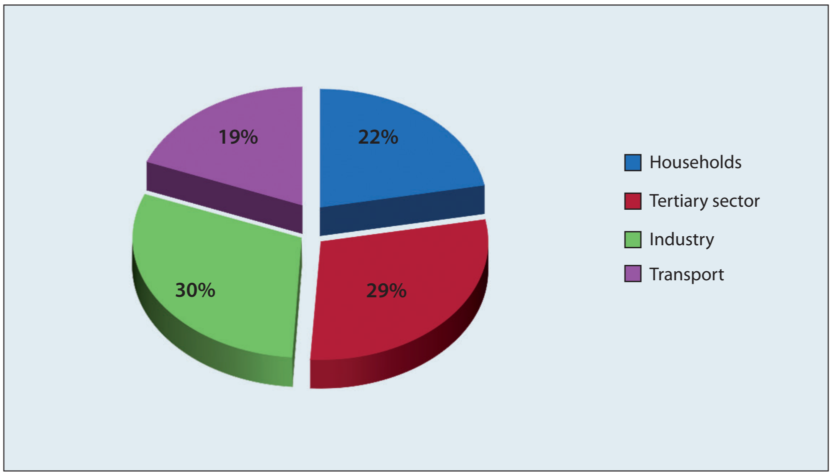

Fig. 4: Distribution of final energy consumption by user groups, IBP according to (ifeu 2013).

An analysis of the energy sources shows: the greatest proportion of final energy is accounted for by electrical power (30 %), followed by natural gas (around 25 %). District heating and district steam make up 5 % and 15 % respectively. Petrol and diesel have a share of 10 % and 9 %. 4 % of the final energy is provided by oil-powered heat generators, coal accounts for 0.1 %. Renewable energy sources also account for 0.1 %.

2.1 Updated carbon footprint of the City of Frankfurt

Overall, the carbon emissions dropped between 1995 and 2010 by around 8 %, in terms of head of population, this figure is actually 13 %. On the basis of the data in 2010, the energy source electricity accounted for by far the greatest share of carbon emissions (59 %). This shows where action needs to be taken: When it comes to reducing carbon emissions, the main focus must be on energy efficiency measures and the development of renewable energy sources. If the aim is to reduce the overall final energy consumption, the focus clearly moves to the heating sector.

2.2 Initial situation in the electrical power sector

In 2010, the power consumption in Frankfurt was 6,580 GWh. The largest consumer group, with 43 %, was commerce, trade and services (tertiary sector), followed by industry with 38 % and households with 15 %. The power consumption rose in all consumer groups between 1995 and 2010; in industry it actually rose by 49 % due to the expansion of the Industriepark Höchst. The tertiary sector required 12 % more power – a result of the changeover from manufacturing to services. Domestic consumption rose by 18 % between 1995 and 2005, attributable to the growing prevalence of multimedia equipment. Interestingly, despite a rise in population numbers, consumption dropped between 2005 and 2010, among other things due to the replacement of old appliances with more efficient ones.

Households

According to the Bundesverband der Energie- und Wasserwirtschaft final energy in households is consumed primarily for heating (71 %), 14 % is accounted for by water heating, 5 % by process heat (cooking, baking, tumble drying, dishwashing, laundry washing), a further 4 % by air conditioning. Compared to the national average, Frankfurt displays one special feature: a high number of single households. This is compounded by the high number of commuters who only spend five days of the week in Frankfurt.

This too is reflected in the electrical power consumption: A Frankfurt household consumes just under 20% less electrical power than the national average. However, according to the study, these figures also reflect "Frankfurt's above-average dedication to the promotion of energy-efficient appliances". This explains why the electrical power consumption in Frankfurt was significantly reduced between 2005 and 2010, while the national average is stagnating.

Trade, commerce, services (tertiary sector)

The study categorises the tertiary sector area into four major consumer groups: In additional to trade, these are office-like operations, hotels and server and data centres. Businesses which cannot be categorized into these branches (e.g. butchers, bakeries) appear under "miscellaneous". Frankfurt's tertiary sector is characterized by services. In order to allow the city to achieve and maintain its climate targets, efficient solutions need to be implemented specially for electrical power applications in this area.

Overall, the tertiary sector consumed around 2,970 GWh of power in 2010. Among the main consumers are data centres and server centres (21 %), the most minor share is accounted for by commercial enterprises with 5 % and hotels, restaurants, cafés (Horeca) with 2 %.

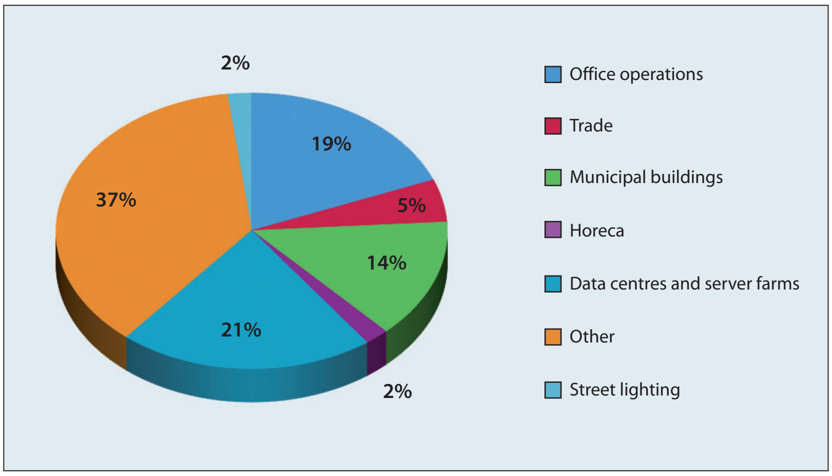

Fig. 14: Electrical power demand in GWh and the distribution by consumer groups in the tertiary sector in Frankfurt/M. own calculation according to Bluewien Gesa AG, 2011, Gesellschaft für Markt- und Absatzforschung, 2009, Mainova AG, 2013.

What is the electrical power used for?

Trade, commercial and service operations use around 8 % of the electrical power for cooling (ambient and process cooling), 39 % for lighting and 31 % for the generation of mechanical energy.

A further 8 % is required for heating (room heating and process heat). The power consumption of information and communications technology (ICT) accounts for 14 %.

Broken down by branches, this means:

In office-like buildings, the lion's share of electrical power is used for lighting (45 %); in second place comes information and communication technologies (38 %). In the commercial area, 55 % is accounted for by lighting, with process cooling (14 %) in second place, particularly in the grocery trade. Hotels require electrical power primarily for mechanical energy (35 %), followed by lighting (25 %). A special position is occupied by data centres. No other European city has as many data centres and server farms; 80 % of German internet transport passes through Frankfurt. The annual electrical power demand lies at 625 GWh, with power being required primarily for the operation of IT systems (30 %) and for cooling (33 %). Peak demands occur in the summer months in particular. The study concludes that if the growth trend in this area remains unchanged, the expansion of network capacity will have to be considered in the long term.

Finally, street lighting: Almost 73,000 street lamps illuminate Frankfurt every night, 92 % of them electrical (32.6 GWh), the remainder gas-powered (41.4 GWh). The City intends converting all lamps to electricity by 2025.

Industry

The point "industry" comprises all operations in the manufacturing sector using process heat in their production processes. The power consumed by industry rose sharply between 1995 and 2005, but remained almost constant between 2005 and 2010 at around 2600 GWh. By far the greatest proportion was accounted for by the Industriepark Höchst, which alone consumes around 1,800 GWh per annum – 70 % of the electrical power used by industry.

Side note: Electrical power generation in Frankfurt/Supply structure

Frankfurt produces approximately 2,100 GWh of electricity and thus, in 2010, was able to supply around 32 % of the city's electricity demand. The city's largest energy provider is Mainova AG, which operates nationwide and whose generation capacity can supply 24 % of the municipal energy demand. Further important energy suppliers are Süwag AG and its subsidiary, Syna.

Most of the electrical power is won from natural gas and anthracite, and the increase of the share of natural gas in recent years has significantly improved the carbon footprint. Further major power suppliers are 1,359 local generation plants (status: beginning 2014) which, in a mix of combined heat and power plants (105 GWh), photovoltaic (22.9 GWh) and biogas/biomass (77 GWh) provide a good 200 GWh. Of the overall electrical power consumption, the proportion generated from renewable energy within the city lay at around 6 % in 2010 and had risen to around 8 % by 2013. But this figure still lies significantly below the city's climate target (50 % by 2050, in terms of today's power consumption). Frankfurt can only achieve its goal if the demand for electricity from all consumers drops significantly and the potential for generation within the city is fully exploited.

2.3 Initial situation in the heat sector

Since 1995, heat consumption in Frankfurt has dropped by 8 %. In 2010, a total of 11,700 GWh of heat were supplied, representing 52 % of the final energy consumption. The largest consumer was industry (37 %), followed by households 33 % and the tertiary sector with 30 %. 50 % of the heat came from natural gas. As a result of the uncoupling of district heating and district steam from gas power stations, the share of heat won from gas increased further to around 88 %. Approx. 7.5 % was covered by oil. The proportion of coal has been dropping constantly since 1995 and lay at 0.5 % in 2010, with the share of renewable energies at 2.5 %.

Households

Between 2005 and 2010, heat consumption in residential buildings rose by around 6 % due to growing population figures. At the same time, the specific heat consumption sank from 153 kWh/m^2 to 140 kWh/m^2. Overall, households consumed 3, 830 GWh, distributed over natural gas (80 %), oil (10 %), district heating (9 %) and coal (0.9 %).

This was augmented by a very small share of renewable energy (0.42 %). Of this, 99 % was won from solar thermal units located on rooftops.

Naturally enough, residential properties with the building age categories I (up to 1918) to V (1969-1978) displayed the poorest energy efficiency standard and should be the focus of retrofitting. Overall, they consume 78 % of the total heat in the household area. The heat demand is are particularly high in those building types which account for the greatest share of living space in Frankfurt: apartment buildings and apartment complexes built prior to 1918 and in the post-war years.

Tertiary sector

In the tertiary sector too, heat consumption dropped between 1990 and 2010, specifically by around 10 %. Overall, around 3, 576 GWh (heating and warm water) were consumed in 2010. 47 % of the heat is generated from natural gas, followed by district steam (20 %) and district heating (16 %). Oil accounts for 13 %, heat from renewable energies 0.38 %.

Industry

In 2010, industry consumed around 4,306 GWh of heat, 65 % of which was supplied by district steam. District heating and district steam are provided primarily by gas-powered and coal-powered CHPs. By far the greatest share of thermal energy in the industrial sector is consumed by the Industriepark Höchst (3,030 GWh), which, however, covers almost all of its own demand through combined heat and power plants and waste heat recovery.

2.4 Initial situation in the transport sector

The following chapter deals with the initial situation in the transport sector. In this context, the transport sector is subdivided into the groups involved in transport: MPT, local public transport and road haulage.

Motorised private transport (MPT)

As is the case nationwide, the number of private motor vehicles is also increasing in Frankfurt. In 2006, the degree of motorization was 512 cars/1,000 head of population. Between 2007 and 2010 car density rose by an average of 0.68 % per year. The mileage covered by car in Frankfurt in 2010 was around 4.1 billion vehicle kilometres (Ifeu, 2010). Over half of this (57 %) was accounted for by commuters (originating/terminating traffic), 24 % by transit traffic, 19 % by inner-city journeys. 72 % of the cars are petrol-driven, 27 % use diesel, 1 % are hybrid vehicles. The entire MPT carbon emissions, including for motorbikes, lay at 872,543 tonnes.

Local public transport

Passenger numbers in busses, trams and underground trains rose significantly from 2007 to 2011. The underground train system is by far the most-used mode of transport (2011: 322,000 passengers daily), however, in recent years the bus has made greater gains in passenger numbers. The inner-city vehicle fleet (traffiQ) is augmented by rapid-transit trains, regional trains and regional busses of the transport association Rhein-Main-Verkehrsverbund (RMV). Overall, the mileage covered by vehicles provided by traffiQ and RMV in 2010 amounted to around 39.5 million vehicle kilometres operated and 2,088 million passenger kilometres.

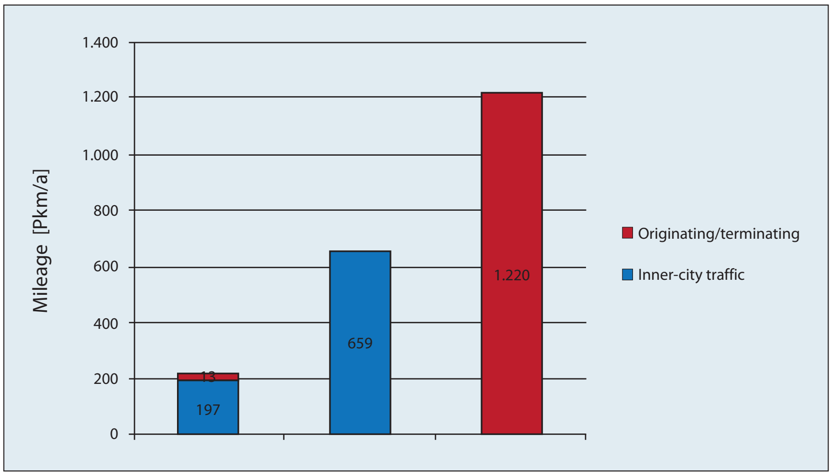

Fig. 44: Distribution of passenger mileage in inner-city and originating/terminating traffic by local public transport modes of travel, own representation (IBP) based on data from the Institut für Energie und Umweltforschung, 2010.

The carbon emissions from local public transport in 2010 lay at around 158,000 tonnes, shared equally between inner-city traffic and originating/terminating traffic. Almost 100 % of the carbon emissions of originating/terminating traffic are caused by commuter rail transport, which includes the rapid-transit train. In inner-city transport, the emissions are caused by trams and underground trains. Busses in the scheduled service account for only a share of 23.6 %, at around 19,500 tonnes of carbon emissions.

Road haulage (HGVs and vans)

Light utility vehicles (vans) and heavy goods vehicles (HGVs) contributed 534 million kilometres of mileage to the volume of traffic (vans: 34 %, HGVs: 66 %). By far the greatest proportion (47 %) was accounted for by transit traffic. Inner-city deliveries made up 11 % of the transportation, 42 % are accounted for by originating/terminating traffic. Overall, transport and deliveries caused 345,000 tonnes of carbon emissions. Half of this is accounted for by transit traffic, 40 % by originating/terminating traffic.

2.4.1 Carbon footprint of traffic in Frankfurt

In 2010, the entire carbon emission of the transport sector amounted to 1,374,000 tonnes. Of this, 63 % was accounted for by MPT, 11.6 % by local public transport and a good 25 % by HGVs/vans. Only 21 % of the emissions are caused by inner-city traffic. Originating/terminating traffic accounted for 51 % and transit traffic for 28 %. The high percentage of emissions caused by originating/terminating traffic would suggest that Frankfurt must create and promote solutions encouraging motorized commuters to transfer to more environment-friendly modes of traffic. New approaches must also be developed for transit traffic and inner-city traffic.

In this context it is likely that inner-city and outside transport and delivery traffic will present the greatest challenge. If the climate target is to be achieved, freight carriage, in particular, must be more efficiently structured. The aim must be to limit the trips taken to a minimum, or avoid them.

For a sustainable mobility concept, it is not enough to replace vehicles powered by fossil fuels with electromobility. Rather, reducing the mileage of cars and trucks must be the primary objective, i.e. avoiding as many trips as possible in motorized private transport (MPT), transferring them to other modes of transport – busses and rail transport, bicycle and pedestrian traffic.

Side note: Modal share – the choice of transport

Frankfurt can be proud of the fact that its citizens do a lot of their travelling on foot (30 %). By European comparison, they are among the front runners. Local public transport accounts for 23 % of the distances covered, corresponding to the national average. However, cities such as Vienna and Budapest show that a share of 40 % is certainly possible. Bicycle transport could also be increased: The proportion of journeys covered with this mode of transport is 13 % in Frankfurt. This figure lies at 31 % in Copenhagen; in Basle it is 20 %. The largest proportion is accounted for by MPT with 34 %.

A special feature of traffic in Frankfurt is the large number of commuters: In 2010 it was around 325,500 incoming commuters and 68,000 outgoing commuters. According to the statistics, around 82 % of the private trips between the city and the surrounding area were covered by car, only 18 % of road users avail of local public transport. Overall, traffic between the city and the surrounding area caused around 568, 000 tonnes of carbon emissions in 2010, and therefore around 41 % of the overall emissions from traffic in Frankfurt.

2.5 Adapting to climate change

A successful strategy for climate protection must consider global climate change and its consequences for urban development. One example: large shady trees display a positive effect on the microclimate but can compete for light with photovoltaic systems.

Conversely, greened roofs, with their cooling effect in summer, can support the effectiveness of photovoltaic systems. All these factors must be taken into consideration in the planning process. The mutual effect of exterior climate/urban climate and interior climate/use is moving increasingly to the focus of scientific attention and is being incorporated into strategies in city planning.

3. Energy-saving potential and the use of renewable energy sources in the power sector

By expanding renewable energy sources, in particular photovoltaics (PV) and wind power, sustainable power generation can be created in Germany. But the potential is limited and power not always available to the same extent. Therefore, flexible operation of standard energy generation plants on the part of the provider is necessary and the orientation of the consumer to the supply (load management).
At around 456 kilogrammes of carbon per MWg, electrical power has the highest emission factor by comparison. When electrical power based applications are designed more efficiently, a relatively large volume of emissions can be saved. Inefficiencies can be detected much more easily in the household sector than in other sectors, for example, by comparing the consumption data of appliances.

The study presents efficiency measures for the household, tertiary and industrial sectors:

3.1 Households

In 2010, Frankfurt's households consumed a total of 1,024 GWh of electrical power.

The average consumption per household lies at 2,825 kWh.

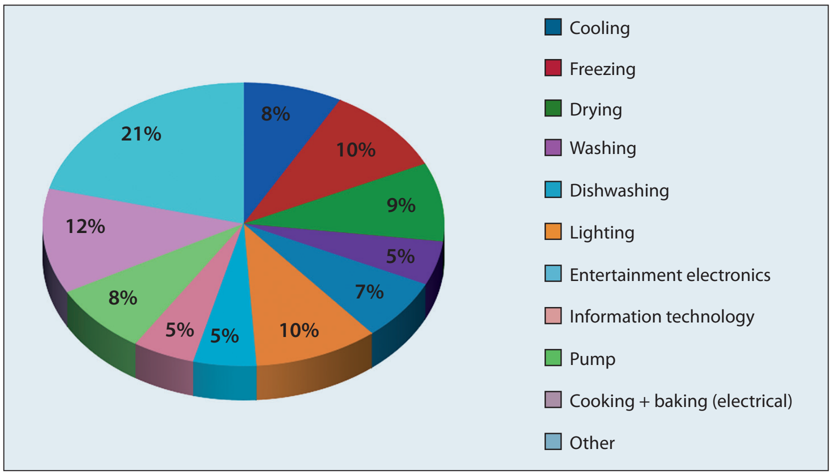

Fig. 61: Electrical power consumption by application in household, own figures and graph (IBP).

In the household, the use of new technologies can produce the greatest savings. According to the study, the consumption can be almost halved with the consistent use of efficient appliances and the latest technology. In the current power mix, 220,000 tonnes of CO_2 could be saved just by replacing outdated appliances with new ones. However, any change only makes economic sense when the purchase pays for itself within the service life of the appliance.

Best Practice: *The electrical power demand of a heating circulation pump in a single-family house accounts for between 5 % and 10 % of the overall electrical power consumption. When the old pump is replaced with a speed-regulated high-efficiency pump, it consumes up to 80 % less power. The purchase pays for itself within three to four years.*

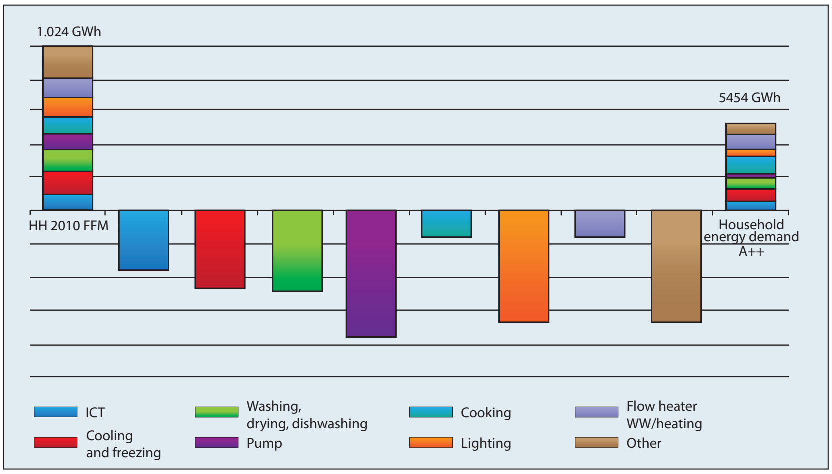

Fig. 62: Overall electrical power saving by application in household sector, own diagram (IBP).

In order to further motivate consumers to save power, utility companies and service providers should present the invoice in a more transparent way, the study suggests. Typical power consumers and their costs could be identified and a top-ten list of economical appliances enclosed. Mobile advisory services, attractive offers for socially disadvantaged households and the training of energy saving detectives in schools are further possibilities.

Parallel to this, it is essential to **increase the proportion of renewable energies**, for example through PV systems. The costs of manufacturing and installing these systems have dropped by almost 60 % in recent years, making their use economically enticing, even without grant aid. At present, the self-consumption rate lies at between 20 % and 30 %.

A significant increase is possible through the use of smart load management. With the help of a timer or a "Home Manager", for example, washing, dishwashing and drying can be coordinated with the times of peak input. In addition to load management, thermal and electrical storage systems (e.g. lithium-ion batteries) increase the self consumption rate. When all the possible measures have been implemented, self-consumption can be increased to 70 % and more.

3.2 Trade, commerce and services (tertiary sector)

Lighting

In the tertiary sector, lightening accounts for 38 % of the overall power consumption. The current high rate of tubular fluorescent lamps (over 60 % in trade and offices) and filament lamps (in hotels and restaurants) leads to the assumption of an enormous savings potential. Switching lamps, combined with intelligent light management, can save up to 75 % of the power consumption. Measures for improved use of daylight are light-directing blinds, pale wall and floor colours as well as window panes with a high light transmission rate. Greater economy generally also applies. This can be augmented with the installation of presence detectors or a daylight-dependent control system, which generally pays for itself in under two years.

***Best Practice:** In the Town Hall in Menden, energy consumption was cut by 85 % by using electronic series transformers and light management, the city therefore saves 83 % of the original costs*

Mechanical energy

Around 30 % of the electrical power used in the tertiary sector goes on mechanical energy: for pumps, fans, suction plants or compressed air production. This energy is predominantly used in the manufacturing trade, for example by butchers, bakeries and the hotel branch. In this area, efficient and regulated motors, in particular, assist in power saving. Depending on performance and age of the existing pumps or motors, up to 60 % less electrical power is consumed, the payback period is often less than two years.

Best Practice: *In Pfungstadt, the brewery replaced the pumps in the cooling circuit and saved 61 % of the operating costs per year. The installation paid for itself within five months.*

Use of energy management systems

Since 2013, energy tax and peak load adjustment is only refunded to companies with certified energy management systems. While energy management has a firm place in the corporate culture in many large companies, significant backlog demand remains in small and medium-sized enterprises. The study determines that time, staff and problem awareness are generally lacking. A high level of unexploited potential (91 %) exists in operations with fewer than ten employees. Here, additional incentives and specific advice from independent bodies (city) are necessary.

Space cooling

For a large city like Frankfurt, the heat build-up during the summer months has a major effect on the demand for cooling. Buildings and sealed surfaces store solar heat and prevent the city cooling down at night. Around 1.5 % of the power in the tertiary sector is used for air-conditioning (26.7 GWh). The study assumes a growing demand for ambient cooling, in particular in office buildings. It suggest an avoidance strategy under the keyword "passive cooling" as the most economical and simplest way of reducing this electrical power demand: Extensively greened roofs and facades can combat overheating, as can parks, cold-air corridors and less motorized traffic. In office and administrative buildings, night-time ventilation can replace active cooling in some cases. Where this is not possible, a ventilation system is a realistic alternative. Passive cooling can also ensue by means of geothermal heat exchanger. The passive measures require only investment costs; almost no operating or consumption costs apply. In refrigerated warehouses, server facilities or certain manufacturing processes, active cooling systems are unavoidable. With a share of 90 %, compression refrigeration machines represent the most commonly-used cooling system. Often, considerable energy can be saved by optimizing the control engineering and replacing inefficient plant parts such as compressors, ventilators and pumps. Further savings are possible by recovering waste heat from the coolants. Under certain conditions, absorption refrigeration systems offer the possibility of using waste heat at a high temperature level for cooling. However, it is difficult to make statements on the economic aspects of active cooling systems.

Best Practice: *The refurbishment concept for the KfW Administration Headquarters in Frankfurt includes HVACR, air conditioning, lighting, heating and cooling and has reduced the energy demand by almost 50 %.*

Process cooling

Around 155 GWh of power are required every year in Frankfurt for the provision of process cooling; this represents 7 % of the power consumption in the tertiary sector. Refrigerated warehouses, restaurants and hotels, canteens and butchers require process cooling for maintaining low temperatures in foodstuffs, machinery and plant. In this area, the focus is on increasing efficiency. In addition to technical solutions, this can often be achieved through amended operation and usage patterns.

Information and communication technology

Information and communication equipment accounts for around 40 % of the power consumed in office buildings. In this area, technical improvements such as the replacement of old appliances, standby-switches and thin-client solutions and terminal work-places, as well as the replacement of desk-top computers with laptops, can reduce power consumption.

Best Practice: *Ostarkade in Frankfurt, distinguished as "Green Building Frankfurt 2009". Many of the measures described are combined; the primary energy value lies 50 % lower than that of an air-conditioned standard new office building (www.greenbuilding-award.de).*

Data centres

As one of the branches displaying the greatest growth worldwide, data centres occupy a special position in Frankfurt. Potential for savings begins as early as the building's planning stage. Incident solar radiation should be as low as possible, roofs and facades greened and a shady spot selected for the heat exchanger. The optimization of hardware and software is of even greater consequence with both offering possibilities for reducing the server's power consumption.
High efficiency potential is to be found in the air-conditioning, where technical enhancements permit significant savings. According to the study, it is also possible to reuse around 90 % of the electrical energy consumed in the form of lost heat energy. In many cases, the fact that this is not done is due to the lack of awareness of holistic energy management.

Best Practice: *Thanks to the use of a fresh air cooling system, the NetApp Data Centre in Sunnyvale, California, can completely forgo conventional cooling.*

In public building too, the IT infrastructure should be recorded and weak points analysed. The costs (several thousand euro) are low compared to the possible savings. In addition, the study suggests expanding the energy development scheme of the city to include an IT focus. It can be anticipated that the output of Frankfurt's data centres will have doubled by 2050. Therefore minimum energy efficiency standards should apply for new installations and conversions. In order to implement these and turn Frankfurt into a green IT centre, political support is decisive.

Street lighting

In this context, the 5,467 gas lamps which still illuminate Frankfurt's streets are of particular significance. The annual operating costs for a gas lamp are 260 euro, an electrically-operated lamp costs 80 euro. If all lamps are converted to high-pressure sodium vapour lamps, the energy consumption can be reduced by 59 %, the carbon emissions by 37 %. The conversion of all lamps to LED technology would actually reduce the energy consumption by 93 %.

Promotion of a zero-emissions business park

If the targets of the Masterplan are to be achieved, new business parks and buildings must be designed as zero-emission structures. The city could forge ahead with a trendsetting project and invite tenders for a zero-emissions business park. The investment costs for the project would be offset by minimal operating costs.

Activation of tertiary sector representatives

In order for it to be possible to implement changes, all the actors in the tertiary sector need to be specifically addressed, for example with inter-branch dialogue or targeted marketing campaigns. The aim is to develop networks (working groups) for professional exchanges. IHK (Chamber of Industry and Trade) committees could be the initiators here. Impulses of this kind can contribute to improving the negative image of "energy" in the tertiary sector. Because, according to the study, most operations associate it with obligations and stipulations, without recognizing the opportunities. Small and medium-sized enterprises (SME) are often simply overwhelmed by the wealth of information.

3.3 Industry

The industrial sector consumes 2,582 GWh of power per year, the largest proportion of which is accounted for by the Industriepark Höchst.

Side note: Industriepark Höchst

The Industriepark Höchst encompasses 90 companies, most of which belong to the chemical industry and which consume 1,800 GWh of electricity annually (the equivalent of 600,000 households). The electrical supply comes from a coal-fired power station, augmented by two gas turbines. In addition, a biogas plant produces an annual 80 GWh of electricity from the industrial park's sewage sludge and waste. A bio natural gas treatment plant is also in operation feeding methane into the gas grid.

As well as these, a refuse-derived fuel plant for domestic and commercial waste is available with an annual output of 70 MW of electrical power or 250 tonnes of steam.

A small hydroelectric power station in the waste water treatment plant provides 30 kW of regenerative energy. Around 400 busses can be run on hydrogen, which arises as a coproduct in chemical processes.

High-efficiency motors and compressed air

At 68 %, mechanical energy (motors for compressors, ventilators, etc.) accounts for the greatest share of the power consumed in the industrial sector. In order to reduce power consumption, existing motors need to be replaced by high-efficiency motors, which would save around 20´% of the energy. The chemical industry is among the greatest consumers of compressed air. As the leakage in this area lies at 27 %, pneumatic processes should be replaced by electrical systems wherever possible.

According to the study, the energy saving potential in the industrial sector could be increased overall by around 20 % by 2050.

Establishing networks

Like in the tertiary sector, a network should also be established among industrial companies, serving the exchange of information, motivation and further training.

Conclusion: Households, the tertiary sector and industry consumed around 6,580 GWh of power in 2010 and produced around 4.04 million tonnes of CO_2. If all the efficiency measures shown were implemented, this figure could be reduced by around 38 %.

3.4 Renewable energy potential from the local region

The entire electrical power consumption in the Regional Authority Rhine-Main (Regionalverband Rhein-Main) in 2010 amounted to around 13,437 GWh. Accounting for 49 %, the city of Frankfurt was the largest consumer. The territory of the Regional Authority has the potential to generate 11,000 GWh from solar energy if rooftops, facades and open spaces are used for the systems (degree of efficiency 25 %). That means that, theoretically, 80 % of the region's power consumption could be supplied by solar power. Frankfurt, with its roofs and open spaces, has the greatest potential. But this is not sufficient to cover the city's own power demand completely from renewable energy. The city also needs the PV potential of the adjacent administrative districts. Wind energy can only cover 4.3 % of the overall electrical power needs of the region (576 GWh), a fact which is also the result of legal stipulations, such as those relating to air safety. Potential is offered by the Hochtaunus, Main-Kinzig and above all the Wetterau administrative districts. However, even the latter is only able to meet a maximum of 45 % of its own electrical power demand from wind energy. The use of biomass permits the generation of 1,024 GWh of power, around 7.6 % of the entire power consumption of the region. At first place here is the Wetterau Administrative District (251 GWh). The share of the City of Frankfurt amounts to 184 GWh. This biomass potential is already being almost completely exploited today.

If the power consumption remains at today's level, Frankfurt will only be able to cover 35 % of its electrical power demand from renewable energy sources, the Regional Authority, at least, 92 %. However, if all the proposed energy saving measures were implemented by 2050, the power consumption in Frankfurt would be reduced by 38 %. The Regional Authority would actually be able to halve its power consumption through efficiency measures and meet its demand completely from renewable energy sources. Frankfurt can increase the coverage to 56 % though energy savings alone.

4. Energy-saving potential and the use of renewable energy in the heating sector

4.1. Use of renewable energy sources and local systems in residential and non-residential buildings

Combined heat and power units

Among local energy systems, combined heat and power units (CHP) are particularly efficient. In particular, they should be deployed where heat pumps can only be operated inefficiently. Due to their flexibility, CHPs can make up for shortfalls in the energy supply – decisive argument in view of the increasing share of wind and solar energy. This requires the development of heat reservoirs, which at the same time permits interaction between heat and power generation.

In 2013, around 260 CHPs with a total thermal output of 177 GWh were in operation in Frankfurt.

In addition, there are 6 biomass CHP plants in the city with an output of 22.2 GWh of heat.

The use of CHPs in residential buildings is oriented towards the heat demand of the specific premises. In city districts, local stand-alone solutions can be realized economically, when a number of premises are linked by means of a small district heating network.

CHPs have one drawback: Depending on the energy sources, they emit CO2. While the use of biogas and wood gas can reduce the carbon emissions to a minimum, the availability of biomass is limited.

Solar thermal power plants

The share of heat generated in solar thermal power plants in 2013 amounted to one tenth of a percent of overall heat consumption. According to statistics of the Energy Agency, 1733 solar thermal power plants were installed in the city area at the end of 2013, with a collector surface of 20,171 square metres.

Overall, the city has a potential area of 2,514,784 square metres, corresponding to 1,386 GWhth. If the entire area of the Regional Authority is taken as a basis, the potential rises to around 6,283 GWhth. Consideration is also given here to the fact that the space requirement for solar heat is competing directly with photovoltaic. By the year 2050, the share of solar heat could be increased to around 15 % of the local demand (excluding industry, as the temperature level is not sufficient to permit use) but greater efforts are required. Long-term development schemes by the city could help, offering investment security for companies and private individuals. Solar heat systems are particularly suited to users requiring a constant level of warm water throughout the year, such as hotels, restaurants, retirement homes and sports facilities. In a single-family house, a standard plant can supply around 60 % of the domestic warm water demand and 15 % to 35 % of the overall heat demand. The use of solar heat to support space heating only makes sense in conjunction with a low-temperature heating system (45 °C inlet temperature) in new buildings and refurbished existing buildings. The costs of a system amount to an average 700 euro/m²; for the conventional 15 square metres this corresponds to €10,500. The payback period can be as long as 20 years.

One stumbling block is the funding situation at federal level: Here low-temperature solar heating comes in last compared to PV, wind and deep geothermal energy.

Heat pumps

Heat pumps only come into consideration for existing buildings to a limited extent due to the necessary low inlet temperature. In new buildings, however, optimal conditions can be created by planning low radiant panel heating with low inlet temperatures from the beginning. Due to the relatively high investment costs, the conventional heat pump system is suitable only for low-energy buildings. Coupling this with a solar heat system or PV system can further optimize the energy balance of the building. Particularly in winter, when the heat generation from solar systems is limited, heat pumps can make a significant contribution to heat production. At best, the system generates more than the residents can consume (plus-energy homes).

For heating and cooling non-residential building complexes, large multi-family buildings and data centres, high-capacity heat pumps (>100 kW) are suitable. Particularly in the built-up Frankfurt area with a high percentage of multi-family buildings and large multi-family complexes (ca. 80 % of the existing living space) they can contribute to sustainable heat supply.

In the city centre, the ambient air lends itself to being used as a natural source of heat; furthermore, in the outlying areas, geothermal energy can be used by means of geothermal heat collectors. Further heat sources to be considered are river water and cooling water from industrial plants and data centres as well as exhaust gas systems.

The efficiency of the heat pump can be significantly increased when it is combined with a solar heating plant and an ice bank. A 10 cubic meter ice bank can store energy equivalent to that of 100 litres of heating oil. Depending on the efficiency of the ambient air, the heat source management can draw on the ice bank or a combination of both. The heat pump-ice bank-solar heat system for a single-family home currently costs around € 27,000. The annual savings amount to around € 1,000 compared to conventional oil-fired heating. The payback time is therefore ca. 27 years. With regard to load management, heat pumps allow the evening out of a fluctuating supply, and uncouple supply and demand in terms of scheduling. Furthermore, a heat pump combined with a hot water accumulator can increase the self-consumption rate of a PV system by around 15 %. The carbon emissions of the heat pump lie significantly below those of gas condensing boilers or oil-fired appliances. With an increasing proportion of renewable energy in the power mix, the carbon emissions will be further reduced; the same applies to the implementation of load management. A detrimental factor for heat pumps is the rising price of electricity and the still low level of expertise in radiant panel heating among plumbers, so that subsidy schemes and training programmes for regional tradespeople are indispensible.

Bio energy

Bio energy can be used both in the power and heat sectors and for mobility. It is available in solid form (split logs, pellets, wood chips), in gas form (biogas or treated bio natural gas) and in liquid form (biofuels). In its gas and liquid form it can be used for long-distance transport (truck, ship, air transport) but also converted into electrical power thus closing gaps resulting from wind and solar energy. It is not seasonal and, when stored, can be regarded as an energy buffer in the heating sector. However, due to its limited availability, its use needs to be well-considered. In the industrial sector, steam is often required in high-temperature process applications (e.g. chemical industry, temperatures > 300 °C). The provision of steam from renewable energies proves difficult. Only biomass or renewable direct current provides the high exergetic quality to guarantee these temperatures through incineration or conversion to electrical power.

For this reason, the use of biomass in high-temperature industrial processes must be given highest priority. In some district heating networks too, biomass is irreplaceable: Due to their high heat intake and the absorption cooling, office complexes and high-rises in the city centre will continue to require connection to a steam grid. In terms of environment compatibility, biomass is second to none: The carbon emissions from wood, gas and liquid biomass are given as zero, as only carbon-neutral engineering and products are used in their treatment. However, a higher level of particulate matter pollution occurs with the incineration of firewood and pellets than with the use of gas. Furthermore, the delivery of biomass into the cities results in increased volumes of traffic.

Thermal storage systems

If the regenerative proportion of heat generated from electricity and biomass is to be increased, thermal storage systems are indispensible. They permit an uninterrupted power supply even on cloudy and calm days.

The development of large-scale seasonal heat reservoirs permits, for example, an increase of the fraction of large-scale thermal systems in specific residential streets and districts to 50 %. Combined with flexibly-switched CHP plants and heat pumps, sufficiently large reservoirs permit interaction to be implemented between the electricity and heat sector.

In power-operated plant, a reservoir stores contingent heat production. This allows the full load hours of the CHP system to be increased and the economics improved. Frankfurt is faced with the task of finding suitable areas for larger thermal storage systems; the building density calls for creative solutions. The results of simulations carried out by the Fraunhofer Institute for Solar Energy Systems (ISE) show that by 2050 the demand for thermal storage systems in Frankfurt will have to rise to between 2.7 and 4.2 GWh if the targets are to be achieved.

4.2 Energy-efficiency standard in new building

Since the resolution of the City Council in autumn 2007, the passive house standard (thermal heat demand: less than 15 kWh/m²) applies to all newly-constructed municipal buildings. Furthermore, a developer who purchases a site from the city must observe the passive house standard when building on it. It was this resolution which fostered Frankfurt development as Europe's Passive House Capital. In the meantime, a total of 1,000 apartments, schools, childcare facilities, gymnasia and office buildings have been constructed or renovated to the Passive House Standard. The floor space of all the passive houses built in Frankfurt up to 2014 summed up to 560,000 square metres. For the calculation of scenarios, it is assumed that the

Passive House Standard will apply for all municipal buildings and, from 2020, for all other new buildings. In addition, from 2020, the number of completed plus-energy buildings is to rise. Due to these measures, the energy demand for heat and power would experience only a minimal increase.

Even so, the study recommends that the city should continue to occupy a pioneering position for municipal new buildings to demonstrate to private real-estate companies and builder-owners that economics and ecology are not necessarily a contradiction in terms.

4.3 Energy-efficient retrofitting of residential and non-residential buildings

According to the calculations of the study, the heat consumption of residential buildings could be reduced by 62 % to 1,627 GWh, if energy efficient retrofitting were consistently implemented in all construction age categories and use types (single-family homes, two-family homes, multi-family buildings, multi-family complexes). This corresponds to an annual 2.4 % decline in heat consumption. In order to achieve this value, the number of energy-efficient retrofitting would have to be more than tripled or higher retrofitting standards applied. But there are a number of obstacles to be overcome. For example, a complete refurbishment is often only possible when the building is unoccupied.

Part of the solution could be pre-fabricated facade elements. They offer the possibility of combining the work of a number of different trades. They could help reduce construction times and lower costs. Ultimately, the residents could remain in their apartments during the retrofitting. Insulation restrictions can also be an obstacle, particularly as they arise in older buildings (low ceiling heights, superstructures, monument protection). Partially-heated and fully-heated basement rooms, on the other hand, offer a high insulation potential, as do uncovered pipes and fittings, whose saving potential, relating to Frankfurt, amounts to around 300 GWh (8 % of the overall heat demand of households).

The study also identifies further obstacles, among them the long payback time, lack of funding and lack of knowledge on the part of landlords regarding energy consumption and retrofitting potential, the failure to win over a majority in owners' associations as well as the investor-user dilemma.
However, the willingness to retrofit properties can be increased by various incentives such a reduced property tax, a retrofitting fund or an ecological rent index, with landlords being able to charge higher rents for retrofitted buildings. Further measures: handcraft businesses receive qualifications and certification for energy-efficient retrofitting, show premises are made available for viewing.
It is particularly important to increase general acceptance, e. g. by expanding advisory centres and specifically addressing and appealing to building owners.

4.4 Efficient installation engineering and heat distribution

Even when the entire insulation potential has been exhausted, a residual heat demand remains. The aim is to meet this residual demand efficiently and sustainably by using modern generation and distribution systems, thus reducing the use of primary energy and the associated carbon emissions.

Replacement of inefficient heating systems
The stock of central-heating boilers in Frankfurt is divided between oil-fired and gas-fired. Gas-fired boilers dominate with a figure of around 91 %. The majority (43 %) go back to the period from 1998 to 2009. Furthermore, there is a high percentage of central-heating boilers from the years 1991-1997 (36 %). Systems which are over 24 years old account for around 19 % of the stock. Only 2 % of the central-

heating boilers installed are no older than 4 years. In particular, systems from the 70s and 80s display an extremely low level of effectiveness. Assuming that the heating systems have a service life of around 20 years, just under 50 % of the systems could be replaced in the coming years. However, the replacement of the boiler alone is not enough to allow the city to reach its climate targets. The use of synergies must also be considered. This could take the form of the expansion of district heating schemes described above, the use of heat pumps, solar heat and CHPs. A critical view must be taken of the installation of pellet heating plants in the inner city due to the particle matter pollution.

Local circulation pumps

Central heating systems are generally supplied by central circulation pumps. They must provide pressure constantly in order to supply even the most unfavourably located radiator. Miniature pumps can significantly reduce the energy input. These local circulation units pump only the volume of water required for the specific radiator.

A trial conducted in a test building by the Fraunhofer IBP determined a saving of 19 % for gas and a saving of around 53 % for electricity compared to a conventional central circulation pump.

Low-temperature heating systems

When outdated heating systems are being replaced, a change-over to a low-temperature operating at temperatures of approximately 35° C is recommended. With the aid of underfloor heating, an adequate room temperature can still be achieved. Due to the reduced temperature, heat pumps and solar thermal collectors can be incorporated into the heat supply. However it is generally costly to retrofit old buildings with low-temperature heating systems. Due to the high heat demand, the building's envelope needs to be additionally insulated along with the changeover of the heating system.

As a result of the changeover, an energy saving of between 30 % and 80 % can be achieved compared to conventional heating systems; however, due to the diverse situations, the payback period can only be estimated with difficulty.

4.5 Grid-connected solutions

Almost half of the heat demand in Frankfurt is supplied through district heating and district steam (47 %). The largest consumer is the tertiary sector (54 %), the second-largest is households (31 %) and industry accounts for only 15 %. However, with regards to district steam, it is at the forefront with a share of 80 %. This is attributable to the high temperatures required in technical processes. District heating offers significant benefits, including a constant and reliable heat supply, low space requirement and low investment costs. Nonetheless, district heating is also environmental protection in practice, as the regenerative share in the heating sector can be increased relatively easily. Existing networks which are currently fired with natural gas or coal can be easily adapted to biomass. According to the Study, here lies the greatest benefit of district heating. However, district heating presents major challenges for the operator, among them high initial investments and uncertainty regarding the rate of connection. The largest supplier of district heating in Frankfurt is Mainova AG. It maintains over 250 kilometres of district heating networks and supplies over 4,300 buildings in 32 municipal districts – from single-family homes to the Industriepark Höchst. The entire district heating grid is further subdivided into local and district heating networks, with the district heating networks making up by far the largest share. The study identifies three core points for increasing the efficiency of the district heating supply systems: Expand and increase the density of the grids, reduce grid temperatures and integrate renewable energy forms.

Expansion of the grid

By expanding and increasing the density of the grid, losses are reduced – operation becomes more economical and environment friendly. Mainova AG is already planning to amalgamate individual systems to an integrated network. The aim is to cut carbon emissions by 100,000 tonnes per year. Additional plants are planned at new sites, in order to be able to connect new buildings.

In residential areas with a low heat density (e. g. large-scale residential estates with low-energy single-family homes) the trend is turning to small, local heating solutions with low temperature levels. Local heating grids of this kind already exist in the new housing developments such as the Frankfurter Bogen, Edwards Garden and Lindenviertel.

Reducing grid temperatures

In the past decades, the district heat supply has shifted from high-temperature grids to low- temperature grids. This reduces investment and operating costs as well as the space required. Above all, renewable forms of energy (solar energy, geothermal energy) and secondary energy (waste heat from industrial processes and waste water) can be used increasingly. While the temperature level cannot be lowered indefinitely – in Germany to a maximum of 65° C to 70° C – it is still possible to heat residential buildings and other properties with low energy sources and at the same time minimize energy losses in the grid. One restriction applies due to the fact that district steam is necessary to supply the high-rise buildings in the Frankfurt inner city, so that the grid temperatures cannot be lowered there.

In cascading energy usage, the temperature level within a district heating grid is flexibly adapted. Locations with a good mix of high-temperature and low-temperature customers are particularly suitable. **"Cold district heating grids"** can be an alternative to conventional local and district heating grids in new developments with very low energy demands, as they work with temperatures which are only marginally higher than the surrounding soil.

Best Practice: *In Aurich, pre-treated waste water from a creamery is cooled and the heat harvested transported over a 1.5 kilometre pipe to a function hall as "cold district heating" When it arrives, the water has a temperature of 14° C and is available for use with the heat pump.*

In order to be able to reduce grid temperatures, energy-efficient retrofitting is indispensible, so that most of the responsibility lies with the customer. For example, low temperature heating systems (underfloor, ceiling, wall heating) needs to be integrated into the existing residential buildings, but are cost-intensive. The obstacles in the way of development of district heating are therefore of a sociological-economic nature rather than technical or structural. Not least among these is the lack of awareness of the benefits of district heating on the part of the consumer, and marketing.

Integration of renewable energies into heating grids

Biomass power plants generate power and/or heat by burning biomass (incl. wood). As biomass is suitable for a diverse range of uses, utilisation competition applies between the heat and transport sectors. The study assumes that biomass is used primarily in district steam for industry and the tertiary sector. Potential for around 168.5 GWh from biomass exists in Frankfurt, of which 88 % is currently being exploited. In the region, around 1,225 GWh thermal biomass potential exists. The quantity exploitable for Frankfurt is limited, however, as the associated communes themselves require biomass.

Solar energy can only be incorporated into the district heating grid with certain restrictions. Both flat plate collectors and vacuum pipe collectors achieve the highest annual yield in a low temperature grid. In the inner city, only part of the rooftop space can be used (monument protection, in some cases already occupied by PV modules), alternatives are open spaces on the outskirts of the city, roofs of multi-family buildings and multi-storey car parks. In the banking district, collectors could be integrated into the

facades. The study assumes that, by 2050, it will be possible to win around 5 % of district heating from solar energy; this equates to around 90 GWh.
Studies have shown that in Frankfurt's city centre, at a depth of 100 to 140 meters, above-average temperatures of 18° C to 22° C exist. Good conditions for using what is known as **near-surface geothermal energy**, which uses the geothermal energy to a depth of 400 meters. Low-energy housing developments could be heated with this energy and cooled indirectly in summer through their radiant panel heating systems. Public parking areas would lend themselves to this, as would such parks as the Ostpark. The space could be used again, without restriction, once drilling was completed. Even if the use of near-surface geothermal energy is still in its infancy in Frankfurt, an expansion to 15 % of the district heating demand by 2050 is possible.
While near-surface geothermal energy can only be used with low inlet temperatures, **hydrothermal geothermal energy** is suitable for inlet temperatures over 80° C. Drilling reaches a depth of between 400 and 6,000 meters, the drilling sites must be around 10,000 square metres. This – along with the higher costs – is likely to be one of the major obstacles to hydro thermal geothermal energy use.
Waste heat from industrial processes can provide temperatures between 30° C and 140° C, making it a major potential for district heating. It occurs regardless of weather or season and is therefore primarily suitable as base load heat. Sources of waste heat can be production machines of plant which radiates lost heat. Furnaces and motors can also be considered. For Frankfurt, apart from the industrial operations, data centres are particularly interesting as sources of waste heat. But there are also obstacles such as uncertainty regarding the service life; in addition, the payback time may be daunting for the tertiary sector.

***Best Practice:** In Göppingen, waste heat from the Deutsche Gelatinefabrik Stoess is used to heat the school, the swimming pool and multi-family apartment buildings. By means of a gas heat pump, the 30° C cooling tower water is made available for heating purposes.*

Waste heat from waste water also occurs throughout the year in almost constant volumes and at almost constant temperatures (between 10° C and 20° C). A heat exchanger installed at the bottom of the canal extracts the heat from it. In combination with a large heat pump, this waste heat can be used for heating, particularly in small local heating grids with low grid temperatures. Temperatures of up to 80 °C are technically possible. Overall, the heat potential from Frankfurt's waste water is estimated to be around 119 GWh per annum. The drawback: As the waste water is rich in nutrients, a biofilm can form on the vaporiser, which need to be removed regularly.
The study assumes that, in 2050, around 460 GWh annually could be won from the waste heat of industrial operations and data centres and waste water in Frankfurt to provide district heating and district steam for households and enterprises in the tertiary sector. The savings in CO_2 compared to oil heating is therefore around 40 %.
Power-to-gas systems offer a further possibility to increase the share of renewable energy. In May 2014, the first **power-to-gas plant** was commissioned in Frankfurt's Ostend district, producing 60 cubic metres of hydrogen per hour. Cost-effective operation of this plant will only be possible with increasing surpluses of wind and solar energy.

4.6 Thermal efficiency measures in the industrial sector

In the chemical industry – in particular the Industriepark Höchst is to be mentioned here – the greatest potential for savings is a **modern, efficient reactor**. In second place are systems for separating mixed substances, most of which are very energy-intensive in operation but which could be converted to more economical processes with lower temperatures. A further point is the retrofitting of existing systems with modern process control engineering.
Improvements in the area of process heat with high-energy consumption should also take first place in the overall industrial sector. In this way, significant

savings are to be expected through **heat recovery**, or improved thermal insulation, for example for tanks or piping.
Solar process heat also displays major potential. In general, **solar energy plants** can be run more economically in industrial operations than in residential buildings.
In the **power-to-heat concept**, surplus power from regenerative energy sources is used for process heat. In the year 2010 alone, the unused surplus power from regenerative sources amounted to around 127 GWh. Surplus wind and photovoltaic power could also serve to produce hydrogen by means of water electrolyses. Combined with oxygen in a fuel cell, it can produce electrical power. The ensuing waste gas is pure water vapour. In the Industriepark Höchst, 30 million cubic metres of hydrogen occur annually in any case as a by-product of chlorine production. Even today, this can run 400 busses or around 10,000 cars. Overall, around 15 % of the fuel could be saved in the industry by 2050.

5. Increased efficiency and sustainable mobility in the transport sector

In order to develop sustainably, mobility must be socially, ecologically and economically compatible. The study presents various measures. But it also points out that Frankfurt's citizens need to rethink their habits when it comes to mobility.

5.1. Avoiding traffic – short-range mobility

Pedestrians

In terms of the number of trips covered on foot, Frankfurt occupies a place in the upper quarter of the rankings compared to other cities. The above-average share is the result of consistent urban planning based on the concept of "short ways". The number of foot journeys can be further increased if traffic is tailored more closely to the requirements of pedestrians, e. g. by introducing 30 kilometre speed zones on main transport routes. The city has already introduced 30 kilometre speed zones in almost all residential areas. The introduction of 30 kilometre speed zones on main transport routes would be the next important step.

Cycling

Promoting cycling as a means of transport is one of the main points of focus of the City of Frankfurt am Main. Around 13 % of the trips in the city are covered by bicycle. The share in some other cities is higher (Copenhagen: 31 %, Amsterdam: 22 %, status 2010). Fast bicycle paths round Frankfurt could contribute to increasing this share. In a study, six main corridors became evident, based on the volume of commuters and the population density. Their development can cut one third off the travelling time on each of these routes.
In particular, commuters in the catchment area of 5 to 15 km could reach their destinations faster in this way than by car during the rush hour. According to data from the Regional Authority Frankfurt RhineMain around 130,000 to 140,000 commuters come from the potential catchment area. This corresponds to approx. 33 % of all of Frankfurt's incoming and outgoing commuters. Combined with feeders at local public transport stops or P+R car parks, this step could significantly reduce car traffic in Frankfurt. Furthermore, inside the city, the proportion of routes covered by

bicycle could be increased through traffic light circuits tailored to bike traffic, secure bike parking (biketowers), more bike stations at local public transport stops and better cooperation between bike lending schemes and local public transport.

The sales figures for pedelecs have been rising steeply for years. Prognoses indicate that by 2020 electric bikes will account for 10 % of all existing bicycles. Even today, greater use of the pedelec is being promoted in Frankfurt, e. g. with the "bike+business" initiative of the Regional Authority – an option which is also of interest to commuters, particularly in combination with the development of the fast bike lanes. If the model is to be successful, employers will have to provide bike parking spaces, changing rooms and showers. Further incentives for changing over to the bike might be company bikes, subsidies for e-mountain bikes or racing bikes. The average purchase price of an e-bikes or pedelec currently lies at around € 1,700. With an average daily distance of six kilometres covered, the investment will pay for itself, compared to the pure running costs of a car, within just two years. And the environment also benefits: In the current power mix, the carbon emissions of the pedelec is four to five grammes per kilometre covered. If the battery is recharged using renewable energy, the trip is carbon-neutral.

Parallel to this, the close-meshed, comprehensive development of the existing **bike-lending scheme** is essential. Business people and tourists in particular benefit from the fast and inexpensive alternative to the car. There are currently two bike-lending schemes operating in Frankfurt. "Call a bike", offered by Deutsche Bahn makes 1,000 bikes available at 60 stations. "Nextbike" has over 32 stations with 200 bikes. A range of established bike-lending businesses already show today that economical operation is possible. An inter-city lending scheme increases commuter willingness to change over. It would make sense to consider cooperation and develop bike stations in such towns as Raunheim and Kelsterbach A cooperative scheme with Offenbach is already in place.

5.2. Motorised private transport (MPT)

Compared to other European cities, the MPT share in Frankfurt occupies a place in mid-field with 34 %. If commuter traffic is included – one million trips per day – the share of MPT increases to around 50 %. This figure clearly indicates that solutions need to be found for commuter transport in particular.

Electric cars can be a central pillar of the solution concept. Alongside Munich and Hamburg, Frankfurt already plays a pioneering role today. In order to increase acceptance, the city must promote the change-over in the introductory phase. This will also create incentives for companies to convert their car pool to electric vehicles. Lower power costs for electric cars also make the change-over easier for the commuters, as will reduced-price parking for car sharing and for electric vehicles. Another necessity is inner-city charging stations and parking for residents, for example in multi-storey car parks and district garages.

In addition to private customers, companies also use car sharing (CS) to cater for peaks in demand in their own vehicle pools. CS is used mainly for irregular trips and transport. For commuters who cover the entire way to work by car, lift-sharing or car pools make more sense.
A number of stationary CS providers have become established in Frankfurt. In total, CS cars can be used at over 300 stations. The providers work with the Deutsche Bahn, the Rhine-Main-Verkehrsverbund (RMV) or other commuter transport companies and offer special conditions for users of both schemes.

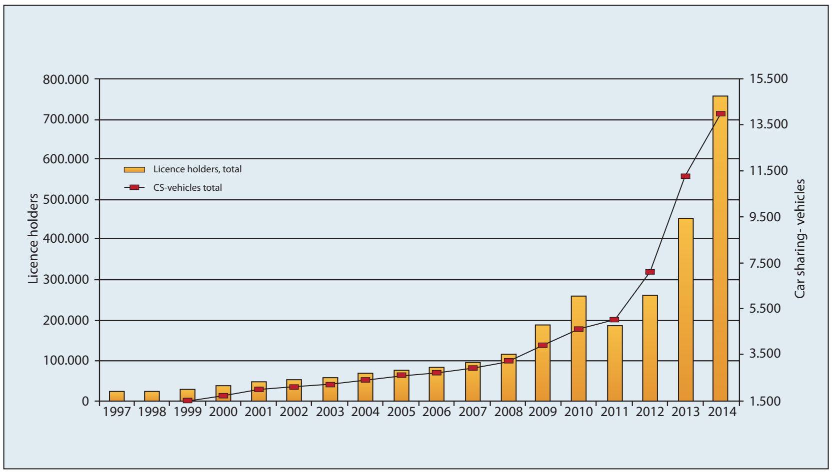

Fig. 127: Growth rates (Federal Carsharing Association, 2014).

The supply of parking spaces for CS vehicles should be further increased, according to a suggestion in the study. Increases are possible: In Frankfurt, at present, there are 0.63 car sharing vehicles per 1,000 residents, in Karlsruhe (the highest rate nationwide) this figure is 1.63 vehicles. CS can significantly reduce the volume of city traffic. By extrapolation, around 3,456 private cars have been replaced by 432 car sharing vehicles in Frankfurt. In the view of the Fraunhofer IBP, the expansion of CS in Frankfurt will hinge entirely on regulatory intervention and priority for CS vehicles. Both could be implemented at minimum cost. Furthermore, an augmented RMV-Mobility Card could allow its owners to use car sharing, public transport and rental bikes.

***Best Practice:** In Freiburg, parking spaces for CS are marked out in large residential developments and spaces in public car parks re-dedicated for CS users.*

In order to increase the popularity of e-vehicles, CS parking spaces for e-vehicles should also be made available in residential areas. However, this is not yet economically viable. Further suggestions are a municipal marketing concept and the stipulation for investors in single-family and multi-family dwellings to include charging stations and parking spaces for e-vehicles in the planning.

5.3. Local public transport

In Vienna, the share of local public transport in the modal split is 35 %. Frankfurt, Munich and Berlin display a local public transport share of 26 % to 29 %.

The Study suggests also raising the local public transport share in Frankfurt to around 35 % by 2050.

Electric busses/ hybrid busses, express busses

At peak times in 2010, 292 busses were deployed in inner-city traffic and 17 in originating/terminating traffic. Overall, they covered around 17.6 million kilometres with 210 million passenger kilometres. Fuel consumption amounted to approx. 6.95 million litres of diesel. This gave rise to carbon emissions of around 21,000 tonnes. As with cars, the city bus fleet should be converted to electrical operation.

Since 2010, two hybrid busses have been deployed in the north of Frankfurt for demonstration purposes. Electric busses can have removable batteries or be recharged using induction coils directly at the stops. With an average journey distance of around 250 kilometres per day, a battery capacity of 250 to 300 kilometres range is sufficient. Express busses which stop only at a few strategic points can further take the pressure off the city’s transport at peak times.

A good service (scheduling, network of stops, cleanliness) and a well-developed infrastructure are central points when it comes to encouraging further MPT users to change over. An electric bus currently costs € 300,000 to € 400,000, around € 100,000 to € 150,000 more than a conventional diesel bus. At a rate of 65,000 kilometres travelled per year, the investment pays for itself in five to six years. Simply by replacing diesel busses with electric busses, round 58 % of the carbon emissions could be saved.

Best Practice: *The first electrically-powered articulated bus which requires no overheat contact line has been in test operation in Geneva since May 2013. It charges up for 15 seconds at the bus stops by connecting a flexible arm with a contact integrated into the bus stop.*

Underground, rapid-transit and regional trains and trams

In 2010, at peak times, 199 underground trains, 191 rapid transit trains, 34 regional trains and 81 trams were deployed in Frankfurt. The power required for all these modes of transport totalled 219 GWh; the emissions amounted to 137,000 tonnes.

HGVs / city logistics

24,000 HGVs and vans were on the roads in Frankfurt in 2012, consuming around 1,174 GWh of final energy. 16.6 % of the energy consumption was accounted for by van traffic, 83.4 % by HGVs. Most of the energy was used in originating/terminating traffic and in transit traffic. Internal traffic accounted for only 10 %.

In this area, the study recommends drawing up a city logistics concept for e-vehicles and pedelecs/delivery bikes and encouraging the parcel service providers to convert their fleet. With adequate kilometres travelled, most electric vehicles can be operated economically in transport and delivery situations. The potential annual saving lies between € 1,000 and € 8,000.

A further model project could be to persuade regional logistics firms to become involved in cooperation. This could prevent empty or half-loaded HGVs and vans being driven around Frankfurt.

5.4. Marketing, competitions and advertising campaigns

Marketing and competitions could attract public attention to the various projects: Possibilities include a competition on the city's bike paths, a Commuter Mobility Day on which as many people as possible are encouraged to make their journeys on foot or by bicycle. A further suggestion is an annual "**Green Mobility Award"**, which would go to a company.

5.5 Developments in the traffic sector in various scenarios

What will the traffic situation look like in Frankfurt in 2050 if the measures described or not implemented, or implemented only to a minor extent? And what will happen if the city implements all the above measures completely by 2050? The study answers these questions in a benchmark scenario and a "with-measures" scenario.

Developments in the traffic sectors in the benchmark scenario

With a figure of 30 %, **MPT** continues to account for the largest share of the volume of traffic in the year 2050. The percentage of hybrid and electro cars rises to 30 % each, as this technology is only promoted in a half-hearted way. The number of vehicles in car sharing rises by 5 % every 10 years. The energy sources diesel and petrol dominate in MPT final energy consumption, with a figure of 87 %. The proportion of biofuels is limited to the minimum share required by the EU (10 %).

In local public transport, the daily journeys have risen by approx. 10 %. The bus fleet in both inner-city transport and originating/terminating traffic consists of 50 % electric busses, 40 % diesel busses and 10 % hybrid busses. The number of railed vehicles remains constant up to 2050. However, the capacity utilisation of the trains and trams is increasing as more commuters are changing to this mode of transport. The final energy consumption in public transport decreases by 20 % by 2050. Instead of 289 GWh (2010), consumption is now around 232 GWh.

In road haulage, the vehicle miles travelled in inner-city traffic, originating/destination traffic and transit traffic increases. The 10 % share of biofuels (biodiesel) stipulated by the EU remains constant up to 2050. There is still lack of biomass as well as a lack of the acceptance among the general public required for an increase. In HGVs, diesel-powered trucks retain their market share of 90 %. By 2050, only 25 % of vans are equipped with electric drive, 65 % drive with diesel, 10 % with biodiesel. Compared to the situation in 2010, the final energy consumed in road haulage has risen by 13 % (132 GWh). The share of electricity in the final energy demand lies at around 1 %, 10 % is covered by biodiesel, the remainder (89 %) is accounted for by diesel.

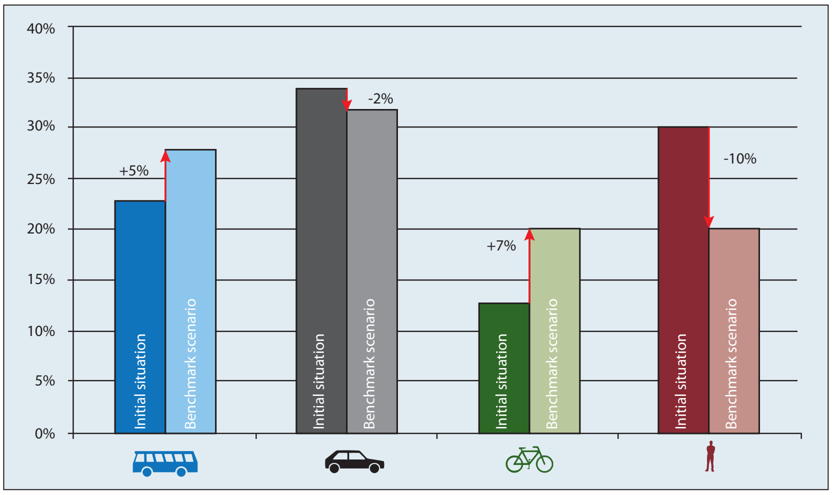

Fig. 141: Changes in the modal split in the benchmark scenario 2050 compared to 2010, own figures (IBP).

Developments in the traffic sectors in with-measures scenario

MPT: The daily journeys decline by 24 percentage points; MPT now accounts for only 9 % of total traffic. This can be attributed, among other things, to the expansion of the cycle infrastructure and improved local public transport. Carsharing offers are further expanded, rising to around 17 vehicles per 1,000 inhabitants in 2050.

The proportion of hybrid and in particular electric vehicles rises rapidly from 2020 on, as electromobility has reached the break-even point. Supportive measures on the part of the city (e. g. free parking spaces for e-vehicles) also contribute significantly. By 2050, petrol and diesel cars will have been completely displaced by hybrid and electric vehicles. The final energy demand in the MPT sector drops from 2,888 GWh to 413 GWh, the share in electricity lies at 68 %. The remaining energy is shared between bioethanol (18 %) and biodiesel (15 %).

Local public transport has become more attractive as a result of the supporting measures. Overall, use rises by 12 percentage points compared to 2010. Because more commuters are changing over, the capacity utilisation in originating/destination traffic is increasing. The bus fleet consists of 98 % electric busses and 2 % hybrid vehicles. Despite increasing vehicles kilometres travelled, and an expansion of the fleet, the final energy consumption can be significantly reduced through electric motors and more efficient engines. The rail systems also display increasing capacity utilisation: In 2050, there are 13 more underground trains, 11 more regional trains, 12 more rapid-transit trains and 11 more trams in operation than in 2010. While the power demand rises as a consequence, this is balanced out by more efficient engines. Overall, the final energy consumption in local public transports in 2050 is 31 % lower than in 2010, sinking from 289 to 199 GWh.

In road haulage, the vehicle miles travelled increases by 10 % by 2050 – due to the improved city logistics, the increase is significantly lower than in the benchmark scenario. Just under 70 % of the vans have electric engines; among HGVs the figure is 50 %. The phased change-over from diesel to electricity or hydrogen permits a 60 % reduction in final energy consumption. The saving amounts to 700 GWh. The share of electricity in the total final energy demand of the transport sector now amounts to 77 %. The remainder is covered by biodiesel (approx. 23 %).

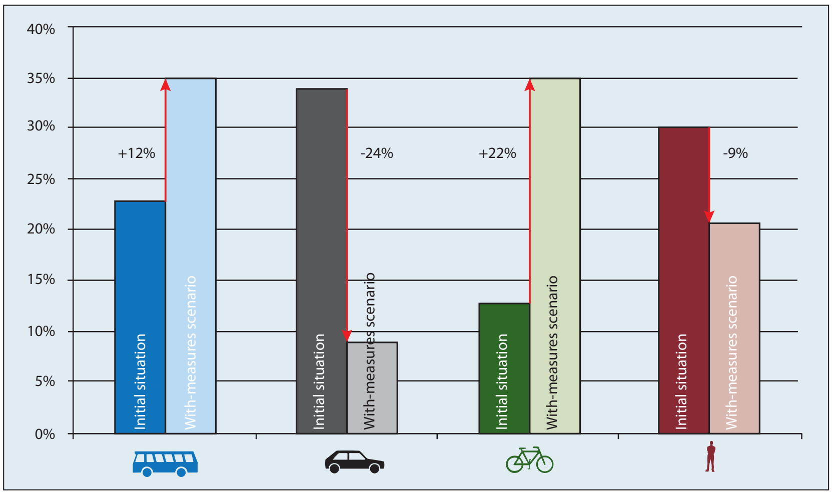

Fig. 152: Change in the model split in with-measures scenario 2050 compared to 2010, own figures (IBP).

Because of the development of infrastructure for cyclists and the existence of a widespread bike-sharing scheme, there has been a sharp rise in bike journeys. In 2050 around 35 % of trips are taken by bike. The proportion of trips undertaken on foot declines to 21 %. The reduction is attributable to the increase in bike trips and the greater use of public transport. As a result of the development of express cycle lanes and the equipping of bike-sharing stations with pedelecs, commuters use the bicycle for around 15 % of daily trips. Job tickets and increasing fuel prices also make local public transport more attractive.

In 2050, car pools have become the rule rather than the exception due to the sharp increase in fuel prices.

While the car is still the defining mode of transport in the with-measures scenario, with a share of over 30 % of daily trips, MPT loses significance considerably in the with-measures scenario. By sensitizing the population and improving local public transport and bike or car-sharing schemes, it has been possible to replace the car with bikes and local public transport.

6. Redirection of present spending on energy in Frankfurt and the region

Even in times in which financial resources are tight, there are convincing economic arguments in favour of implementing the measures. Primarily, these are regional value added and positive effects on employment. The local character of the energy reversal can be a chance to retain medium-sized companies in the region, create jobs, boost spending power and increase fiscal income. This is augmented by the fact that energy costs decrease annually, freeing up further financial resources. The feasibility study envisages replacing the import of energy feedstock and final energy with regional energy sources, technology and services. In order to achieve this, the potential for renewable energy forms must be fully exploited and optimised. This too increases regional value added and prevents financial resources flowing elsewhere.

6.1 Development of energy costs

With energy consumption remaining constant and a budgeted price increase, the overall expenditure on energy will rise between 2010 and 2013 from € 2,203 million to € 2,605 million. Specifically: The tertiary sector consumes € 884 million more, the transport sector € 637 million, and in the households the expenditure rises by € 571 million. In all sectors, electricity accounted for the highest expenditure with a total of € 1.3 billion (2013).

In the study, this is contrasted with Scenario A developed in the Masterplan. This indicates that in the year 2050 around 59 % of the required electricity will be generated within the city. Private households and operations in the tertiary sector will occupy a central role, as a high percentage of consumers will become so-called “prosumers” (prosumers generate energy themselves; they store any power not consumed or pass it on to neighbours or into the energy grid). The city can support this by making spaces available for local generation plants. Even today, many schools and municipal buildings are among the prosumers. Their share will rise further when the storage costs fall and the self-generated power can be used more and more for e-vehicles.

This means that the energy spending on natural gas and coal no longer leaves Frankfurt and between € 115 million and € 144 million remain in the city. If natural gas and heating oil are completely replaced by renewable energy forms (EE) expenditure of € 314 million (natural gas) or € 63.5 million (oil) does not arise. Thus a further € 203 million would remain in the city. Overall, this represents € 12 billion (budgeted price increase of 2.5 % per year) by 2050.

Conclusion: With the change-over to renewable energy forms, the outflow of financial resources from the city can be decisively counteracted.

6.2 Development of energy production costs

The power and heat production costs of renewable energies declined significantly in recent years. A reverse development is displayed by conventional power stations. It can be anticipated that this trend will continue. From as early as 2020, payback periods of under 8 years can already be achieved for PV systems and electrical storage for the cellar. By 2020 the price for pushdown electrical storage for electricity and e-vehicles is likely to have been halved. Combined systems (PV system and pushdown storage) are of interest for a quarter of the single-family and two-family homes, but could also present a solution for housing associations. Increasingly, combination solutions are becoming economically interesting for companies in the tertiary sector.

6.3 Saving energy means regional value added

Using a number of examples, the study shows how energy saving and energy efficiency specifically impacts local and regional value added:

- If energy efficiency upgrading is consistently carried out in the households, the expenditure of all of Frankfurt's households is reduced by an annual € 230 million (up to 2050 by € 8.5 billion) – financial resources which are freed up and can be redirected.
- In the tertiary sector, energy management solutions reduce the energy consumption by around 15 % – provided half the companies work with it by 2050. Even today, companies can make savings of € 40 million per year.
- Good local public transport connections and cycle paths increase the value of properties, make employers more attractive and boost turnover in the retail trade.
- In the tertiary sector, the comprehensive use of LEDs reduces power consumption by 30-40 % and brings further annual savings of € 75 million.

6.4 Subsidy schemes and financing models

Subsidy schemes and financing models can help to achieve the objectives. The Renewable Energies Act (EEG) is the most important building block for the development of regenerative energies. In addition, the Market Incentive Scheme (MAP) for regenerative energies in the heat sector is a central Federal Government subsidy scheme. The drawback of both of these: Time and again, changes in conditions and volume of the scheme unsettle medium-sized companies in particular, reducing the willingness to invest. For Frankfurt, an incentive scheme is recommended which is independent of fluctuations in the budgetary situation or politics. In addition, new forms of financing can be beneficial: Existing incentive schemes could be augmented via a newly-conceived energy tax. A new tax (e. g. climate tax) relating to the energy efficiency quality of the building is also conceivable. Another model is a fund-linked levy relating to the building's energy efficiency quality (energy savings fund). Obligated parties who do not save energy must pay a levy into a fund out of which the incentive schemes are financed. A recommendation for Frankfurt: Companies pay into a newly-established fund, the city doubles each euro paid in. An increased levy for new buildings is conceivable. The background is that each new building, regardless of how efficient it is, takes up resources and space. The levy could increase the incentive for energy efficiency retrofitting, thus saving resources and space. In crowd funding, a number of individuals finance a certain project via internet platforms. In Frankfurt, this form could be applied to local district projects.

What is known as contracting is a contractual service between an external, private service provider (contractor) and the energy consumer. The contractor plans, finances and implements the energy saving measures for a customer and participates in the cost savings. A foundation based in Frankfurt which supports such energy efficiency projects as kindergartens and schools is also thinkable.

Summary

The examples show that despite the necessary investment costs, expenditure can be reduced in all areas. The increasing share of decentrally-generated energy helps to retain a high level of value added in the city. Furthermore, regional value added can be increased through existing and new financing methods for energy generation, geared particularly to the interest of local investors.

7. Development of the scenarios for Frankfurt up to 2050

7.1 Demographic development and area development

According to the forecast demographic development, Frankfurt will have a population of around 720,000[1] by the year 2050, occupying 405,000 residential units. The average household consists of 1.78 members. Estimating how land consumption will develop in the tertiary sector proves difficult, as the data is insufficient. Therefore, for the calculation of the scenarios, information is drawn from workshops in which parties from the various branches participated. According to this information, the area occupied by the retail trade and office-like operations will rise significantly, the area occupied by server and data centres will almost double. The space requirement in the tertiary sector will therefore grow by 33 % from 22.8 million square metres (2010) to 30.3 million square metres in 2050.

[1] This was an estimation based on prognoses of the Hessen Agentur of 2010.

7.2 Scenarios

In order to demonstrate the development opportunities in the period up to 2050 a benchmark scenario and a with-measures scenario were developed. The benchmark scenario assumes that the proposals are implemented less speedily and not with complete consistency. In the with-measures scenario, the measures presented in the study are consistently implemented.

7.2.1 Scenarios for the Frankfurt electrical sector

Benchmark scenario – Electrical power demand

In the tertiary sector, only half of the electrical power-saving measures are implemented; the employees at their workplaces have not been sensitised to the topic. For this reason, the savings are only around 10 %. In households, all appliances are replaced, but not with A+++ appliances. As user behaviour does not change, there are no further savings; overall the consumption in households drops by 18 %. Industry can retain the consumption level of 2010, but not reduce it. Overall the power demand drops by 7.3 %. Compared to the overall energy consumption of 2010, around 2.6 % of final energy can be saved.

With-measures scenario – Electrical power demand

The tertiary sector fully exploits all power saving potential; furthermore, there are savings through altered user behaviour at the workplace. By 2050, the overall savings lie at 46 %. The electrical power demand can be reduced from 2,970 GWh (2010) to 1,603 GWh (2050).

In households, all the household appliances have been replaced by new A+++ appliances. The population has been sensitised to the rational use of power. Therefore around 58 % of the electrical power demand is saved: Consumption drops from 1,028 GWh to 432 GWh. Because industry has also implemented the proposals from the study, the electrical power demand is reduced by approx. 20 % from 2,582 GWh to 2,066 GWh. The total electrical power consumption of all three areas drops by 38 % to 4,080 GWh in the with-measures scenario.

Demand increases due to the growing significance of electricity for heat and transport. In the heating sector, it is the large number of thermal pumps and power-to-heat applications; in the traffic sector, electric cars and hydrogen HGVs/vans dominate road transport in 2050. The expansion of underground, rapid-transit and regional trains as well as trams requires more electrical power. The associated increase totals 773 GWh.

However, overall, the savings dominate by far: The electrical power demand in the year 2050 amounts to 5,140 GWh and thus lies around 22 % lower than in the initial year 2010.

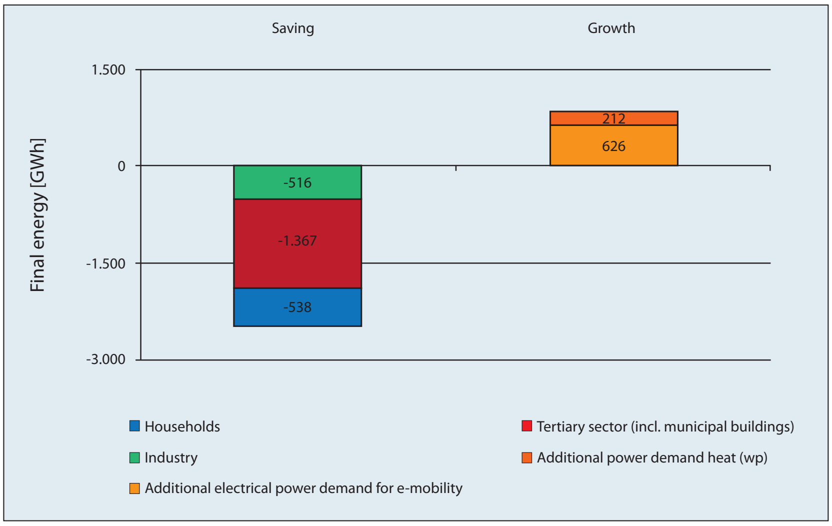

Fig. 160: Power increase and power savings by sector, based on IBP calculations.

7.2.2 Scenarios for the Frankfurter heating sector

Benchmark scenario – Heat demand

Residential and non-residential buildings in Frankfurt are not all upgraded. As in the tertiary sector, the rate lies at 50 %. The replacement of central circulation pumps by local speed-regulated pumps has not been carried out. In the industrial sector, only small efficiency measures are implemented, however, the heat demand has been kept constant.

In households, the thermal heat demand drops by 35 %, in the tertiary sector by 45 %. The overall heat consumption declines by 25 % from 11,713 to 8,801 GWh. Compared to the overall energy consumption in 2010, final energy consumption in the heating sector drops by around 16 %.

With-measures scenario – Heat demand

By 2050, all residential and non-residential buildings in Frankfurt will have been retrofitted; circulation pumps will have been replaced.

In the industry sector, heat demand is reduced through more efficient structuring of production and the exploitation of waste heat potential. Heat consumption in industry is reduced by 1,077 GWh to 3,230 GWh (25 %). Whereas heat consumption in the initial 2010 was almost evenly distributed across the three sectors, industry dominates in 2050 with a share of 62 %. Major savings are achieved in the tertiary sector. Here, through complete energy efficient modernisation, replacement of circulation pumps, etc. heat consumption has been reduced by approx. 73 % from 3,576 GWh to 955 GWh. Households also save 73 % of heat consumption, which declines from 3,830 GWh to 1,034 GWh.

Overall, heat consumption drops by 55 % to 5,219 GWh. Thus, between 2010 and 2050 it is possible to save around 6,483 GWh of heat.

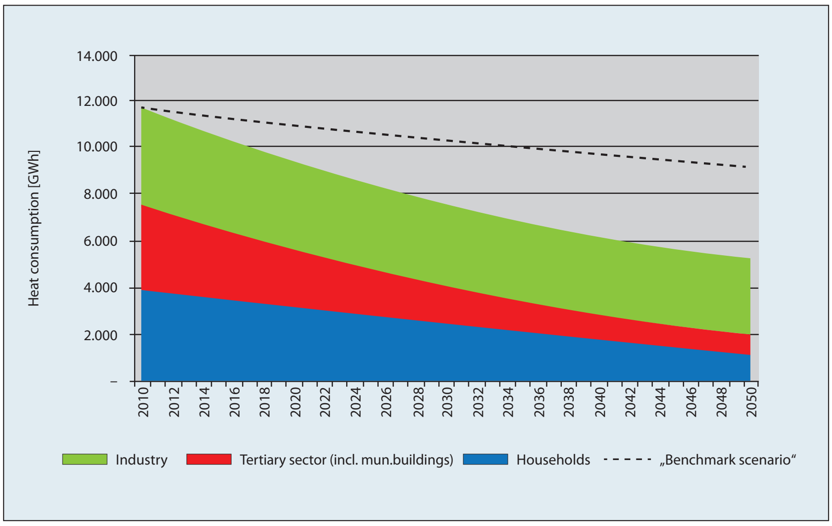

Fig. 162: Development of heat consumption in the with-measures scenario, source: Fraunhofer IBP.

7.2.3 Scenarios for the Frankfurt transport sector

Benchmark scenario – final energy transport

The final energy demand sinks by approx. 29 % (1,252 GWh) by 2050. The greatest potential saving (approx. 47 %) lies in MPT, as some users change over to alternative drive due to the rising petrol prices. In local public transport, the electrification of the bus fleet and more efficient engines result in a 20 % saving in final energy. Due to the increase in vehicle miles travelled, van and HGV traffic consumes 13 % more energy. Thus, in 2050, half the final energy consumption is accounted for by MPT, 43 % by the road haulage sector and only 7 % by local public transport. The consumption of petrol declines, but power demand rises by 13 %.

With-measures scenario – final energy transport

Electricity now accounts for 78 % of the final energy consumption (2010: 5 %). Petrol consumption sinks by 97 %, diesel consumption by 75 %. The hybrid vehicles in MPT, the busses in local public transport as well as HGVs and vans run on biofuel. The lion's share of savings is achieved in MPT (minus 2,475 GWh), as many travellers drive electric cars or use public transport. MPT now only accounts for 38 % of final energy consumption (previously 66 %).
In local public transport, 90 GWh are saved by more efficient engineering and driver assistance systems. Its share in final energy consumption rises from 7 to 18 %. The largest energy demand now comes from the transport sector with 44 % (2010: 27 %).
Here it has been possible to save 711 GWh.
Overall, final energy consumption in the traffic sector has been reduced by 75 % in 2050. Instead of the previous 4,362 GWh now only 1,086 GWh are being consumed.

7.3 Energy scenarios for 100 % renewable energy in Frankfurt

Which energy sources must be exploited, how are they to be combined, for 100 % of Frankfurt's demand to be met completely by renewable energy by 2050? How closely must the region and other potential sources be involved? How expensive will energy be? To find out, the findings report of the Fraunhofer Institute for Solar Energy Systems (2014) ran through various scenarios. The initial basis is the data from the year 2013, projected to the year 2050. This took into account the consumption of electrical power and heat including the electrical power consumption for the traffic sector. Similarly considered are the electrical power and heat demands of the airport. The most important results from six different scenarios are shown below, each with three different versions.

Version 1: »City«: Only the potential for renewable energy forms within the municipal area of Frankfurt is used. Solar heat panels are permitted only on roof areas facing 50° east through south to 50° west. For photovoltaic, roof areas from 100° east through south to 100° west are used, as well as facades and open spaces.

Version 2: »City: with region«: In addition to the above potential, 50 % of the biomass potential and 50 % of the wind potential of the Regional Authority FrankfurtRhineMain is exploited. Renewable energy, biomass and household waste are imported to Frankfurt. The transport of heat from the region into the city is not permitted, as it is uneconomical in most cases. Furthermore, it is assumed in the calculation that all household waste in the region is incinerated in Frankfurt, as this is the site of the Regional Association's only waste incineration plant.

Version 3: »City: with state«: In this version, Frankfurt exploits biomass and wind energy from the state of Hesse in proportion to the share of population. As Frankfurt's population makes up 11.6 % of the population of the state, this figure is applied as exploitable potential.

Potentiality versions/ models	Photo-voltaic	Wind	Biomass	Water power, solar heat	Waste
City	City*	City	City	City	City
City and region	City* +50% RV	City +50% RV	City +50% RV	City	City + RV
City and state	City* +50% RV	11.6% BL	11.6% BL	City	City + RV

RV = Regionalverband, BL = »City with state« (Hesse), * Roofs + Facades + Open spaces

Tab. 9: Catchment areas considered for the various renewable energy sources in the 3 potentiality versions.

Each of the three models above was calculated with differing boundary conditions (scenarios).

Scenario "Without restrictions": The potentials of all energy sources may be exploited. Power may be imported or exported up to a maximum of 20,000 MW. Import and export of heat is excluded in all scenarios. No further stipulations apply.

Scenario "Autarky": Import of power is not permitted. However, export is possible and corresponds to a limiting of wind generators and photovoltaic systems. The maximum exploitation of the solar thermal potential is stipulated.

Scenario "10 % electrical power import" and "limitation of percentage of own electrical power 70 %, 80 %, 90 %": A defined share of imported electrical power is stipulated in each case. No limitation applies to exported electrical power. The solar thermal potential is fully exploited.

Results of the scenarios

Each of the most economical solutions for supplying Frankfurt's heat and power demand, including the power needed for local mobility, is shown below.

As a matter of principle, there is no reimbursement for exported power in order to prevent power being exported although it could be used locally.

Recommended scenario: "City with Federal State, 10 % electrical power import"

In this version, complete supply of the city of Frankfurt with renewable energy is possible every hour of the year. The degree of autarky is 95 %, 5 % is imported. In order to achieve this degree of supply, large storage facilities are necessary (2,036 MWh electrical and 2,594 MWh thermal). Based on the optimisation calculations, this version is recommended as it offers a high degree of self-provision of renewable energy at acceptable costs (power production costs 12 €ct / kWh).

With the exception of the PV potential of which only 31.9 % is used, the potential of the various energy sources is completely exploited. 34 % of power is generated from wind energy and 21 % from PV. biomass covers 15 % and waste 9 % of energy demand. Heat pumps supply 21 % of heat demand solar heat 21 %, boilers 11 %. In the thermal area, biomass power stations account for 13 %; waste plays a comparative large role with 31 %.

For the purpose of comparison, the scenarios "Without restrictions" and "Autarky" were also calculated for the "City with Federal State" version.

"Without restrictions": In this scenario, no electrical storage facilities are installed, thus reducing the electrical power production costs to 8.7 €ct/kWh. Only 75 % of the electrical power can be generated from renewable energy sources.

"Autarky": This is the only scenario in which electrical power and heat demand can be met completely with existing potentials. However, high storage facility capacity is required (9,160 MWh), leading to comparatively high power production costs of 22.1 €ct/kWh. This scenario is not recommended as the costs drop significantly when even a small quantity of imported electrical power is permitted.

Scenarios of the version "City and Region"

For this version, it is assumed the city of Frankfurt can use half the wind, biomass and PV potentials of the Regional Authority.

"Without Restrictions": Here, as in all scenarios, full heat supply is stipulated (no heat may be imported or exported). However, in the Regional Authority, the potential for wind energy is so low that complete exploitation could only meet 5 % of the demand for electrical power. PV meets 25 % of the electrical power demand. Overall 53 % degree of cover (8.9 €ct/kWh) is achieved for electrical power.

"Limitation of electrical power imports": Three scenarios were calculated in which the percentage of self-generated electrical power lay at 70 %, 80 % or 90 %. In order to reduce the share of imported power, the share of PV power had to be increased. If 90 % of the power is self-generated, 68 % of it must be met from PV power. This, however, requires a storage facility capacity of 8,037 MWh and increases electrical power production costs to 20€ct/kWh (at 80 % self-generated electrical power: 17.3 €ct/kWh, at 70 %: 14.1€ct/kWh). Further benefits: The high proportion of PV power harbours risks for supply reliability, e. g. during periods of poor weather.

Summary of the KomMod simulation calculation

For the calculation of the scenario, the municipal energy system model "KomMod" was used. KomMod calculates energy systems which can meet the electrical power and heat demand for each hour in the year and determines the most economical version. The hourly resolution also permits the determination of the necessary storage facility capacity.

However, a prerequisite for all the calculated solutions is significantly lower energy demand. How these energy savings can be made is described in detail in the General Concept. The findings show that Frankfurt can be completely and reliably supplied with renewable energy if half of it comes from within the city and the other half from the neighbouring region and if some wind power and biomass from the state of Hesse is used as well (scenario "City with Federal State – Autarky"). Nevertheless, this scenario is not recommended due to the relatively high costs.

The scenario recommended for implementation is the version "**City with Federal State, 10% imported electrical power"**, which guarantees 95 % autarky in terms of the total energy demand. Here, pro ratio potentials of the federal state are also exploited, as well as 50 % of regional potential. Capacities from the federal state are particularly helpful with regard to wind energy. They increase the output compared to the City/Region version from 151 MW to 1,624 MW. The scenario represents a good compromise between a high degree of autarky and acceptable energy costs.

Scenarios of the version "City"

In densely built-up cities the potentials for renewable energy forms are naturally limited. Cities like Frankfurt must cooperate with the neighbouring region in order to achieve a sustainable and climate-neutral energy supply. Even so, it is important to know the extent to which Frankfurt can meet its requirements internally. The scenario shows that 30 % of the electrical power demand can be met, and 31 % of the heat demand if all renewable energy potentials are exploited. Solar energy represents the greatest potential: PV power meets 23 % of the demand for electrical power, solar heat 17 % of the heat demand. Waste contributes 6 % to energy generation.

8. Summary of results

Frankfurt can achieve its target by 2050 and save around 50 % of the final energy consumed today. The city has a major potential in terms of energy consumption reduction and can make a considerable renewable energy contribution. However, the potential is not sufficient for the city to supply all of its own electrical power from renewable energy sources. The balance can be maximised by including 50 % of regional potential. Without electrical storage facilities, around 53 % of the required electrical power could be self-generated; with the use of storage facilities, the figure is around 90 %. However, storage facility capacity would lead to a considerable increase in electrical power production costs.

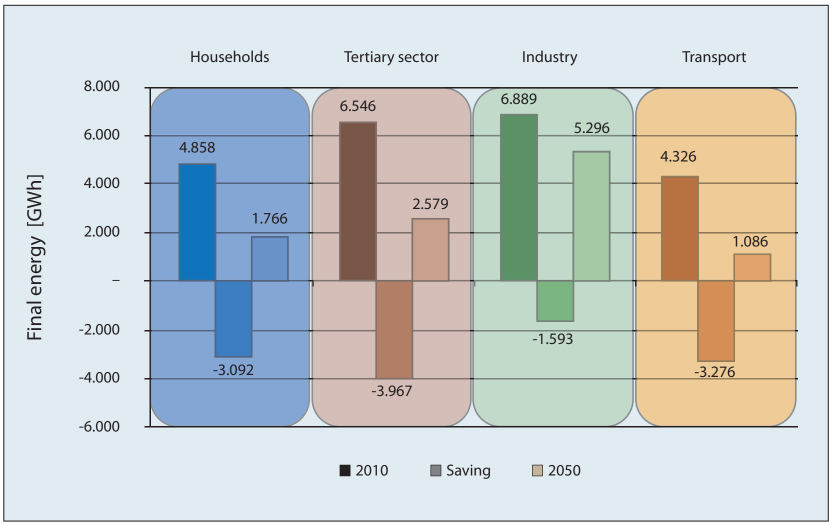

Fig. 203: Potential savings by sector, own figures for "with-measures" scenario IBP.

If the proportional capacities of wind energy and biomass from the federal state are included, Frankfurt can meet 100 % of its needs from renewable energies. From an economic perspective, the proportion of self-generated electrical power should, however, be set at 90 % and the remaining 10 % imported. The heat demand will be met completely from renewable energy sources. This model offers a cost-optimised solution, together with the greatest possible self supply. The implementation of this scenario will depend on the courage of the acting parties faced with the task of taking decisions of historical significance. A further significant factor is the acceptance of the project among citizens and companies who should participate in the process. Numerous further factors will play a role in the success. However, the feasibility study shows that Frankfurt am Main can realize its ambitious aims and implement a visionary and exemplary urban development project.

Long version of the study in German:
www.energiereferat.stadt-frankfurt.de

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