Sustainable Urban Infrastructure

Munich Edition – paths toward a carbon-free future

This report is based on research conducted by the Wuppertal Institute for Climate, Environment and Energy GmbH and supported by Siemens AG.

Contents

The facts are undeniable: Climate protection must begin in the cities. Large cities cover only about one percent of the Earth's surface. Yet they consume 75 percent of the world's energy, and they produce 80 percent of the world's greenhouse gas emissions – carbon dioxide (CO_2) above all. And the cities are growing. Today, about half of the world's population lives in cities. By 2025, that figure is expected to reach 60 percent. Until now, bustling metropolises around the globe have thrived primarily on fossil fuels like natural gas, coal, and oil. Year after year, the burning of these fuels releases billions of tons of carbon dioxide into the atmosphere.

There is no doubt that it is the cities that have the greatest impact on global climate change. At the same time, they will experience the consequences dramatically in the future. For example, the Umweltbundesamt (Germany's Federal Environmental Agency) expects that by the end of this century, Munich will see a distinct increase in the number of very hot days and tropical nights. Extremely hot summers, like that of 2003, will become the rule instead of the exception. On the other hand, the fact that the causes of climate change are concentrated in the cities has a decisive advantage. Because the problems are centralized, they are easier to manage, since climate-protection measures will have their greatest impact here. The world's metropolitan areas are thus in a unique position to pave the way for environmentally friendly lifestyles and economies and to generate solutions that could serve as a model for the other regions.

This study describes how an urban metropolitan region could pursue the path of achieving a nearly carbon-free future over the coming decades. The city of Munich, with its 1.3 million inhabitants, serves as the model. The timeframe examined spans from 2008 to the city's 900th anniversary in 2058. Munich has already set itself

1.0 Paths toward a carbon-free future: Key findings

the goal of reducing its CO_2 emissions by 50 percent (compared to the 1990 levels) by 2030. The analysis presented here is based on these findings, yet also looks further into the future.

The study is divided into two sections. Using two scenarios, the first section shows general strategies for how energy efficiency can be improved through a variety of measures and the impact each of these has on reducing CO_2. It also analyzes the cost-effectiveness of selected measures.

The two scenarios anticipate different levels of efficiency gains: one is very optimistic, while the other is more conservative. Nevertheless, both scenarios clearly demonstrate that CO_2 emissions actually can be significantly reduced within just a few decades.

Using a tangible urban model district as an example, the second part of the study demonstrates how the transformation into a nearly carbon-free district could be accomplished, from the perspective of both infrastructure and technology.

The study analyzes how a nearly carbon-free environment can be created by improving energy efficiency in a settled district as well as an adjacent area of new construction.

The most important elements first – the key findings of the energy efficiency study:

→ **In response to the IPCC report, Climate Change 2007, the EU environmental ministers established the goal of reducing greenhouse gas emissions by more than 50 percent worldwide by the middle of the century, which means less than two tons of emissions on average per capita. With existing technologies alone, this goal can be achieved and even exceeded in large cities such as Munich.**

With a consistent and rigorous emphasis on the goal of a carbon-free environment, it is possible in both of the scenarios presented here to reduce greenhouse gas emissions below the levels set by the EU environmental ministers. This goal was based on the Intergovernmental Panel on Climate Change (IPCC) report, Climate Change 2007. More specifically, the "target" scenario anticipates that, through comprehensive and consistent use of efficiency measures, the emissions would be reduced by about 90 percent – to a level of just 750 kilograms per resident per year – by mid-century.

This is despite the fact that Munich's population, contrary to predicted trends for the rest of the country, is expected to continue growing in the coming years. The forecast for CO_2 emissions per Munich resident in 2008 is 6.5 tons. The "bridge" scenario does not have such far reaching expectations for reducing private vehicle use nor for decreasing the demand for electricity. In addition, this scenario has a stronger focus on the technology of carbon capture and storage (CCS), which has not yet been fully developed. These limitations notwithstanding, total emissions will be reduced in the "bridge" scenario by 80 percent to roughly 1.3 tons per resident. That is also well below the goal of two tons of CO_2 equivalents per person per year.

→ The most promising methods for reducing emissions are better insulation in buildings, more efficient heating and power cogeneration systems, energy-efficient appliances and lighting systems, and power generation from renewable resources and low-carbon power plants.

Certain parts of a city's infrastructure can be clearly identified as major producers of CO_2. Applying efficiency measures to those areas is particularly beneficial. In Munich, for example, there is especially good potential for CO_2 savings in the areas of heating and electricity. Progress could be made by using thermal insulation in accordance with the passive house standard, by using efficient heating and power cogeneration systems, by installing energy-saving electric appliances and lighting systems, as well as by using renewable resources and low-carbon power generation technologies. Not as much electricity will need to be generated in large, centralized power stations because more and more electricity will be generated and stored in decentralized locations such as thermal power stations, or even in individual homes with micro heating and power cogeneration systems. Also, traffic reduction and changes in traffic patterns, along with technical improvements to improve vehicle efficiency, will contribute significantly to lowering the level of emissions.

→ Initial investments in efficient, energy-saving technologies are mostly significant, but the cost can in many cases be offset over the product life cycle through energy savings.

A number of impressive examples prove that energy-saving measures can also be economically viable. Thus, for example in Munich, refurbishing older buildings and constructing new ones in accordance with the particularly efficient passive house standard – as opposed to the 2007 Energy Savings Ordinance, currently in effect – would cost an additional €13 billion through the middle of the century. That comes out to roughly €200 annually per Munich resident – about one third of an annual natural gas bill. However, these additional investments will be offset by annual energy savings, estimated to be between €1.6 billion and 2.6 billion in the year 2058. That would equal annual savings of between €1,200 and 2,000 per capita, meaning, on the whole, energy savings of more than €30 billion over the course of 50 years.

→ To achieve the ambitious CO_2 reduction goals, citizens would not have to change their behavior in any fundamental way. However, they would need support and incentives to encourage them to invest more consistently in environmentally friendly, mostly cost-effective technology and to increase their use of environmentally friendly transportation.

The city is limited in its ability to impact CO_2 reduction through its own investments. However, improving energy efficiency in public buildings and developing the public transit systems are important steps. However, a large portion of the investments must be made by the city's residents and businesses if the ambitious reduction goals are to be achieved. Unfortunately, the high initial investments often required for efficient technologies have yet prevented their deployment on a large enough scale.

Often, potential energy cost savings are not taken into account, so that the cost over the entire product life cycle is not taken as a basis. However, experience clearly shows that governments can influence citizens' behavior by provid-

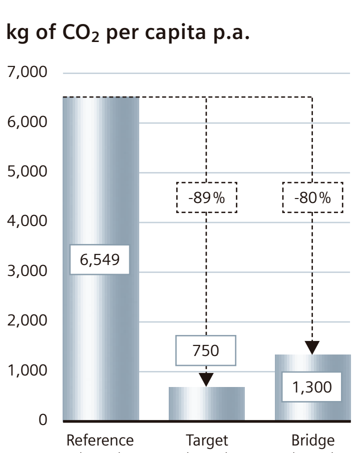
ing financing schemes or other incentives, or by mounting targeted information campaigns. Energy efficiency becomes particularly appealing when it also saves money. Therefore, an important future task for both public authorities and private providers is to clearly demonstrate the advantages and the financial benefits of energy-efficient technologies and to remove existing barriers.

→ State-of-the-art building insulation can dramatically reduce the heat energy required. Today, passive house designs can already be economically implemented.

The technologies required for construction of particularly energy-efficient passive houses, such as improved insulation, triple-glazed windows, and ventilation systems with heat recovery, are already well established on the market and have been tested and proven. The heat required for this type of building is roughly five times less than that of an average house. In most cases, a passive house is less than 10 percent more expensive than a building constructed in accordance with the 2007 Energy Savings Ordinance. However, over a 40-year period the reduced energy expenditure leads to annual cost savings, making the additional investment in passive house construction financially attractive. The passive house standard pays off not only for new construction, but also when refurbishing existing buildings. However, builders can be deterred because the initial savings on energy costs during the first years may be less than the additional cost of their loan.

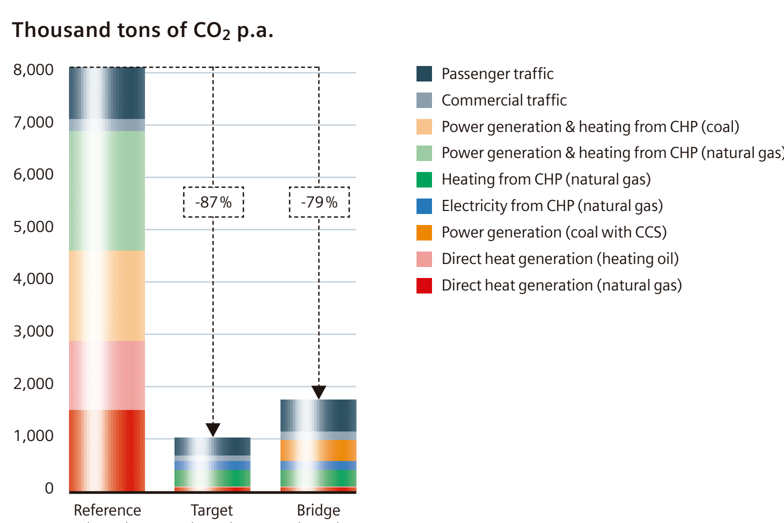
→ Because heat requirements will decline in the future, it will become more difficult to construct economically viable district heating systems with heat and power co-generation. Consequently, new technologies, such as low-temperature networks,

Per capita CO_2 emissions



Source: estimate of the Wuppertal Institute, 2008

CO_2 emissions by category



Source: estimate of the Wuppertal Institute, 2008

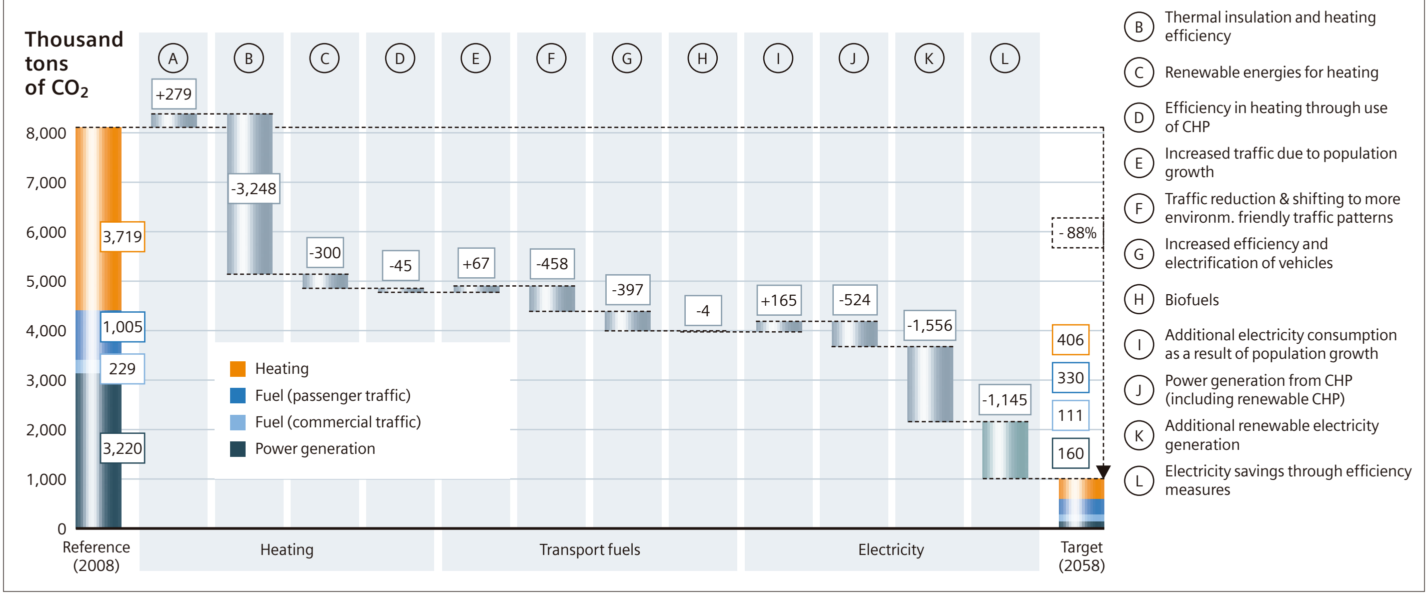
must be developed to improve the return on investment.

Increasingly state-of-the-art insulation will result in a dramatic reduction in heating needs – around 80 percent less within 50 years. Consequently, it will become much less cost-effective to operate the current district heating systems. On the one hand, heating demand will decrease, while at the same time the network will need to be upgraded – at considerable cost – in order to supply more citizens with the efficient heat produced by the heating and power cogeneration systems. This dilemma could be solved with new technology such as low-temperature networks, which would require significantly lower operating temperatures. In this type of network, surplus heat from industry could also be used. In addition, more cost-effective line and connection technologies could further reduce the cost of the district heating network, including new connections to the buildings.

→ **If all potential energy savings are fully utilized, most of the electricity needed can be produced from renewable and low-carbon resources. However, this cannot occur in the cities alone. The transmission of climate-neutral energy across long distances will require highly efficient, transnational networks.**

By mid-century, if all potential energy savings are rigorously utilized, enough power can be generated with renewable resources to meet most of the needs of a large city like Munich. The city will continue to draw a portion of its electricity from outside sources, such as from the major power plants in the region, in Germany, and even

CO_2 emissions reduction – "Target" scenario



Source: Wuppertal Institute, 2008

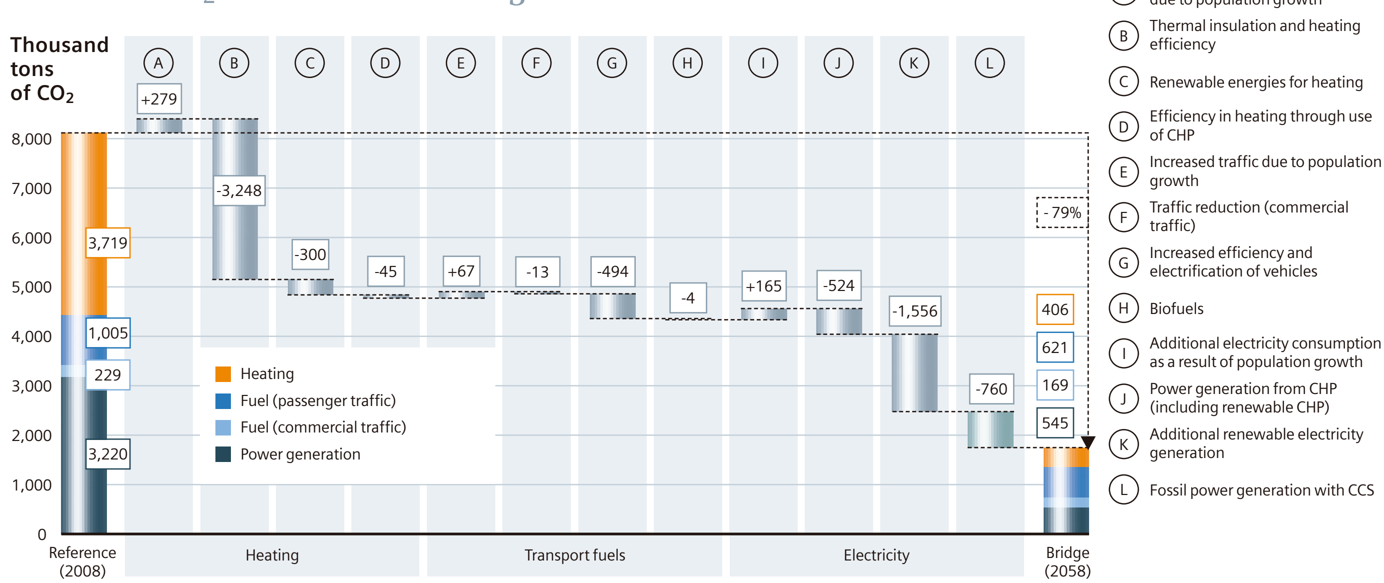
abroad. This electricity could be produced in large on- and off-shore wind parks in northern Europe, or in solar-thermal power plants in southern Europe and North Africa. A portion of the electricity could also be produced in low-carbon, coal-fired power plants that use carbon capture and storage (CCS). A prerequisite for the connection to these far-distant power producers is, for example, the construction of high-capacity, transnational, high-voltage direct current (HVDC) networks that can transmit electricity over several thousand kilometers with little loss. This technology is already available and well-established.

→ The use of cars can be reduced by creating compact residential settlements and through use of bicycles, buses, and rail wherever possible. In addition, electric vehicles can meet almost all the future needs of inner-city transportation for individuals. With the proper infrastructure in place, electric vehicles can also be used to store energy.

In 50 years, people could get around in Munich's inner city much more on foot, by bicycle, bus, or subway than is the case today. Information services, targeted to commuters' needs and delivered via their mobile devices, will simplify their use of the bus and subway system as well as the combination of different forms of transportation.

Traffic guidance systems ensure optimum route planning – from both an environmental and a cost perspective – for people and goods. Inner-city automobile transportation could be mainly via electric vehicles. A large part of the electricity needed would come from renewable power generation delivered by the public grid.

Reduced CO_2 emissions – "Bridge" scenario



Source: Wuppertal Institute, 2008

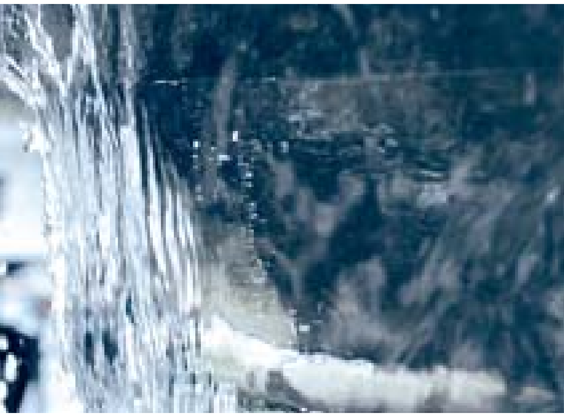
What does carbon-free mean?

Following the publication of the fourth assessment report, Climate Change 2007, by the Intergovernmental Panel on Climate Change (IPCC), the EU's environmental ministers defined more specifically what actions need to be taken: By the year 2050, global greenhouse gas emissions must be reduced by "more than 50 percent compared to the level in 1990." Globally, that corresponds to an emission of approximately 18 billion tons of CO_2 equivalents, or, with an assumed 2050 world population of nine billion, two tons of CO_2 equivalents per capita. That means that by 2050, industrialized countries will have to decrease their emissions by 80 to 95 percent from their 1990 levels. The underlying concept of this study rises to these challenges. Thus, Munich's economic, energy, and transportation systems which today – like nearly everywhere in the world – mainly rely on energy produced by burning carbon-laden fuels, must become significantly more efficient over the next 50 years. The energy needed at that point should be produced largely from renewable resources, in other words, carbon-free or at least low-carbon. The term carbon-free refers primarily to the electricity and heat supply to the population as well as to the transportation infrastructure. This study points out several important paths and technologies for achieving a carbon-free future. By no means does it assume that every kilowatt hour of renewable electricity that will be used in Munich will also be produced within the city's boundaries. Rather, it must be assumed that a portion of Munich's renewable electricity will be generated by sources outside the city. It is also important to note that not all greenhouse gas emissions were considered in the analysis; the study focuses only on energy-related CO_2, which accounts for approximately 80 percent of greenhouse gas emissions in industrialized countries and approximately 60 percent worldwide. The scope used includes all CO_2 emissions from heating systems and power stations in the city, the CO_2 emissions from electricity obtained elsewhere, and traffic emissions produced by Munich residents both within and outside the city limits. Air traffic was not considered, nor were emissions produced elsewhere in connection with goods and services provided to people and businesses in Munich. The study took into account changes in consumer behavior only if those changes resulted from introduction of new technologies or other necessary investment decisions. Also not considered were CO_2-offset possibilities, such as reforestation.

This would allow vehicles to serve as an integral component of the power supply network. Electric vehicles could function as energy storage devices, helping to manage the electrical load and balance the fluctuations arising from the increased use of renewable energy resources (such as photovoltaics and wind energy). At peak times, when the electricity is particularly expensive, the fleet of electric vehicles could return electricity to the grid, thereby partly compensating for the additional cost of their expensive batteries.

→ Individual low-carbon city districts could be created within just 30 years. The costs saved from more efficient heat supply in those districts would cover the long-term costs of energy optimization.

As indicated by the financial analysis of the model city district, optimizing the energy consumption of a settled district as well as an area of new construction could pay off within 30 years, even if the additional costs are significant. The study assumes that this model city district, with a future population of roughly 27,000 residents, will adhere to the passive house standard in its construction and that it will utilize a district heating system that obtains its heat from deep geothermal energy. Refurbishing existing buildings and building new ones according to the passive house standard (on top of the 2007 Energy Savings Ordinance, currently in effect) and developing the geothermal district heating supply system would cost some €177 million. But the energy savings would more than offset that cost. The study demonstrates that investing



in carbon-free heating systems not only significantly reduces emission, but – calculated over the lifetime of the facilities – the investment could also lead to annual cost savings.

➔ Focusing on the goal of a carbon-free environment opens up great opportunities for cities. Fundamental improvements to buildings and energy systems can save energy costs as well as provide financial impulses to the local economies. In addition, such advancements will help ensure that cities remain livable in the future.

This study presents the first comprehensive analysis of how a large city like Munich can become nearly carbon free within 50 years. It demonstrates that large-scale climate protection is currently feasible and even economical. Moreover, it shows that rigorously focusing on the goal of a carbon-free environment can completely alter a large city's buildings and infrastructure, thereby offering the metropolis, its businesses, citizens, and research institutes a valuable head start on the future. After all, the entire world will soon have to become a low-carbon society.

A carbon-free future – how experts view the challenges

Improving energy efficiency and developing energy-saving technologies are fundamentally necessary to curb rising CO_2 emissions worldwide and to protect mankind from the consequences of climate change. "Today, energy efficiency is a widely used planning parameter, and its importance is no longer disputed among experts – it is common sense," says Konrad Otto-Zimmermann, secretary general of ICLEI – Local Governments for Sustainability.

However, according to Otto-Zimmerman, investing in advanced technology cannot yet be taken for granted. "I believe that the shortage of natural resources worldwide will ultimately force the issue of energy conservation," he says. It is clear that climate protection will above all have to begin in cities. As the sustainability expert notes, municipalities worldwide have begun to do their homework. "In many countries, it is the individual cities which are already proceeding successfully with climate protection, while some national governments still fear that focusing on climate protection could put their domestic economies at risk."

Ottmar Edenhofer, chief economist at the Potsdam-Institut für Klimafolgenforschung (PIK—Potsdam Institute for Climate Impact Research), agrees that, from an economic point of view, there is no reason to delay climate protection. "Climate protection and economic growth are certainly compatible with one another," he says. However, economic growth must be decoupled from emissions. Edenhofer, who is on the board of the Intergovernmental Panel on Climate Change (IPCC), sees "no reason why economies must consume more energy in order to grow. In the past 150 years, labor productivity has risen more sharply than energy productivity. Now we just have to reverse that proportion." Edenhofer urges the implementation of climate-protection measures as quickly as possible – because mankind cannot afford a catastrophe.

He believes that, in addition to general improvements in energy efficiency, carbon capture and storage will prove to be an effective measure for climate protection. In his opinion, financial support for renewable energies is also an important way to help mankind move toward a carbon-free path. "We are seeing that, with a rise in the capacity of new renewable-energy systems, the cost per kilowatt hour is dropping dramatically." With that kind of progress, support for renewable energies is completely justified – "if it is intelligent."

Konrad Otto-Zimmermann adds that individuals will also increase their support for energy efficiency in the future. "Citizens generally react reasonably to reasonable requests. They will join in if everyone is joining in. But they need to understand what's expected of them." And for Otto-Zimmermann, what's expected is clear: "We must live with what nature provides us, without destroying it. Otherwise, we won't have a future."

The phrase "think globally, act locally" has been around for a long time, but it's as relevant as ever. Climate protection begins at home, and this is especially true for cities. Using two scenarios, this study demonstrates that the global goal issued by the EU environmental ministers in 2008 that, by 2050, greenhouse gas emissions in industrialized countries be reduced by at least 80 percent below 1990 levels may be a challenge for cities, but is definitely achievable. The first scenario – the "target" scenario – is highly consistent and anticipates a major increase in efficiency and CO_2 savings. The term "target" implies that the vision of a carbon-free environment within this 50-year period can actually come close to being achieved. In contrast, the "bridge" scenario takes a slightly less optimistic view of citizens' behavior – especially with regard to transport and electricity requirements. Fossil fuels will continue to meet the increased demand for electricity. The "bridge" scenario, however, also predicts that electricity generated from coal will emit much less CO_2 in the future thanks to carbon capture and storage (CCS).

By mid-century, the measures suggested by the "bridge" scenario would also reduce annual per capita emissions in Munich to approximately

2.0 Two paths toward the future – the “target” and “bridge” scenarios

1.3 tons of carbon dioxide – below the stipulated two tons. The term “bridge” indicates that the city of Munich will still be on its way to becoming a carbon-free environment by the middle of the century. Nevertheless, for both scenarios, the guidelines for achieving an appreciable reduction in CO_2 emissions are the same:

➔ High-efficiency energy applications – less energy is consumed to achieve the same level of convenience and utility.

➔ Adaptation of the heating, electrical, and transport infrastructure to accommodate a demand that has been reduced through greater efficiency.

➔ Extensive conversion to renewable and low-carbon energy sources.

➔ No expectation of self-sufficiency – the city of Munich will import some energy from the outside, while ensuring that this energy is generated in as climate-neutral a manner as possible.

Naturally, these scenarios can’t include every conceivable measure that would increase efficiency or reduce emissions. They do take into account, however, the most important technological tools – for example the use of renewable energies, efficient combined heat and power cycle (CHP) plants, electric vehicles, intelligent traffic guidance and building management systems, and passive house concepts. This study also considers changes in consumer behavior to the extent they are accompanied by the introduction of new technologies and the necessary investment decisions. It does not examine, however, how changes in behavior could or should otherwise influence emissions.

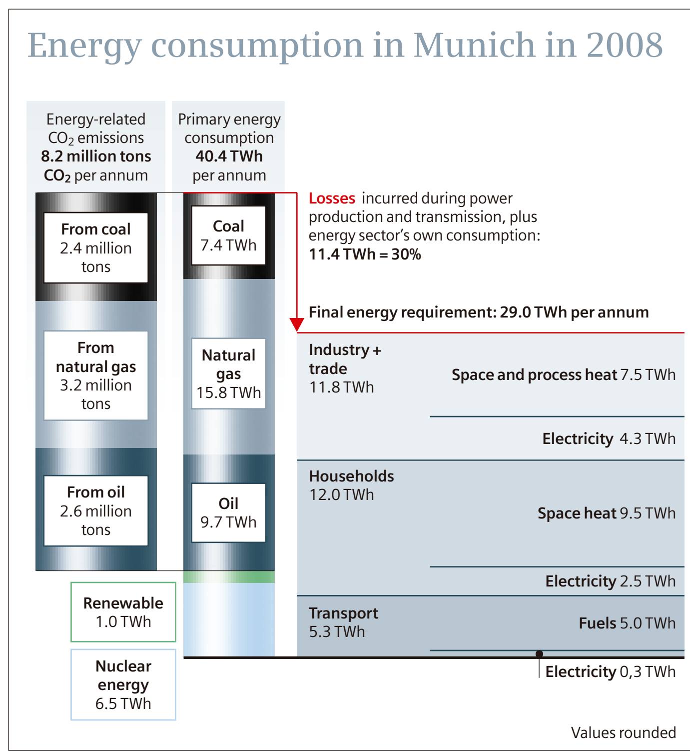
Specifically, the “target” scenario anticipates a much lower demand for electricity in the future. That will result from more efficient devices and technologies, intelligent building management systems, and energy-saving lighting systems. Decentralized, renewable plants should hereby meet most of the demand for electricity.

In the transportation sector, traffic avoidance measures are expected to shorten the routes traveled. At the same time, it would be possible to facilitate the shift from motorized private transportation to public transportation, bicycles, and foot traffic. An electric mobility strategy will also help to increase significantly the number of electric vehicles.

The "bridge" scenario, on the other hand, expects future per capita demands for electricity to remain at their current levels. It assumes that any efficiency gained through energy-saving technologies will be balanced out by the greater number of electrical devices and applications in households, the service sector, and industry. In the transportation sector, the number of trips per capita will remain the same, as will the percentage of motorized private, public, bicycle, and foot transportation.

The "bridge" scenario anticipates a lower percentage of electrically powered vehicles than does the "target" scenario. The "bridge" scenario as well expects a large portion of electricity to be generated in combined heat and power cycle facilities and to be produced on a renewable basis. Part of the electricity will also be supplied by fossil fuel-fired power plants with carbon capture and storage (CCS). There is no difference between the two scenarios, however, with regards to the energy efficiency of buildings in which the majority of final energy is used for heating. Both anticipate substantial savings in terms of the heating supply.

The extent to which efficient technologies are actually used depends primarily on their cost-effectiveness. This study assesses their economic efficiency based on individual examples.

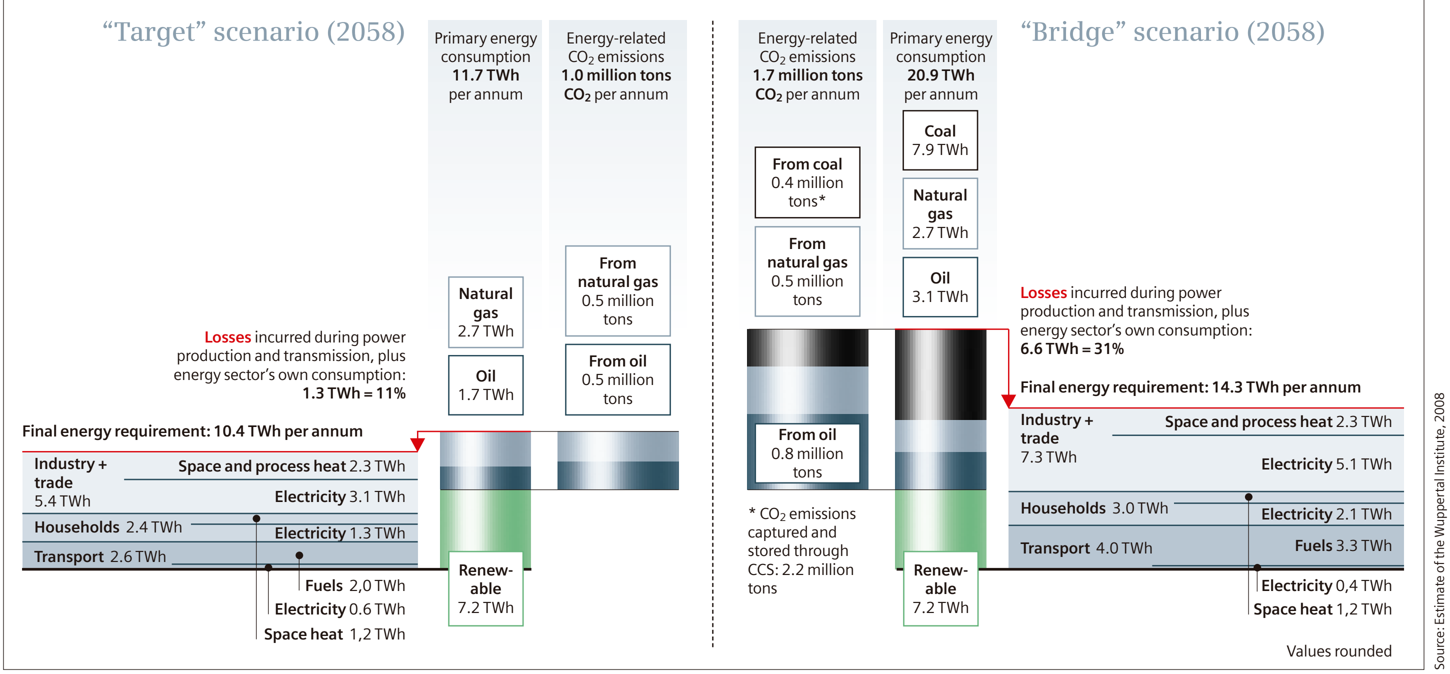


Source: City of Munich 2008; Stadtwerke München; Estimate of the Wuppertal Institute, 2008

It shows the level of additional investments required for energy-efficient technologies as compared to conventional technologies. It also shows the amount of energy cost savings that can be expected through the use of energy efficient technologies. This is especially challenging when considering a 50-year period because over time, technological development will bring about changes in the cost of efficient technologies, renewable technologies, and conventional energy production technologies. In addition, the economic efficiency of a particular technology differs greatly depending on how often or how many hours per year it is used. And thirdly, the economic viability of efficient technologies such as energy-efficient lighting, electric vehicles, and heat insulation depends directly on the development of electricity, oil, and gas prices. The huge fluctuations in crude oil prices in 2008 clearly demonstrated how difficult it is to make

[1] Primary energy is any quantity of energy in the form of gas, coal, or oil used to generate heat or electricity. Whenever this primary energy is converted to a usable form, losses occur – for example, due to consumption by the energy producer or during transmission. Final energy is the amount of energy available to the end consumer for heating or operating electrical devices.

“Target” vs. “bridge” power consumption scenario



long-term forecasts about the price of fossil fuels.

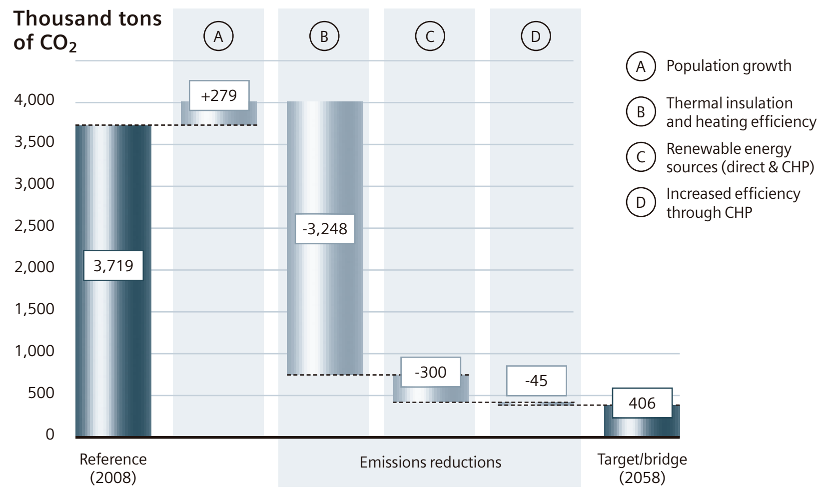
When discussing the development of energy prices, this study therefore uses two price paths to cover the range of forecasts up to 2058 – a high-price path and a low-price path. For the coming decades, the high-price path assumes on average a real annual 2.5 percent increase in the cost of heating oil and natural gas – from the current €0.08/kWh to €0.26/kWh in 2058. For electricity, it assumes a real annual growth rate of two percent – from the current average of €0.14/kWh to €0.36/kWh in 2058. By contrast, the low-price path anticipates a real increase in the cost of heating oil and natural gas of 1.5 percent, for a total of €0.16/kWh in 2058, and an annual real increase in the cost of electricity of one percent, for a total of €0.23/kWh in 2058. These figures are based on the Lead Scenario 2008 issued by the German Ministry for the Environment.

2.1 Heat requirements for buildings

Almost half of Munich's carbon dioxide emissions today are produced by building heating. That's why the refurbishment of buildings to improve their energy efficiency can go a long way toward helping reduce emissions. Given that the refurbishment cycle for buildings is about 50 years, it is extremely important to implement high-quality refurbishment based on the passive house standard.

While an inefficient refrigerator or freezer can easily be replaced, a badly insulated building shell cannot. The effects of today's refurbishment decisions therefore extend far into the future.

CO_2 emissions reduction in the heating sector



Source: Wuppertal Institute, 2008

Both scenarios are based on two important paradigm shifts that would permit a largely carbon-free heating supply by mid-century. The first shift involves energy optimization that could transform buildings from energy consumers into energy producers. It assumes that carbon-free buildings will cover most of their own energy requirements for room and water heating. This will be made possible by an optimization of the building shell that is primarily aimed at significantly reducing energy consumption, and by alternative energy sources such as solar-thermal energy, photovoltaics, and even mini-CHP plants. The second paradigm shift has to do with the heating infrastructure. In this case, the residual heating demand in carbon-free buildings would no longer be met directly by the combustion of fossil fuels in conventional heating systems. Rather, it would be met primarily by district heating or the use of local renewable sources such as biomass-fired thermal power stations and deep geothermal sources.

According to both the "target" and "bridge" scenarios, this would mean that, by 2058, Munich's energy requirements for space heat, process heat, and water heating would be at least 80 percent less than today's requirements.

It is assumed that these paradigm shifts will be brought about by the following measures:

➔ In the refurbishment of residential and service buildings, it is assumed that the passive house standard can be implemented almost across the board. To ensure that almost all buildings are made energy efficient within the next 50 years, the quota for thermal refurbishments will be increased from 0.5 to 2.0 percent per year. This means that four times as many building owners would be required to thermally refurbish their buildings than is currently the case. This will reduce the heat requirement of

refurbished buildings from the current level of approximately 200 KWh per square meter and year (kWh/m2/year) to a total of 25 to 35 kWh/m2/year.

➔ For new construction, the heat requirement could be even lower because a large percentage of buildings will actually be built according to the "plus energy" standard. Such buildings produce more energy than they consume. The heat requirement for new buildings will be 10 to 20 kWh/m2/year, way below the current standard of 80 to 100 kWh/m2/year. At the same time, the new buildings will be equipped with solar energy, enabling the majority to meet their own residual energy requirements, or even to feed excess energy back into the grid.

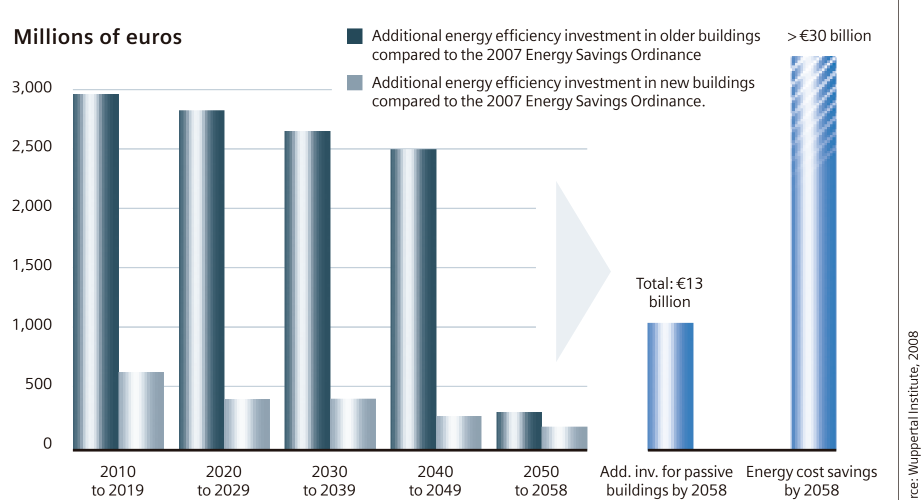
It is further assumed that most buildings – up to 85 percent of new construction and up to 80 percent of existing buildings – will be able to comply with these exacting standards. Only a small percentage will not be able to meet these standards for various reasons, for example, when the standards conflict with the specific uses of a building (such as an ice skating rink) or would violate the rules of historical preservation.

At the present time, a mere 1.5 percent of existing buildings are being refurbished in Germany each year. As long as there is no obvious damage, buildings and building elements such as windows and heating systems often continue to be used beyond their originally intended lifespan, thereby creating a refurbishment backlog that reduces the value of the building substance over the long term. Currently, only around 0.5 percent of German buildings are undergoing thermal refurbishment each year, despite the potential for substantial savings. Yet thermal refurbishments should be considered whenever a façade is due to be painted or an attic is being renovated. Because the building already will need a scaffold or its roof is being replaced, the added costs associated with an energy-optimized refurbishment will be lower. Furthermore, the added costs will be subsidized through programs from the federal government and the city of Munich. Another reason for thermal refurbishment is that such investments can pay off financially by making buildings more comfortable and easier to rent. And they can even bring in higher rents. The thermal refurbishment of existing buildings is now being promoted on the political level as well; the German Ministry for Building wants to achieve an annual thermal refurbishment quota of three percent.

This study assumes that the best available and usable standard will be applied for all the measures mentioned. Altogether, the average heat requirement of residential buildings in Munich will be reduced from the approximate current level of 200 kWh/m2/year to an average of 23 kWh/m2/year. By mid-century, this would reduce the heating requirements in Munich by 80 to 90 percent below the current level.

On top of this, the second paradigm shift

Additional investments for energy-efficient refurbishment and new construction in the housing sector



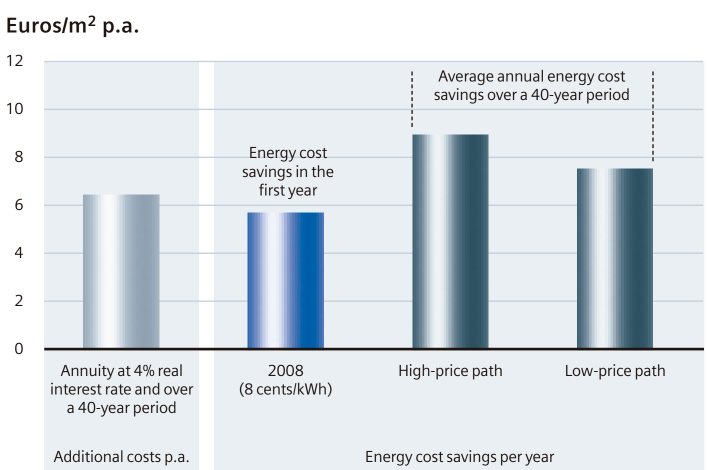
Source: Wuppertal Institute, 2008

would entail infrastructure changes that would affect the provision of heat energy. By mid-century, four-fifths of the now drastically reduced heat energy demand could be met by district heating systems. These systems are much more efficient, thanks to the combined generation of electricity and heat. Most of the remaining heat energy, which would still be generated decentrally in the buildings, could come from renewable sources such as solar-thermal energy. The two strategies would reduce the corresponding CO_2 emissions to just under 400,000 tons, or about 300 kilograms per capita per year – which is about one tenth of the current level! The subsequent increase in the number of district heating customers – and thus in the number of costly service connections – would pose a tremendous challenge for heat suppliers. On the other hand, the heat requirement per household – and thus the revenues – would shrink considerably. This study presents possible solutions in Section 2.4, "Heat supply."

Economic efficiency analysis: Of course, the insulation and thermal refurbishment of buildings to meet passive house standards is not without its costs. And the construction of new, passive buildings, not to mention "plus energy" buildings, also requires additional investments. Compared to standard construction according to the 2007 Energy Savings Ordinance, the added costs are considerable. The financial outlay still pays off, however, as demonstrated by the economic efficiency calculations below. Over time, the savings far exceed the initial investment, thanks to a markedly reduced expenditure on natural gas and oil. According to the detailed economic efficiency assessments shown below, ushering in a carbon-free Munich would require that, by mid-century, the city and its inhabitants contribute a total of about €13 billion more than it would be required for refurbishments and new constructions under the 2007 Energy Savings Ordinance. The investment would go toward the energy-efficient refurbishment of buildings to meet the passive house standard and to the construction of new passive and "plus energy" buildings. Applied to the total population of Munich, this would mean an additional annual cost of €200 per person. The additional investment could result in savings of around 10 billion kWh final energy by 2058. Based on the heating costs that the end user is expected to be paying in 2058 (16 cents/kWh for the low-price path and 26 cents/kWh for the high-price path), the annual cost savings for final energy in the building sector would then be around €1.6 billion and €2.6 billion respectively. That would amount to a per capita savings of about €1,200 and €2,000 respectively. Altogether, energy cost savings over the entire period up until 2058 would be over €30 billion.[2]

In the following text, this study presents two detailed economic efficiency analyses. The first is for new buildings that follow the passive or

Economic efficiency of new, passive buildings
(8% additional costs compared to the 2007 Energy Savings Ordinance)



Source: Wuppertal Institute

[2] Nevertheless, it must be noted that these additional investments are based on the current EnEV 2007 standard. Future upward adjustments of the standard which would reduce the added costs are not taken into account, nor is the interest rate. The calculation of final energy savings was also based on the 2007 Energy Savings Ordinance standard.

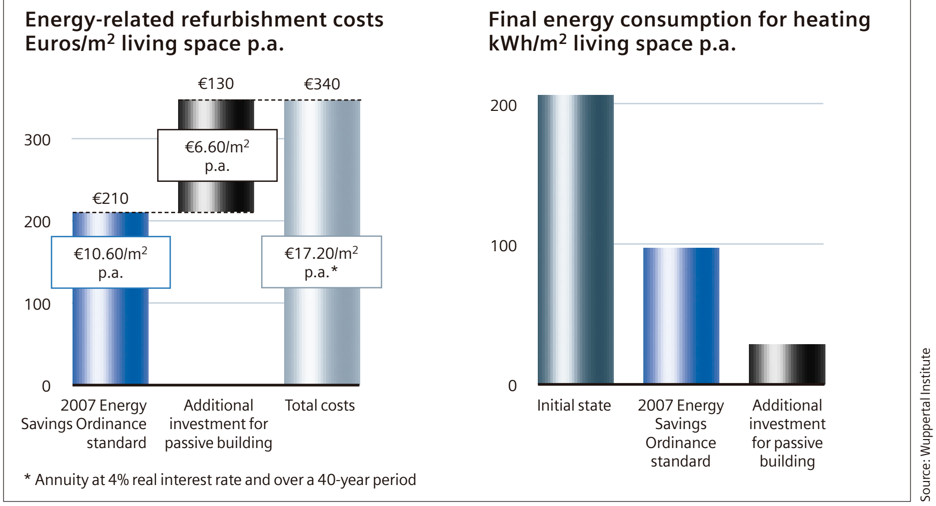
"plus energy" house design instead of the 2007 Energy Savings Ordinance. The other is for existing buildings that are refurbished to meet passive house standards.

1. Worth the cost – passive house and "plus energy" buildings: Passive and "plus energy" are the building designs of the future. Both are highly efficient, superbly insulated building types that drastically reduce heat and energy requirements. Energy consumption in passive buildings is already exceptionally low, but the plus energy concept takes it one step further. Not only do these structures use no additional energy, but they are designed to generate enough electricity and heat using solar systems, for example, to allow them to feed net energy back into the grid.

Thanks to the excellent insulation of the walls, ceilings and triple-glazed or vacuum-insulated windows, passive buildings lose almost no heat in winter. The main source of passive heating is the sun's radiation through the large window areas. Consequently, a very small heating system is all that is required for these buildings, and most get by without any conventional heat. They are instead equipped with heat recovery ventilation systems. Such systems are operable only in airtight buildings because they recover heat from the stale, warm air in the room and transform it to fresh, incoming air by means of a heat exchanger. As initial construction projects have demonstrated, retrofitting existing buildings with these systems is possible but expensive.

Modern systems can recover up to 90 percent of the heat. When the vents are installed in the soil, the air can also be preheated. Such houses can be heated with less than 15 kWh/m²/year.

Refurbishment costs and final energy consumption
(when refurbished to near passive building standard)



* Annuity at 4% real interest rate and over a 40-year period

Best Practice

Passive house and building refurbishment

Even though the passive house standard has long been considered to be state-of-the-art, it's not yet common practice for new construction and refurbishment. There are several reasons for this. First, many building owners lack investment capital, while others shy away from tying up capital for a longer period of time. On the other hand, landlords hesitate because they can't always pass along the added refurbishment costs to their tenants. Another stumbling block is the fact that many craftsmen, planners, and consultants are not familiar with the passive house standard. Nevertheless, there are now numerous examples that show how energy efficiency measures can be executed on a grand scale – even when the passive house standard is not applied from the very beginning; instead, only individual efficiency technologies are used. The city of Munich already introduced its "Energy Savings Concept for 1,000 Buildings" program in 1998, designed to improve the energy efficiency of 50 percent of all municipal buildings. The program's main purpose was to make improvements that could be implemented quickly and would pay off over the short term, such as replacing boilers and pumps. The results show that these individual measures alone reduced CO_2 emissions by 13 percent per year. The annual cost savings are €2.2 million, and the average amortization period is only 4.5 years. In other refurbishment projects, the city of Munich achieved even greater gains in efficiency. The primary school at Agilolfingerplatz is one example. The project included insulating the ceilings on the upper floors, refurbishing the flat roofs and heating systems, and installing energy-efficient lighting and a building management system controller, as well as biomass and solar systems. To preserve the outside walls' historical façade, only the heater recesses, jamb walls, and foundation slabs in the basement were heat-insulated. Yet, the energy savings and CO_2 reductions were still considerable. Despite a slight increase in electricity consumption, CO_2 emissions were reduced by 43 percent.

The city of Frankfurt am Main wants to take things even further. It passed a council resolution that requires the city and, in particular, the housing association in which the city owns a majority interest, to impose the passive house standard for all new municipal construction as well as for public-private partnership projects and refurbishments. Only in exceptional cases may buildings be built or refurbished to a lower efficiency standard. In any event, the standard is 30 percent more energy efficient than is currently required by the 2007 Energy Savings Ordinance. This makes Frankfurt one of the first municipalities and one of Germany's first major building owners to routinely use the passive house standard as the building design to be aspired to today.

The "Meer met Minder" (More with Less) program sponsored by the Dutch Ministry of the Environment, Energy, and Housing is another impressive example of an energy savings campaign that applies to all segments of the population working in construction and refurbishment. The campaign relies on vigorous public outreach to convince private homeowners that energy efficiency measures pay off. It includes craftsmen's trade associations, which can participate in relevant training courses as part of the project. The government's 2020 goal is to reduce by one third the final energy requirement in approximately 2.5 million houses and apartments. Measures include the installation of efficient appliances as well as solar systems and building insulation.

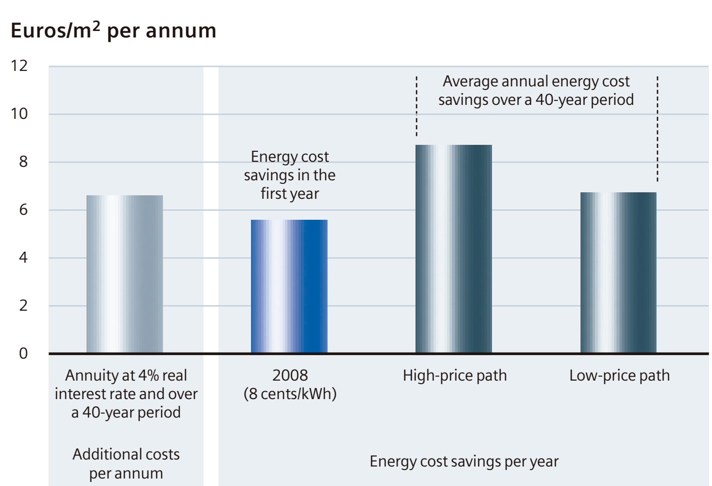
For houses built to the 2007 Energy Savings Ordinance standard, the average rate is about five to six times higher.

Based on past experience, this study assumes that new construction built to the passive house standard is on average about 8 percent[3] more expensive than that built to the 2007 Energy Savings Ordinance standard. If these additional investments are applied on an annuity basis to a depreciation and credit period of 40 years at a real interest rate[4] of four percent, the result is an additional annual cost burden of around €6.50 per square meter[5] for the passive building. This is balanced by an energy cost savings of almost €6 per square meter during the initial year of investment. For the high-price path, the average energy cost savings[6] over the 40-year period are around €8.80 per square meter; for the low-price path, it is €7.40 per square meter. The additional investment in a passive building is thus certainly attractive, even if the energy cost savings during the first five to eight years are less than the additional charge incurred through a suitable loan.

The additional costs can also be substantially reduced through interest-subsidized loans from the Kreditanstalt für Wiederaufbau, KfW, (Reconstruction Credit Institute) and through public subsidies for thermal solar systems and wood pellet systems.

2. And how much more does it cost to refurbish an older building to meet the passive house standard? To calculate the additional costs for refurbishing an older building to passive house standards, this study uses a refurbishment according to the currently valid 2007 Energy Savings Ordinance standard as the basis. The additional costs depend on the type of house (for example, a single-family or multi-family dwelling), its age, and the structure of the building shell.

Economic efficiency of the refurbishment of housing stock (< 35 kWh/m²)



Source: Wuppertal Institute

[3] The construction of a new passive building generally results in additional costs of 0 to 16 percent compared to the current EnEV 2007 standard. The study takes the mean value as basis. [4] The real interest rate is the nominal interest rate minus the average long-term rate of inflation. [5] Of course, it is highly unlikely that anyone would actually take out a loan for a period of longer than 30 years. Nevertheless, the advantage of the 40-year perspective is that the annual charges from interest and repayment can be compared to the average savings on energy procurement, starting from the time of the building's construction, throughout its technical lifespan, all the way to its first basic refurbishment. [6] Discounted mean value.

The first step was to determine the costs of a thermal refurbishment at the 2007 Energy Savings Ordinance level, which corresponds to an average annual heat requirement of about 100 kWh per square meter of living space. The second step was to calculate the additional costs for more extensive refurbishment measures. This yields an annual heating energy requirement of less than 35 kWh/m2 – which is close to the passive house standard. The overall investment costs for thermal refurbishment are on average around €340 per square meter. Of this amount, almost €130 per square meter are additional investments that exceed the 2007 Energy Savings Ordinance standard. Those additional investments can lead to an even greater annual savings of 70 KWh per square meter as compared to a refurbishment based on the 2007 Energy Savings Ordinance. If the additional investment of almost €130 per square meter for the more extensive refurbishment is taken out as a loan with a real interest rate of four percent and a loan period of 40 years, this yields an annual cost burden of €6.60 per square meter of refurbished living space. At a final energy price of eight cents per kilowatt hour, these costs are offset by initial savings of €5.60 per square meter. Throughout the life of the refurbishment measures, this yields an average of €8.50 per square meter for the high-price path, and €7.10 per square meter for the low-price path.

Technology outlook — Building insulation

Building insulation is the most important tool for reducing CO2 emissions in Munich. Until now, the main type has been exterior insulation which is, for example, affixed to the exterior walls using special mortar. The most common exterior insulation materials currently in use are polystyrene, polyurethane, and mineral fiber panels. However, at a thickness of 30 centimeters, the panels are very large and heavy. In the future, there will be a lighter alternative – thin vacuum insulation panels (VIP) that can be prefabricated as large units and mounted on-site onto the building wall using a fastening system. This would reduce both the time and labor costs. VIPs are relatively new but have already been tested in various pilot projects. Each panel has a vacuum core that conducts very little heat. That's why extremely thin VIPs can provide excellent thermal insulation. VIPs with a thickness of 3.5 centimeters insulate just as well as 30 centimeters of sturdy polystyrene.

Micro-encapsulated latent heat storage or phase change materials (PCMs) are another option. To a large extent, PCMs are already technologically mature. They are mainly used for passive air conditioning of rooms, and are mostly in the form of a wax that can, for example, be incorporated in plasterboard or paint. The wax changes from a liquid to a solid depending on the temperature. When the temperature rises, it melts and absorbs more heat. Toward evening, it solidifies and emits heat. Thus, during the day it passively cools the building by drawing heat from the rooms; but during the night, it emits heat with the aid of a ventilation system. This makes PCMs ideal for refurbishing structures built with lightweight materials and buildings with large glass façades. PCMs can significantly reduce the workload of air-conditioning systems, or even eliminate the need for them.

2.2 Electricity demand of buildings

Electrical power is essential for our everyday lives. The coffeemaker, the kitchen stove, the office copier – electricity is needed for hundreds of different uses. Considering how many electrical devices have entered our lives in just the past few years – from leaf blowers to DVD players to cell phones – it is reasonable to assume that there will be a great deal more in the future, many of which are still unimaginable today.

The total electricity consumed by households, trade, industry, commerce, services, and transport in 2008 was responsible for about 39 percent of all CO_2 emissions in Munich. Without appropriate measures, this percentage is expected to increase in the future. Two basic factors determine the amount of CO_2 emissions produced when electricity is generated: the demand for electrical energy and the generation of the electricity itself. At this point the demand side of the transaction is examined.

Paradigm shift to greater efficiency: The "target" scenario assumes that the use of electrical energy in buildings will be much more efficient in the future. Despite additional uses for electricity, future energy consumption in households and offices will be about 40 percent lower than at present. The "bridge" scenario, on the other hand, predicts that energy savings in buildings will be less significant and will mostly be canceled out by the addition of new uses for electricity. As a result, the electricity requirements per inhabitant will remain the same despite increased efficiency. A recent study by the Federation of German Industries (BDI)[7] came to a similar conclusion. It assumes that by 2030, electricity consumption in Germany will decline only slightly – to 255 billion kWh (compared to 267 billion kWh in 2004). According to the BDI study, the reason why there will only be a slight reduction is the further introduction of various electrical appliances into households. At the same time, however, the average efficiency of these devices will be closer to the current state of the art.

The list of possibilities for saving electricity and improving device efficiency is just as great as the diversity of ways to use electricity. The following measures promise to be the most effective:

→ Use of more efficient household appliances and office equipment
→ Use of more efficient lighting
→ Optimization of building management and air-conditioning systems

Already today, just by the use of an intelligent building management system – especially one for heating, air-conditioning, and lighting – up to 30 percent of electricity in large buildings can be saved. Buildings can be retrofitted with these technologies at any time, without costly refurbishing. The backbone of these systems is their use of sensors. Thanks to these sensors, electric-

[7] The BDI study is based more on a business-as-usual scenario. The "target" scenario, however, assumes that the general framework of energy policy will be weighted more heavily in favor of energy efficiency.

ity-draining applications are activated only when necessary. Today, on the other hand, many systems operate continuously. For example, lighting and heat pumps often remain on all day long. In “smart buildings,” motion sensors activate lighting only when rooms are actually occupied. CO_2 sensors in offices measure how stale the air is and instruct the ventilation system to circulate controlled amounts of fresh air as needed. Room thermostats allow for individual temperature adjustments in each office.

Air conditioning and ventilation are still responsible for about 20 percent of electricity consumption in office buildings. Such consumption can be significantly reduced through appropriate planning, an integrated approach to building design, and new technologies. It is especially important to start planning early in the building process. This allows planners to configure the building or shading devices so that rooms heat up as little as possible. Cooling requirements can also be reduced through the use of efficient electrical devices, servers, and lamps that emit very little heat when in operation. There is also a wide range of technical solutions and new concepts for efficient cooling. Ventilation systems are already being designed to cool buildings by drawing in fresh air during the night and morning. In other buildings, the rooms are no longer cooled by traditional air conditioners but by water pipes. Cold water flows through the ceilings and provides pleasant cooling from above. Even the waste heat from cooling systems can be used – for example, to heat service water.

This makes it possible to eliminate conventional central air conditioning systems with their large noisy fans that constantly blow cold air from electricity-draining air conditioners. Ingenious building management systems that manage the large number of parameters and coordinate all the subsystems have been available for

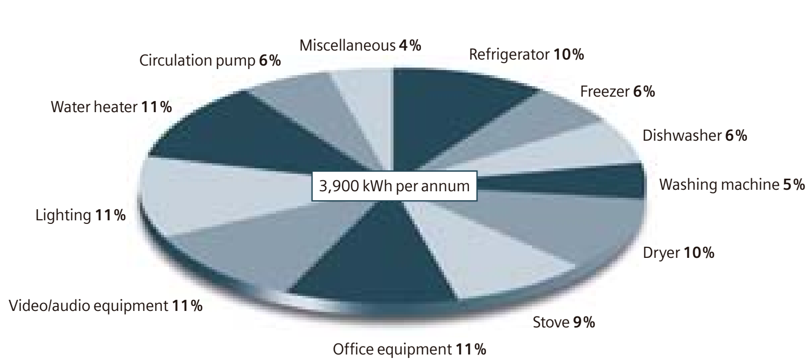
quite some time. With water cooling, even temperature differences within the same building can be easily and efficiently adjusted. Often, a building's upper floors are very warm while the lower floors tend to remain cool. In this case, water cools the upper floors, becomes warm in the process, and flows back down to emit the stored heat into the cool rooms.

Besides energy consumption in buildings, this study looks at how industry in metropolitan area of Munich consumes electricity. Because the manufacturing industry adds relatively little to local value, and industry consumes less than a quarter of the total electricity, its overall contribution to electricity savings is limited. But in individual cases there are still considerable savings potentials that can be exploited – for example, industrial motors that drive machines, conveyor belts, pumps, and blowers. Many of these motors operate inefficiently because they are incorrectly designed and their rotational speed cannot be adjusted to performance requirements. That means that they always run at the same speed even when full power is not required. Thanks to modern frequency converters, however, motors can now be controlled more efficiently. The proof can be found in state-of-the-art, energy-efficient motor concepts that can achieve savings of over 40 percent compared to conventional standard motors. However, electricity consumption is not dependent on the motor alone, but on the entire powertrain, which comprises several components. Depending on the plant, electricity savings of 60 percent or more can be achieved. Given that drive technology is responsible for about two-thirds of industrial electricity requirements, it is clear that industry also offers tremendous opportunities for improving efficiency.

Economic efficiency analysis: Despite the fact that efficiency solutions are extremely diverse, they are all subject to the same proviso – they will be used only if they pay off. To illustrate this point, economic efficiency analyses based on two examples are presented here. Unlike buildings, which have an average refurbishment cycle of 50 years, the electricity sector has a lifespan of 10 to 20 years, depending on the technology. Consequently, the technology used must pay off within this time period. Because it is extremely difficult to assess the cost of efficient devices in the future, the two analyses presented here are based on technologies that are already available on the market.

Example from a private household – the efficient refrigerator: Refrigerators are currently responsible for about 10 percent of household electricity consumption. They thus definitely warrant the use of efficient technology. Actually, the energy consumption of refrigerators and freezers has already been substantially decreased in the past. An EU Efficiency Class A++ high-efficiency refrigerator without a freezer

Current distribution of electricity consumption in a typical, three-person household
(without night storage heaters)

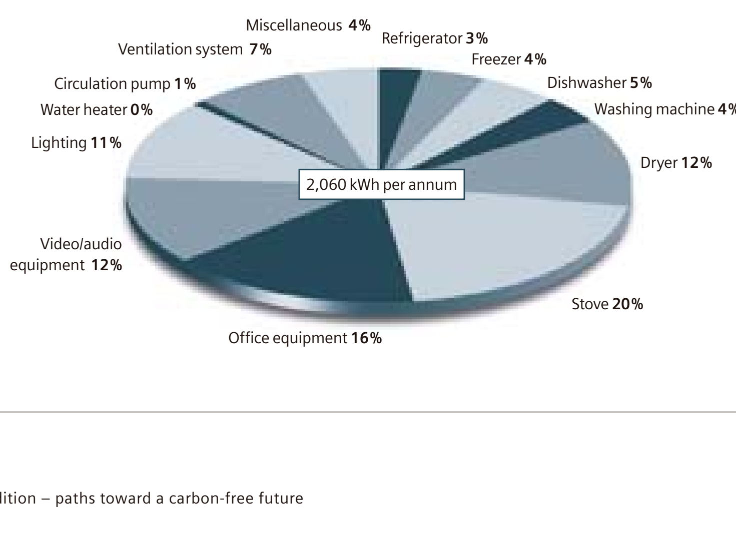


Source: Wuppertal Institute 2008

compartment currently consumes about 80 kilowatt hours per year. A combination refrigerator/freezer in the same class uses about 180 kWh. By comparison, a Class A refrigerator without a freezer compartment uses about 160 kilowatt hours of electricity and a Class A combination refrigerator/freezer uses as much as 320 kWh per year. But high-efficiency A++ appliances today account for barely five percent of the market. There are several reasons for this. First, it took a while most retailers generally offered these devices for purchase. Second, many buyers are unfamiliar with Efficiency Class A++. Some buyers shy away from the higher price, while others have no means of balancing the electrical cost savings against the higher price. As the calculations below demonstrate, purchasing these appliances would still be more economical, even though A++ appliances are generally much more expensive.

Compared to a Class A appliance, the additional cost for a Class A++ combination refrigerator/freezer is estimated here to be €250. Based on the A++ appliance's average service life of 15 years, the additional cost averages out to €26 per year (at a real interest rate of four percent). The annual savings on electricity would already be €28 in the first year. With annual electricity price increase, the extra cost of the Class A++ combination refrigerator/freezer would be more than recouped by the end of its service life.

Distribution of electricity consumption in an efficient, three-person household



Source: Wuppertal Institute 2008

Example from an office building – efficient lighting: Efficient lighting means more than just energy-efficient or fluorescent lamps. It includes a number of components. When planning proper lighting, it is first necessary to determine the brightness, or lighting level desired. The next step is to determine which luminaires, lamps, and ballasts will be needed to achieve this lighting level in a room, based on its particular design.

Finally, daylight must be factored into the lighting concept. Artificial lighting is switched on by means of a daylight sensor. In addition, presence detectors ensure that the lighting is activated only when the room is actually occupied. Today, a number of lighting technologies are available which are much more economical than traditional light bulbs.

In addition to the usual energy-efficient lamps, state-of-the-art, high-intensity discharge lamps (HIDs) used to illuminate department store display cases and factory assembly lines are also a possibility. Whereas conventional light bulbs generate about 10 lumens per watt, energy-efficient lamps generate 80 lumens per watt and HID lamps, up to 140 lumens per watt. The problem is that HID lamps still generally contain mercury. Researchers are working diligently to create variants that don't require heavy metals.

New lighting types are based on an element made of ceramic, which is more robust and has a higher light yield. In addition, energy-saving light-emitting diodes (LEDs) have become

Best Practice

Energy performance contracting

What can be done when intentions are good but the money for energy-efficient technology and new heating and ventilation systems is lacking? One solution is energy performance contracting: An energy service company or ESCO (contractor) is contracted to finance, plan, and implement energy-saving measures. The ESCO also guarantees the client energy and cost savings of a contractually stipulated amount. The contractor is then paid back out of these energy savings. At the end of the contract period, the full amount of the cost savings reverts to the client.

This system works even when a large number of buildings must be refurbished with very little capital. One example is the "Energiesparpartnerschaft Berlin" (Berlin Energy Efficiency Partnership). By 1995, Berlin had decided to thermally refurbish its public properties with the support of a consulting firm. Energy-saving measures have so far been put into effect for about 500 properties. To execute the measures, private ESCOs invested around €60 million, including maintenance costs. The result was a 25 percent reduction in energy costs in schools, day care centers, universities, administrative buildings, and public swimming pools. Annually, the savings amounted to €11 million. Out of this amount, €2.9 million will be paid into Berlin's budget by the end of the contract period. After that, Berlin will benefit from the full amount of the savings.

Energy performance contracting is also suitable for projects that strive to implement most of the available savings potentials, as demonstrated by the Solar & Spar (solar and save) concept. This citizen contracting model financed the energy-saving refurbishment of several large schools in North Rhine-Westphalia. For each of these projects, a large number of private investors committed to financing a concrete refurbishment program as well as the construction of a large-scale photovoltaic system. The private investors will share in the energy cost savings. Four schools were refurbished and equipped with new building technologies at a total cost of more than €3 million. This included the installation of large-scale, photovoltaic systems and efficient lighting systems; the improvement of heating systems (including heating cycles and control engineering); the refurbishment of ventilation technology and controls; and the construction of block heat and power plants. These investments made it possible to achieve electrical cost savings of at least 50 percent and to generate about 120,000 kWh of solar energy per year for all of the projects. Savings were also achieved in the area of heating. In 2007, the four schools were able to reduce energy costs by a total of €400,000 and were able to earn an additional €60,000 from the sale of solar electricity. The schools' CO_2 emissions were reduced by 80 percent.

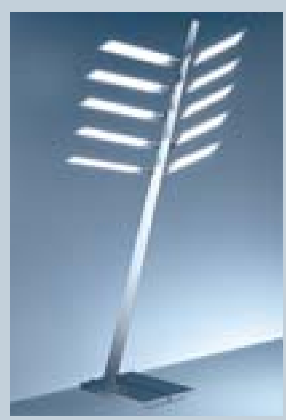
established on the market as bicycle or flashlight bulbs and in the taillights of cars and trains. Their brightness still doesn't compare to that of really bright lights, such as HID lamps. New LED materials or a new LED design, however, will make this goal attainable within the next few years.

The following economic efficiency analysis for an office space measuring 60 square meters shows how much energy is saved through efficient lighting. Dual-element prismatic diffusers without a mirrored base but with conventional luminaires and ballasts previously illuminated the room. A total of 12 prismatic diffusers were used. In our example, these lamps are replaced

with efficient, single-element T5 grid lamps, a new generation of very thin, energy-efficient fluorescent tubes with electronic ballasts that reduce electricity consumption by 75 percent. In addition, a sensor measures the daylight so that only enough artificial light is activated to achieve the exact lighting level desired. Depending on the amount of daylight and the room's utilization period, utilization time can be reduced by several hundred hours per year. The initial additional cost for efficient lighting is more than offset. In the case of the high-price path, €6,300 are saved over the entire lifespan; with the low-price path, savings are still at least €5,450.[8]

Technology outlook

OLEDs



In addition to conventional, light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs) are another very promising energy-saving lighting technology. OLEDs contain thin layers of special organic molecules that light up even when exposed to a low electric current. What's fascinating about this technology is that these organic molecules can also be applied to glass or even to flexible surfaces such as plastic. This makes OLEDs extremely flat area light sources that can even be flexible and transparent. They open up completely new areas of application, such as illuminated billboards, emergency signs, and guiding lights for stairs. For interiors, possibilities include new decorative lighting elements on walls and windows, integrated ceiling lights, or even colored room dividers. What's more, OLEDs are also extremely energy efficient. Today, they're already much more efficient than conventional light bulbs, and in the future they will even surpass compact fluorescent lamps. The challenge is to move from laboratory-scale production to industrial production. Researchers are also working on improving OLEDs' efficiency and lifespan. The first applications for OLEDs, including small cell phone displays, are already on the market.

[8] Amortization for all the measures was calculated over a 20-year period (technical service life of the lighting). In our example, investment costs of €2,900 are offset by annual electricity cost savings of €525 in the first year (four percent real interest rate). These annual electricity cost savings increase in line with the forecasted increases in the cost of electricity.

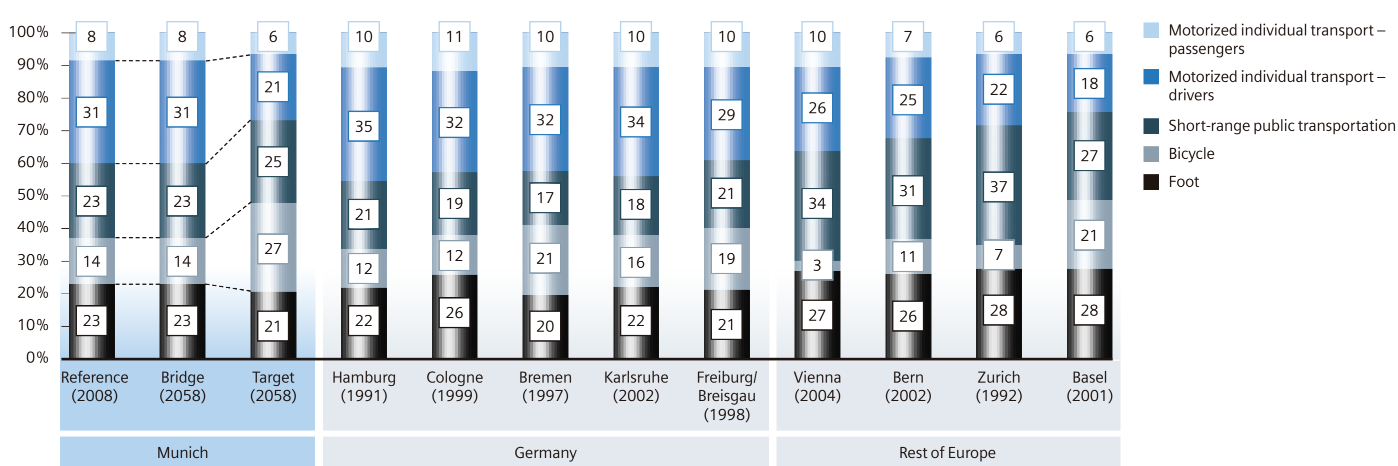
2.3 Transportation

In Munich today, traffic contributes about 15 percent of all CO_2 emissions. About 12 percentage points of this are from passenger traffic, and three percentage points from freight traffic.[9] Compared to other German cities like Hamburg or Cologne, short-range public transportation and foot traffic also play a relatively large role in Munich. But a comparison with major Swiss cities or Vienna makes it clear that the potential of public transportation and non-motorized traffic in the city is far from exhausted.

This study examines the mobility of Munich's population, excluding air transportation. It includes trips that are entirely within the city, but also some that have their origin or destination outside the city, or that are completely outside the city. Thus the analysis even includes travel to vacation destinations. In general, the study assumes that Munich residents will have mobility needs at mid-century that are similar to those of today.

Paradigm shift toward greater efficiency: Both scenarios assume that energy efficiency in motorized individual transport (MIT) and short-range public transportation will rise considerably. For example, it is assumed that the energy consumed by vehicles with internal combustion engines will decrease by about 40 percent, to an average of less than five liters per 100 km (gasoline/diesel). Calculations show that even today a systematic use of low-fuel-consumption technology could reduce total consumption by the motor vehicle fleet by about 50 percent. The range of potential areas for savings is great. It includes lower weight, downsizing, optimizing transmissions, power train, and air resistance as well as low-resistance tires. The increasing use of diesel engines also increases the efficiency of the motor vehicle fleet. Efficiency gains in public transportation, in turn, can be achieved by such means as technical measures to reduce vehicles'

A modal split comparison: Munich vs. other cities[10]



Sources: Socialdata, no year given; Wuppertal Institute 2008

[9] The figures here refer only to fuel, while the electricity consumed in the transportation sector is included under the power generation sector. Emissions from electricity, however, are included under transportation.

[10] The modal split data for the comparison cities come from Socialdata, whose survey design differs significantly from the "Mobility in Germany 2002" survey ("MiD 2002"), which provided an important basis of data for the present scenario. Among other methodological differences that cause systematic differences between the results of the two surveys, Socialdata's studies include only trips of less than 100 km by a city's residents. For these reasons, the Munich data had to be adjusted for the comparison of cities, although these adjustments were not applied for other analyses. Consequently, the modal split for Munich is different in the city comparisons than in other graphs. In the city comparisons, bicycles account for 14 percent of all trips (under 100 km), while the MiD survey found only 11 percent (of all trips) for Munich.

electric power consumption. By recovering braking energy, rail vehicles can today already save as much as 25 percent on electricity. With this technology, braking energy is converted to electricity and fed back into the grid. Lightweight construction can also save about 30 percent in energy compared to conventional subway, commuter train, and tram vehicles. Oslo, for example, has recently started using new "metro cars" that are equipped with sophisticated drive and brake management. In addition, a special aluminum construction makes the cars particularly lightweight. All in all, these metro cars are about one-third more efficient than their forerunners, which were already quite efficient. Highly integrated drive systems that are fastened under the vehicle floor represent another solution for saving weight in trains. These include a newly developed bogie for rail vehicles that incorporates the entire drive system, including the brake unit, and works without a transmission. All this makes it about one-third lighter than conventional models. In all, about two metric tons can be saved in weight, and about 20 percent in energy.

The second fundamental paradigm shift assumed in this study is the electrification of motorized individual transport. When electrical energy comes from low-carbon generation, there is further potential for CO_2 savings. Another paradigm shift is reduce traffic, and shifting it from MIT to lower-carbon or carbon-free alternatives. Here there are substantial differences between the two scenarios. While the "target" scenario avoids and also shifts traffic, the travel patterns in the "bridge" scenario do not differ from those of today.

The assumed paradigm shifts can be brought about by a whole set of measures. The most important are:

➔ Careful urban and land use planning for new construction projects, with appropriate changes in existing districts, would make it possible to organize the infrastructure in such a way as to shorten trips and keep the number of trips stable. As described in the section on the model city, this can be enabled by such means as combining residential, trade, commerce, and service uses in one place – in other words, the mixed use of urban areas. Of course, this type of planning is easier to implement in new districts being constructed than in existing urban areas.

➔ In planning traffic infrastructure and the associated investments, priority should be given to short-range public transportation and to pedestrian and bicycle traffic. There would be more such infrastructures in a carbon-free Munich than today.

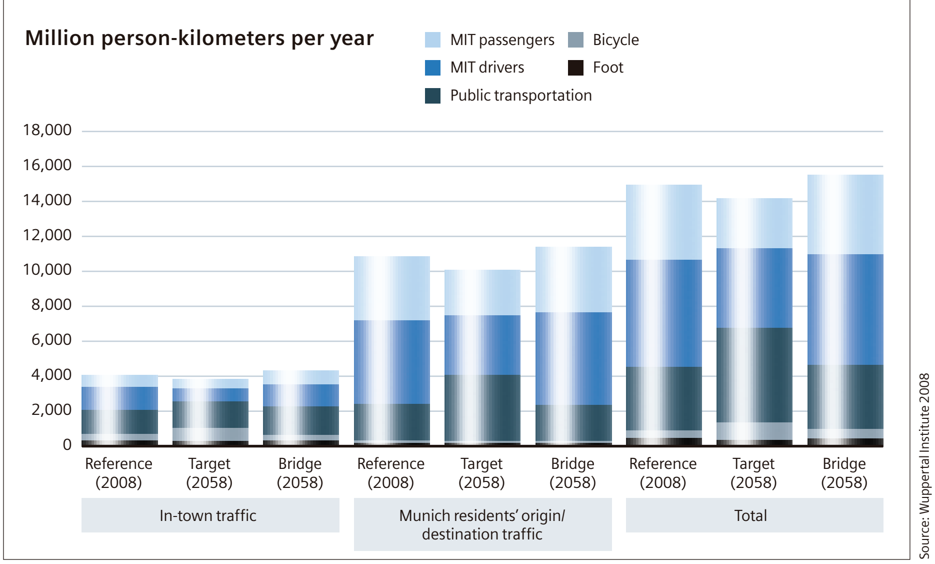
➔ Traffic control measures such as road pricing or a city toll system are also conceivable. The toll system of 2058 would favor the use of low-emis-

sion vehicles. The result would be that motorized urban traffic would primarily involve smaller, more efficient vehicles and electric vehicles. → So-called "Inter-modal" traffic management and customized mobility information would make the various means of transportation easier to use and to combine.

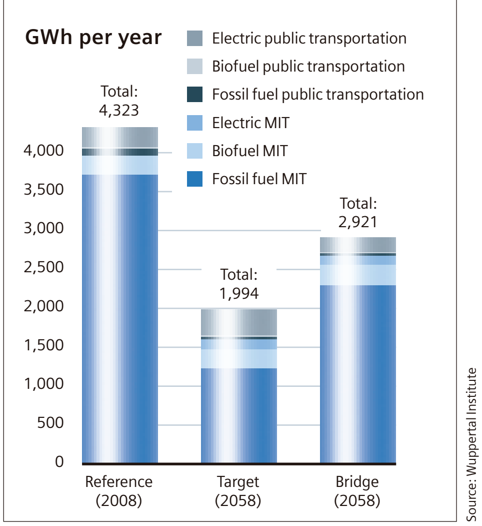
The scenarios in detail: The "target" scenario assumes that transportation usage per person will decrease 10 percent in comparison to 2000. The primary reason is urban planning measures. Today, jobs, homes, and shops are often far apart. In the future, areas could be created where these are more closely intermixed. The result would be districts with short travel distances. Bicycle usage for in-town transportation will increase significantly. Short-range public transportation would lose share to bicycles but pick up share from MIT, so that in 2058 more than 70 percent of all trips in town could be covered using the environmental alliance – public transportation, on foot, or by bicycle. Short-range public transportation could be made more attractive with detailed information systems that inform passengers before and during travel, for example via mobile phone. Simplified payment options employing chip cards or mobile telephones would also make public transportation easier and more convenient to use. An integrated combination of public transportation and flexible car sharing, without fixed car locations, will optimize the use of transportation means: If multiple trips must be made in immediate succession on one day, cars can be used either for individual segments, or alternatively for partial segments, because the car does not have to be returned to its point of origin. The other segments can be covered with short-range public transportation or with (loaner) bicycles.

In the "target" scenario, the share of electri-

Transportation by means of transportation



Final energy used for passenger traffic



cally powered vehicles in MIT expands significantly. At the same time, vehicles will become more compact and thus consume less fuel. For travel within the city, electricity will be drawn from the public grid to power the vehicle for 80 percent of all distances traveled. Because of the short distances involved here, battery-powered vehicles' short range compared to internal combustion engines will be of no consequence. Today's relatively long recharging times would also hardly be noticeable on short trips, because the car could be recharged while it is idle at home, at work, or in a garage. It is also assumed that there will be greater acceptance of fully hybrid vehicles, equipped with electric engines for short distances and internal combustion engines for long distances. For trips that take passengers outside Munich, at least in part, trains would be used more often. However, a prerequisite for this would be that the city of Munich is not left alone in its efforts to make public transportation more appealing. Vehicles with an internal combustion engine and plug-in hybrids would also be used for this purpose, and would each handle about half of all kilometers traveled by MIT.

The "target" scenario assumes substantial changes in citizen behavior. In this regard, the "bridge" scenario is more conservative.

It assumes that transportation provided per person will remain unchanged compared to 2008. The modal split also does not change. In total transportation services will increase because of the growing population. And significantly fewer electric vehicles are used for MIT than in the "target" scenario. Only 30 percent of the transportation provided by MIT in internal

Best Practice

Intelligent traffic management

As examples from other metropolitan regions show, CO2 emissions caused by motorized individual transport can also be reduced through the intelligent management of street traffic. One example of such instruments is "road pricing" – in other words, charging to use streets for MIT. Depending on the intended goal, such charges designed to manage traffic volume could be based on time of day, travel time, or distance traveled. A toll differentiated by vehicle classes, harmful substances, or emissions is also conceivable. Higher fees based on time or traffic density (commuter traffic, vacation travel) might help diffuse the flow of traffic and thus avoid traffic jams. Singapore has had a toll system in place since 1975 that charges fees during rush hours. Rush hour traffic there decreased 45 percent, while the use of short-range public transportation more than doubled.

The London "Congestion Charge" has attracted considerable attention in the past few years. Since 2003, a toll has been charged for all vehicles that enter the city center between 7:00 a.m. and 6:30 p.m. All revenues are used to finance public transportation. Additional bus lines have been added in town, and existing lines run more frequently. The capacity of short-range public rail transportation has also increased. Over the past few years, 1,200 new regional train cars have been added. Experts believe that this measure has made a substantial contribution toward relieving congestion in central London. According to the London operating company, the Congestion Charge has reduced traffic volume by 18 percent. Time lost in traffic jams has been reduced by about 30 percent, equivalent to annual CO2 savings of about 150,000 metric tons. Early in 2008, a "Low Emission Zone" (LEZ) was also introduced for the adjoining districts, known as the Greater London area. Trucks and buses can enter the LEZ free of charge only if they meet the Euro III or Euro IV standard for fine particulate emissions. Any vehicle not meeting the standard must pay a fee. The charge is based on a system for automatically recognizing license plates. Additionally, since 2007, electrical hybrid buses in the traditional red double-decker design are operating on London's streets. They produce up to 38 percent fewer emissions than conventional diesel vehicles, and consume about 40 percent less fuel.

traffic is covered using electricity from the public grid. With the other paths, the share is four percent, compared to five percent in the “target” scenario.

Taken together, all the measures presented here would significantly reduce energy demand in passenger traffic. The “target” scenario would yield the greater savings, with energy consumption dropping by about 50 percent from the 2008 level. Electricity would account for 23 percent, while in the initial year it made up only 5.5 percent of overall energy consumption. Although electricity demand as a whole would increase, 77 percent of energy demand for traffic would be covered by gasoline and diesel fuels even in 2058. And of this, 14 percent would be biofuels.[11] One important reason for this is a relatively large proportion of the trips would be those that go beyond the city limits, and transportation for most of these trips would not use electricity.

All efficiency measures would cut CO_2 emissions roughly in half by 2058, from about 1.1 million metric tons per year to 534,000 tons – despite a moderate increase in population. Including the savings resulting from less carbon-intensive power generation, the reduction is about 70 percent. Important driving forces here would be the efficiency gains in internal combustion engines, the shift in transportation from MIT to the environmental alliance, and a decrease in traffic.

In the “bridge” scenario, the energy savings would only be about 30 percent, resulting solely from new technologies and technological improvements. The share of electricity would rise to 10 percent of energy consumed. But demand for gasoline and diesel fuels would remain high, and they would cover 90 percent of

CO_2 emission reductions in passenger traffic, “target” scenario

Source: Wuppertal Institute 2008

the total energy demand of 2,900 GWh for passenger traffic. Biofuels[12] could cover 10 percent of fuel consumption. The absolute energy demand for passenger traffic would rise 20 percent, whereby a large portion of the additional need for MIT would be compensated for by energy improvements in public transportation.

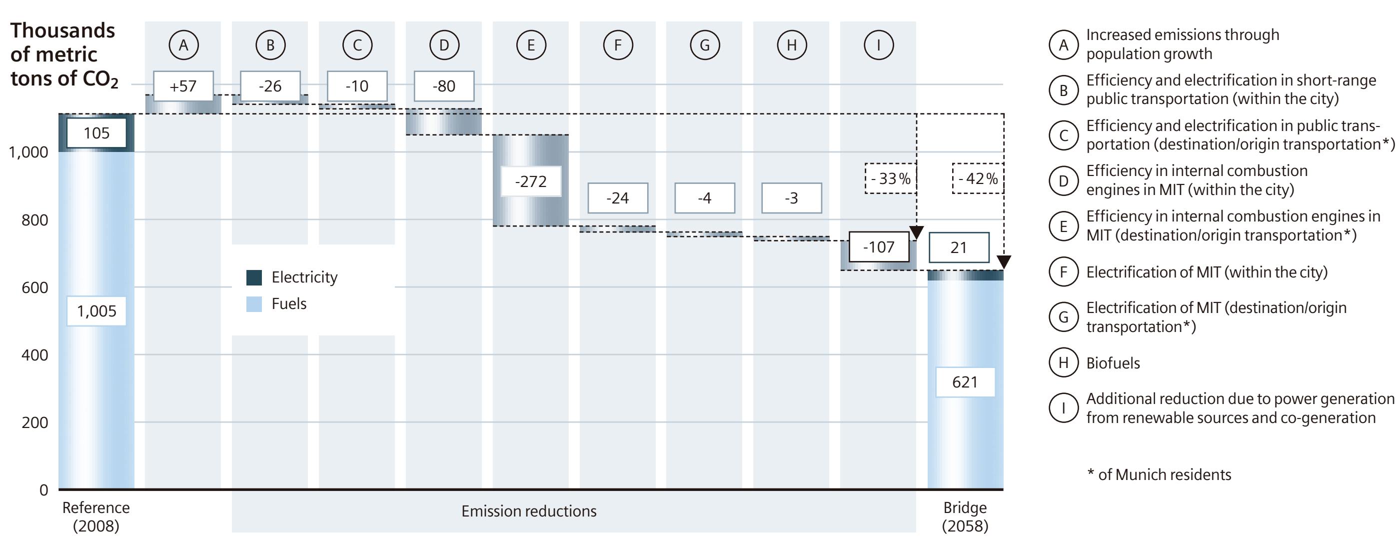
In the "bridge" scenario, CO_2 emissions would decrease only 33 percent, to about 750,000 metric tons of carbon dioxide per year. However, if electricity generated from renewable sources is included in the calculations, the savings would be 42 percent.

Alternative fuels: As described, in both scenarios Munich residents will still use cars with internal combustion engines in mid-century for a substantial portion of their travel – especially outside town. As a result, the search for alternative, non-fossil fuels is of great interest. More widespread use of biofuels could reduce CO_2 emissions in MIT. No additional infrastructure is needed for refueling vehicles with liquid fuels from renewable sources – a factor that has facilitated their introduction in the market. However, from today's vantage point, the impact of biofuels on climate change must be closely examined.

The production of biofuels generates emissions that must be taken into account in an overall assessment. Other aspects must also be given critical consideration, such as the impact on food production. For these reasons, no further expansion in the use of biofuels is assumed. As a result, biofuels contribute little toward reducing emissions below the 2008 levels in either scenario.

Another option for low-carbon cars is hydrogen vehicles, which have been under discussion for some time. However, the fuel cell needed for this purpose is still heavy, relatively unreliable,

CO_2 emission reductions in passenger traffic, "bridge" scenario



Source: Wuppertal Institute 2008

[11] The percentage of biofuel is derived from the admixture of 6.25 percent approved by the German government for 2010. It is assumed that the resulting volume of biofuels per resident will be kept constant over time. Thus, the figure will be increased to 10 to 14 percent only through an absolute reduction in fuel consumption.
[12] The absolute volume of biofuels is the same as for the "target" scenario.

and so expensive that it cannot compete with internal combustion engines.

The question also arises as to what energy source could be used to produce the requisite large volumes of hydrogen. Alternatively, hydrogen can also be used in internal combustion engines, but the storage technologies are still too immature for everyday use. Moreover, a completely new infrastructure of filling stations would be needed for this purpose and would thus have to be developed. For that reason, hydrogen has no role in this study, which instead assumes a significant expansion of electrically powered mobility.

Savings potential in freight traffic: This study also foresees further potential for reducing CO_2 emissions in freight traffic. It assumes that:

➔ Efficiency enhancements will reduce consumption per vehicle kilometer by 18 percent in trucks, vans, locomotives, and boats on inland waterways, compared to 2008 consumption.

➔ Railroad freight traffic services will more than double, especially because of shifts away from transportation on the highways.

The "target" scenario furthermore assumes that the utilization of vehicles will increase by 25 percent. Since a portion of freight traffic will be electrified, fuel consumption will decrease 20 percent. Carbon emissions will decrease by about 50 percent, especially because of the avoidance of highway freight traffic.

In the "bridge" scenario, on the other hand, the number of vehicle kilometers does not decrease from the levels in the reference year. Emissions, however, decrease by about 30 percent. As is the case for passenger traffic, this is mainly the result of higher vehicle efficiency in conventional vehicle drives.

Electricity-saving transportation infrastructure: The transportation infrastructure is yet another lever for saving energy in the transportation sector. However, energy consumption and emissions are accounted for under the electricity sector. One option would be to disconnect parking-token dispensers, emergency telephones, control and instrumentation systems, and signal and telematics applications from the municipal electricity grid, and to power them independently with solar "island" systems. One advantage is that extensive trenching and additional power grid lines would not be necessary. This would allow for a fairly fast amortization of the photovoltaic installations, which are relatively expensive at first. Electricity can also be saved by replacing conventional lamps in traffic lights with more efficient light-emitting diodes (LEDs). This would also eliminate the maintenance expense, which has hitherto been high, because lamps must be changed once or twice a year in conventional traffic lights. LEDs, on the other hand, only need to be changed about once every 10 years. This is why the state of Berlin has been converting its roughly 2,000 stoplights to LEDs since 2003. Energy consumption in 2003 was over 15 million kWh per year, leading to energy costs of €1.8 million. The annual lamp replacement cost was €450,000, and so each traffic light cost about €1,150 per year. By mid-2007, 330 traffic lights had been equipped with LEDs, saving 500,000 kWh of electricity per year. Half of the 2,000 stoplights are to be converted by 2011, saving about five million kWh compared to 2003 – roughly equivalent to the power consumed by 1,000 four-person households.

By last year, the city of Budapest had also equipped its traffic lights with 33,000 LEDs. In spite of the large investment for the LED systems, the city administration has avoided additional financial burdens. The costs are spread over monthly installments – and these are lower than the savings gained from lower power consumption and less maintenance. The city of Budapest is saving €800,000 per year on electricity costs in this way. Another approach is the renovation of street lighting.

A small town in Franconia equipped 1,260 lights with more efficient lamps, and installed 20 lumen regulators to adjust brightness. The power consumption for street lighting was cut from 463,000 to 258,000 kWh per year, and the cost savings of €21,500 per year will amortize the investment cost of €108,700 in only five years.

Technology outlook

Electric-powered mobility

Today almost every car in Munich and in Germany is powered by an internal combustion engine. Given that fact, the idea that by mid-century 80 percent of all kilometers traveled in Munich's urban MIT will use electric cars seems quite visionary. Yet a large number of pilot projects point in precisely that direction. For instance, a U.S.-Israeli company announced last year that within two years it would set up a network of electric charging stations in Israel, Denmark, Australia, California, and Hawaii. In cooperation with car manufacturers, that company plans to put several tens of thousands of electric vehicles on the market. To get around the problem of long recharging times, battery replacement stations will be set up, where discharged batteries can be exchanged within minutes for fully charged ones. In Israel, the necessary electricity is to be derived primarily from photovoltaic sources. In Denmark, it will come from wind power, which already supplies about 20 percent of that country's total electricity needs. However, in periods of low winds, electric cars would have to rely on electricity from Denmark's coal-fired power plants. Since too little is known to date about the practical aspects of driving and recharging electric cars, no reliable estimates are possible yet about the actual impact on the climate.

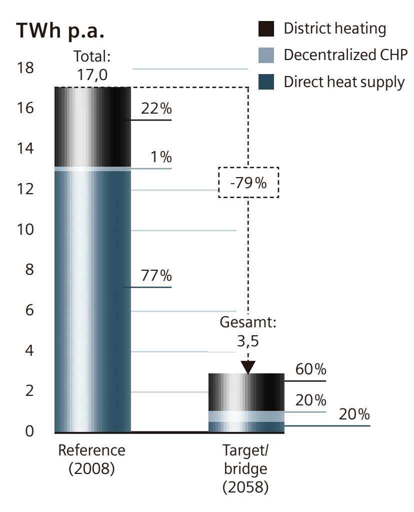
Batteries are still quite expensive, and they also drive up the price of hybrid vehicles. The problem might be mitigated in the future if electric cars are treated as an integral part of the power delivery network. This study assumes that, in the future, electric cars might serve as energy storage devices and as a load management system to balance out fluctuations caused by the heavier use of renewable power sources like photovoltaic and wind power, or from fluctuations in demand in general. For example, the fleet of electric cars could feed power into the grid at peak-load periods, when demand is high and electricity is especially expensive, thus enabling the additional cost of an expensive battery to be amortized faster. Car owners could choose recharging and feed-in times individually in advance, so as to take advantage of especially low electricity rates. Alternatively, such a charging system could be designed and managed so as to trade electricity independently. Such a concept could significantly increase the appeal of electric vehicles and accelerate their introduction in the market if car users find the idea acceptable. Additionally, it opens up a new business model for power utilities. However, today's batteries – modern lithium-ion batteries – are not technically ready for such permanent load changes. Still, the first robust, compact prototypes have now been produced. Among their features: They can store a large amount of energy in a small space, and they are considered especially safe. These batteries have been made possible by the development of new materials, such as lithium titanate for the plus pole of the battery. This substance is far more robust, reliable, and durable than the graphite used until now. All German electric vehicles would presumably not be enough for complete load management; but in total they would provide a significant reserve for load management in a future smart grid.

2.4 Heat supply

If the passive house standard were indeed to prevail across the board for new construction and building refurbishment by mid-century, the benefits would be enormous. This study thus assumes that the energy required for heating building space in Munich could decrease dramatically – by nearly 80 percent – over the next 50 years. The study also assumes that the significantly reduced amount of heat required could be generated more efficiently and in a more environmentally sensitive manner than is the case today. Thus, neither scenario is based on today's common "direct heat supply" – individual gas and oil heating systems for living spaces – which currently accounts for 77 percent of Munich's space-heating needs. Instead, district and local heat, generated in efficient combined heat and power (CHP) plants, would become the most important pillar of heat supply in the future. In addition to heat, these plants supply electricity at the same time. In both scenarios, the share of district heating would increase from the current level of 20 percent to 60 percent.

Smaller districts within the city that are not connected to the district heating grid could alternatively be supplied by small, decentralized local heating networks with block heat and power plants that burn efficient natural gas or

Heat energy supply in buildings



Source: Wuppertal Institute, 2008

biogas. In other areas, so-called microCHP plants could be the right option. These can be used in small multi-family dwellings or even in single-family homes to efficiently generate electricity and heat from natural gas and biogas. Large conventional (CHP) plants and communal block heat and power plants achieve energy utilization rates as high as 90 percent since they are able to use the waste heat from electricity generation for district heating. This is quite remarkable when compared to the average level of efficiency for fossil fuels in Germany, which is 41 percent. MicroCHP units, currently being developed for the market by various manufacturers, are expected to be just as efficient in the future. These microCHP units could replace conventional boilers, which heretofore have been used in residences exclusively for producing heat and hot water, but not electricity. The advantage of the microCHP units is that they can be deployed and installed like boilers – which HVAC technicians are very familiar with. The only new element is the electrical connection. Another advantage: As part of the CHP Act, the electric utility company compensates the homeowner for the electricity fed into the grid. This decentralized CHP will be able to supply 20 percent of Munich's heating needs.

In order to actually implement the options for action presented in the scenarios, a few hurdles would have to be overcome in terms of district heating. Two contrary trends must be reconciled. On the one hand, through implementation of the passive house standard, the district heating requirement per customer will be lower than it is today. The resulting decline in sales will not be markedly offset by the considerable increase in the size of the area supplied. On the other hand, despite decreasing demand, the district heating grid will need to be massively expanded – and that expansion will need to be financed.

In order to successfully expand district heating, these two trends must be reconciled with one another. From today's perspective, this study cannot determine with absolute certainty whether there is a technical and, in particular, a cost-effective solution. What this study can do is to detail the challenges and outline the approaches to solving the problem:

➔ Is it possible to connect 60 percent of Munich's residential and non-residential buildings to the district heating grid? A prerequisite would be that nearly all consumers living in areas served by the district heating grid would actually connect to the grid.

The city of Mannheim obviously assumes that this is possible. Already today, district heating claims a 59 percent share; the goal by 2030 is 70 percent, according to a current resolution. And in Flensburg, for example, 90 percent of all buildings are already connected to district heating.

➔ Is it even possible to finance such a massive expansion of district heating? Such a large investment must be cost effective, and it must be financed by the energy provider. Securing this type of funding will require a long-term, integrated strategy.

➔ The question arises of how to avoid creating a situation that competes with the existing gas supply networks. Presumably, it would nearly be impossible to achieve a 100 percent connection rate for district heating along streets where both district heating and natural gas are available. On the other hand, competition between the energy providers would not make good economic sense. An alternative and logical solution would be a combination with decentralized local heating grids that draw their heat from a communal power station that runs on natural gas or biogas.

The cost of expanding the district heating grid could be further reduced through innovations in control technology, in technology for connecting buildings to the grid, and in transfer stations. These technologies are explained in more detail in the 'Technology outlook' section. If they are implemented consistently, a district heating infrastructure could be set up and operated at a reasonable cost. Moreover, a decline in the heating needs can also offer opportunities: If the heating needs decrease, there is little need to expand the heat generation capacity. Indeed, the scenarios assume that existing combined heat and power plants will gradually be replaced by new, more efficient units. But an expensive expansion program would no longer be necessary. And the decreasing demand would result in an additional advantage – a more consistent load capacity for the district heating grid. Thus, as the heat energy requirement declines, the percentage of water-heating capacity would increase relative to the overall heating capacity. And because hot water demand (for bathing, showers, cooking) fluctuates little over the course of a year – in contrast to the heat energy needs – the heat energy demands would generally be more consistent and easily controlled. In addition, district heating presumably will be used more frequently in the future for climate control in non-residential buildings. This would also contribute to a more consistent load capacity for the district heating grid, adding to the cost efficiency.

Of course, in addition to the paths outlined here, there are other alternative solution models for overcoming the efficiency dilemma posed by carbon-optimized heat supply. For instance, it is conceivable that electric heat could be an alternative in the future, using electricity generated from renewable sources. This perspective is not examined in detail here because Munich's public utility company already has an extensive district heating grid that lends itself to additional expansion. But it is an alternative that could warrant further study. It is important to keep in mind, however, that electric heat cannot be deemed a low-carbon alternative until the entire electricity-generating system is thoroughly developed as a carbon-free system.

Best-Practice

District heating in Copenhagen

The city of Copenhagen has one of the world's largest district heating systems. The approximately 1,300-kilometer network supplies 70 percent of all households as well as several communities in the surrounding region. Since 1984, the system has been run by two companies, in cooperation with the city of Copenhagen. More than two-thirds of the energy comes from combined heat and power (CHP) plants near the Danish capital, which are fueled with natural gas, straw, wood pellets, and larger lumber. The remaining heat comes from trash burning plants and smaller peak load power plants as well as geothermal plants.

Until the mid-1990s, the CHP plants ran on coal. The changeover to alternative fuels now provides Copenhagen with 665,000 tons of CO2 savings annually, according to the city's calculations. A major reason for the success of district heating was a tax relief program for CHP plants introduced by the Danish government in the mid-1980s. This enabled the power plants to offer heating at a low price. According to the city government, district heating today is only about half as expensive as heating with oil. Another reason for the massive expansion of district heating was the Heat Supply Act passed by the government in 1979. It made it easier for municipalities to set up district heating in individual urban areas. Residents of those urban areas were then required to connect to district heating, but heating was supplied at a markedly low price. Another outcome of the Heat Supply Act was that several municipalities and the capital city joined forces for the first time to form a large cost-efficient district heating system.

Technology outlook

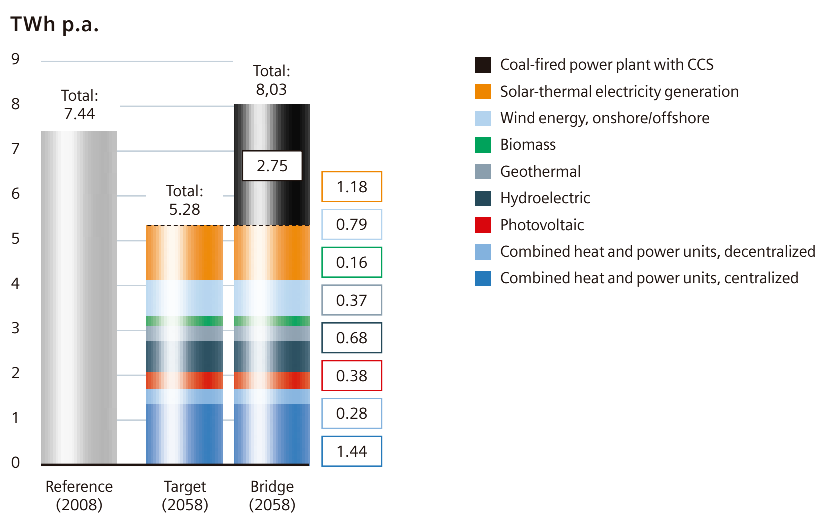
LowEx concepts

Generally speaking, it is highly inefficient to burn fuels at several hundred degrees Celsius in order to generate energy to provide a room temperature of about 20 degrees Celsius. Passive houses, in particular, can contribute in the future to reducing these efficiency losses as their improved insulation means that they require less heat energy than conventional buildings. Today, the water in heaters and hot-water pipes in houses is generally kept at 70 degrees. In order to cover the residual heat requirement of a well-insulated passive house, a much lower temperature – at least 30 degrees – would be sufficient. This could be delivered using low-temperature sources such as industrial waste heat or solar-thermal plants or – with the aid of heat pumps – via geothermal and ambient heat. Of course, people will also still require higher temperatures, about 50 to 60 degrees Celsius, for their tap water. These roughly 20 extra degrees can be achieved, for example, by connecting a heat pump to the heating water circuit for the tap water circuit. Experts refer to such low-temperature solutions as "LowEx" concepts. These seem to be entirely realistic for the Munich of the future, particularly when one considers the use of additional industrial waste heat. On the other hand, it is unlikely that conventional local or district heating grids will continue to be cost effective as heating demands decrease, given the fact that the costs for lines and connections must be economical for the provider. Now, however, there are promising concepts for the future for a more affordable expansion and cost-efficient operation of a low-temperature network. One example is the so-called infrastructure channels that bundle all supply and waste-disposal lines (district heating, natural gas, electricity, water, wastewater, or telecommunication lines) into a common channel. The primary advantage of infrastructure channels is that suppliers no longer need to lay individual pipes or lines. In addition, because these channels also remain accessible, it is easier to add lines in the future. Such infrastructure channels could be laid directly underneath buildings or cellars in areas of new construction. This eliminates the need to provide a costly stub from the street for every individual building. Because the district or local heating lines run directly underneath the buildings, the heat loss is also considerably lower than when supply lines run below the streets. Such savings can be significant, especially in the case of low-temperature concepts. It has already been demonstrated that, when constructing new developments, cost savings of up to 30 percent can be achieved by laying infrastructure channels prior to the construction of the buildings instead of the conventional district heating stubs. The buildings would be connected to the infrastructure channels through an opening in the buildings' foundation slabs. Consequently, the length of lines can be shortened, heat loss can be avoided, and the number of couplings can be reduced. Such a connection system was installed, for example, in Germany's Gelsenkirchen-Bismarck solar-powered district.

2.5 Electricity supply

On balance, Munich's public utility company could fully supply the city with electricity at the present time. The public utility generates more than 100 percent of the amount of electricity consumed in Munich in its own power plants within the urban region, combined with hydroelectric facilities outside of the region and a share in a nuclear power plant. This study assumes that Munich's public utility company will also be able to cover the city's electricity demands in the future, on balance, through its own as well as partly owned power generation plants. Moreover, there are other energy providers active in Munich today that are outside the city's direct

Electricity supply in Munich



Source: Wuppertal Institute

influence. Here, as a matter of simplicity, the assumption is that Munich will be supplied only by the city's public utility company. Because the Munich electricity grid is not self-sufficient – other suppliers also feed in electricity – the source of electricity can only be determined on the books, but not physically. It is impossible to analyze from which source the electricity being consumed actually originates.

As explained above, the "target" and "bridge" scenarios anticipate different levels of electricity consumption by mid-century. However, both consistently assume the following paradigm shifts:

➔ Compared to today, less electricity will be produced in large centralized power stations. Instead, it will increasingly be produced and stored in a decentralized manner. Consequently, the requirements for the electricity grid will change: There will be varied energy flows in all directions.

➔ Electricity will no longer be generated predominantly from fossil fuels. Rather, it will increasingly come from renewable energy sources.

In the future, an entire range of technologies will work together to generate electrical power. On the one hand, households and smaller multi-family dwellings could be very efficiently supplied with electricity and heat via microCHP or fuel cells. Supplementing that would be other decentralized power generation technologies, such as photovoltaic energy, wind energy, or large combined heat and power plants that run on natural gas, geothermal energy, biogas, or solid biomass. To coordinate these many decentralized generation units, a so-called smart grid or virtual power plant will be required. Various efficiency tools, such as an "intelligent electricity meter," read on a regular basis via a data connection, would be a component of such a network.

Such electricity meters would not only ensure

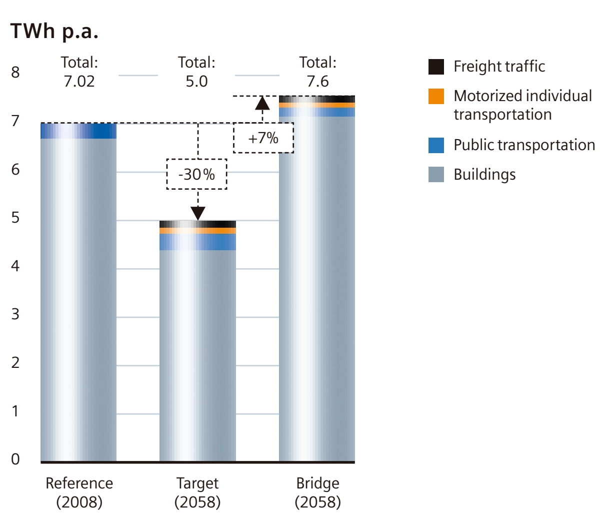
precise by-the-minute billing for electricity. They would also enable centralized control of important devices to avoid consumption peaks and to control consumer usage behavior.

Of course, in the year 2058, Munich will still obtain electricity from sources outside the city, such as power stations in the region, in Germany, and abroad. Unlike today, that electricity could be generated primarily in large offshore and onshore wind parks, solar-thermal power plants in southern Europe or North Africa, and in fossil-fuel-fired power stations with carbon capture and storage (CCS), as outlined in the "bridge" scenario. In addition, biomass power stations, wave power plants, or hydroelectric plants in northern Europe could also play a role. Both scenarios also assume that this electricity will be transported to Munich via a large integrated European network. The high-voltage direct-current (HVDC) transmission lines described below are good options for transporting the electricity over these long distances as efficiently as possible, with minimum loss.

Today, the city of Munich consumes 7.02 TWh of electricity. The "target" and "bridge" scenarios anticipate the following detailed situations for the year 2058, based on differing levels of consumption:

In the "target" scenario, demand for electricity will be considerably lower than what it is today, amounting to less than 5 TWh a year. Roughly 3 TWh, i.e. about two-thirds of the electricity requirement, would be generated locally and regionally. The majority of that would be generated in combined heat and power plant and communal power stations fired with natural gas – and, in the future, also with biomethane (biogas) – in addition to micro combined heat and power plants. A smaller portion could be supplied through other local renewable energy sources, such as photovoltaic power plants. The remaining electricity would be "imported" as carbon-

Electricity demand in Munich



Quelle: Wuppertal Institut

Best Practice

Participation in renewable power generation – wind power projects

Today there are various examples across Europe that demonstrate how public utility companies can successfully participate in renewable power generation projects. The Middlegrunden project is one of the first and, without a doubt, most interesting projects. In the year 2000, a group comprising Danish private individuals, government authorities, companies, and associations came together to form a cooperative. They began constructing 40 offshore wind turbines near the Copenhagen harbor. On average, the 40 wind turbines produce about 90 million kWh of electricity, corresponding to about three percent of Copenhagen's electricity consumption. They avert roughly 76,000 tons of CO_2 each year and provide about 40,000 households with electricity. Management of the project rests with the local public utility company, Copenhagen Energy, and the city's environmental and energy authorities. What makes this project so special is the fact that more than 8,500 private individuals, along with several organizations, have contributed to financing the project through the cooperative. Moreover, the project exemplifies how initial resistance within the population was able to be resolved through transparency and intensive public relations. In Germany, interest in generation of electricity from renewable sources is also on the rise. For instance, 40 German public utility companies, along with the Trianel Group, a joint venture made up of 11 public utility companies, are investing about €1 billion over the coming years in the development of an offshore wind park near the island of Borkum.

The public utility companies intend thereby to diversify their power-generation portfolio even further and increase the proportion of carbon-free electricity. Some 80 wind energy plants with a capacity of five megawatts each are being constructed off the coast of Borkum. The electricity produced will be fed into the high-voltage grid via an underwater cable that also passes over the island of Norderney. This pooling of municipal utility companies is giving rise to the first large producer of electricity in the offshore sector that is not affiliated with a private-sector company. Recently, Munich's public utility company also joined a project to construct one of the first German offshore wind parks off the East Frisian coast. The project calls for 80 wind turbines to be installed there by 2013, generating 1.4 TWh of electricity annually. The public utility company holds nearly a 25 percent stake in the €1.3-billion project.

Technology outlook

Smart grid and load management

Since deregulation of the European electricity market in the mid-1990s, electricity trading, and therefore also the transport of electricity within the integrated European network, has experienced enormous growth. Presumably, the share of fluctuating, renewable energy from wind and the sun will increase considerably in the future. To keep pace with the growing and changing requirements, the integrated European network will have to be more flexible and intelligent in the future. This will enable the large current flows as well as the fluctuations inherent in solar and wind energy to be balanced out. This study assumes that the integrated network will continue to grow. For example, the entire Mediterranean region could be integrated into the European power supply system via a ring line through North Africa, so that electricity from large solar-thermal power plants could be delivered to more northern regions. Moreover, there would be an opportunity to create a larger European network of renewable energy providers. Wind energy generators on the Atlantic and North Sea coasts, hydroelectric plants in northern Europe and the Alpine regions, biomass energy producers from (central) eastern Europe, as well as photovoltaic energy from southern Europe and the solar-thermal power plants in North Africa could balance out the fluctuations in power generation and loads. A so-called "smart grid" in which energy currents can be controlled in a much more sophisticated manner than today – thanks to modern information and telecommunications technology as well as measurement and control technology – can contribute to making the European network fit for the future. The smart grid could link the many small plants that generate renewable electricity, such as photovoltaic power plants, wind parks, or even biomass power plants, so that together they can balance out fluctuations and generate electricity just as reliably as a conventional power plant does.

An additional consideration is smart metering with intelligent electricity meters. These electricity meters could, for example, enable remote control of appropriately equipped private heat pumps and clothes dryers in the future. The appliances could then be turned off or on, based on whether there is a surplus or shortage of electricity at a given time. The tremendous quantity of household appliances could also play a role in load management within the smart grid. Currently, in all of Germany, the four large household appliance categories alone (refrigerators/freezers, clothes dryers, washing machines, dishwashers) could yield a temporary load management potential of between about 1,300 and nearly 3,000 MW on a normal weekday in summer. An appropriately expanded network could collect excess capacities of wind energy. Until now, the rotors have had to be slowed down during times of high winds in order to avoid overloading the lines. In the future, one could take advantage of the excess capacities to charge electric and hybrid car batteries with this natural power source. These could then, if required, feed the stored electricity back into the grid. One could even supply large cold-storage warehouses in such a case. The temperature of the warehouses would be lowered further with the additional electricity – as a cold buffer for peak load times when electricity is expensive.

If, as is assumed in this study, a large proportion of power from renewable sources is generated in northern and southern Europe, it will be necessary to ensure efficient and secure transport of large amounts of electricity over long distances. A solution for that is high-voltage direct-current (HVDC) transmission facilities. These can transport electricity over long distances much more efficiently than the conventional alternating current systems. Numerous projects demonstrate that these systems function well and, on the basis of their attenuating characteristics, even heighten the reliability of large integrated networks by decreasing the number of malfunctions and power blackouts. Recently, a 1,500-kilometer HVDC transmission network was installed in China. From 2010 on, this network is expected to transport 5,000 megawatts of hydroelectric power to the industrial centers in eastern China.

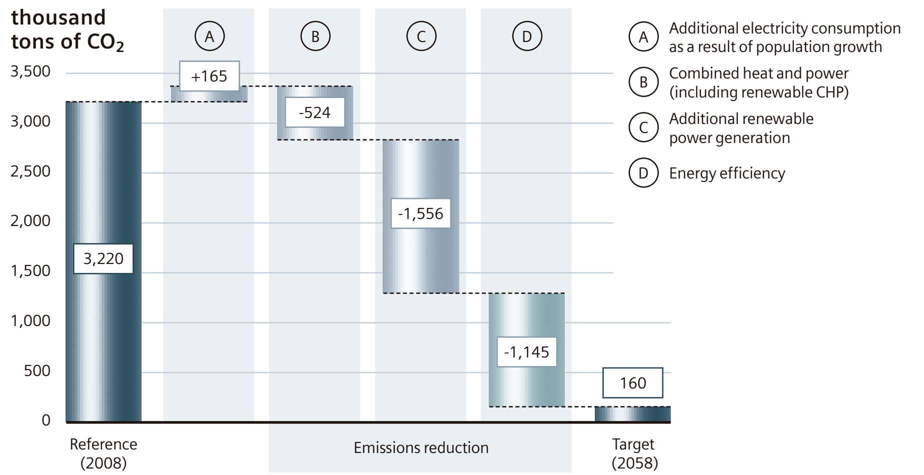
free electricity. The “target” scenario assumes (p. 46) that, to achieve this, the public utility company will invest primarily in larger plants for renewable power generation. Included in this are investments in wind parks as well as solar-thermal power plants. This could potentially be realized within the framework of a large-scale network of renewable energy producers.

The “bridge” scenario, on the other hand, assumes that electricity consumption will exceed seven TWh. The share of electricity generated locally and regionally is correspondingly lower – only about 40 percent. On the whole, it assumes the same amount of renewable power generation as in the “target” scenario. However, the electricity requirements will not be covered by additional electricity from renewable sources. Rather, they will be covered primarily by electricity generated in fossil coal-fired power stations with CCS (on the North Sea coast, for instance). This study assumes that this technology will be market-ready by 2020. However, unlike with renewable energies, (residual) emissions still occur during carbon separation.

Although the “bridge” scenario assumes higher electricity consumption than the “target” scenario, CO_2 emissions are nevertheless massively reduced in this scenario as well. In the “target” scenario, by 2058, emissions will decrease by 95 percent compared to today. In the “bridge” scenario, they would decrease by roughly 83 percent.

In the “target” scenario, the most important action is the expansion of renewable power generation. Its share in decreasing emissions is about 48 percent. The second most important measure is improving efficiency in the use of electricity. This alone could avert approximately 36 percent of CO_2 emissions in the power supply sector. In the “bridge” scenario, renewable power generation (savings potential of 48 percent) is also the most important measure. Power generation using fossil fuels with CCS ranks second, with a savings potential of 24 percent. Further development of CHP in district and local heating net-

Emissions reduction at electricity demand and generation – “target” scenario

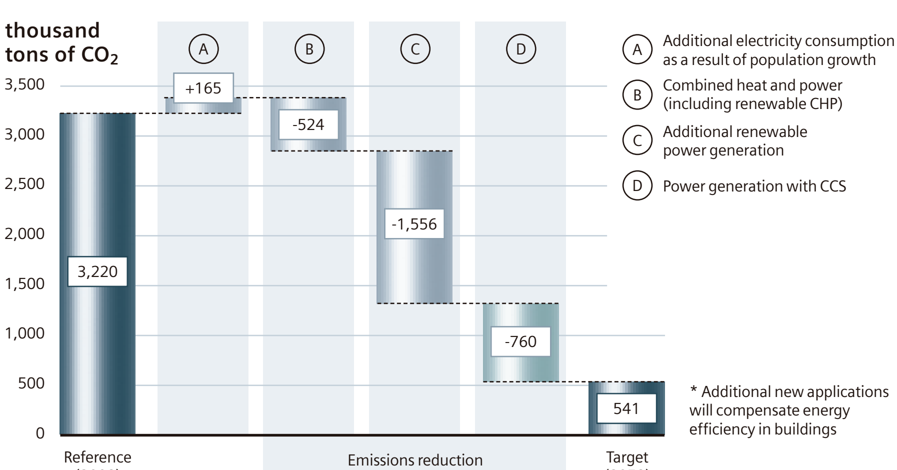


Source: Wuppertal Institute, 2008

works could reduce CO_2 emissions by an additional 16 percent.

How much will electricity cost in the year 2058? Based on the assumptions of the 2008 lead scenario of the Federal Environment Ministry in Germany, this study assumes that it will be possible to offer the new renewable energy generation technologies on average at competitive prices, by about 2020. In terms of the renewable technologies, it is the degression effects, in particular, that will contribute to a reduction in costs. Conventional power generation, in contrast, is likely to become more expensive as a result of the growing costs of primary energy sources and emission certificates, among other things. However, that does not necessarily mean that electricity from renewable sources would be more affordable for end consumers over the long term. There are several reasons for this. For instance, power generation from renewable energy sources experiences fluctuations – during calm conditions, wind parks stand idle; when winds are strong, they produce peak values. To compensate for these fluctuations and to balance power supply with demand, buffer technologies must be employed that enable excess power to be stored for use during periods of low power generation. In addition, peak-load power plants must be available to supply electricity when production from wind turbines and photovoltaic cells is insufficient. In short, more reserves will have to be maintained. Furthermore, in some cases, there may be considerable distances between the site where the renewable energy is generated and the location of the end consumer. The transport of electricity across these long distances leads to higher power transmission costs, which in turn must be added to the price of electricity. Moreover, the electricity grid will have to be upgraded and expanded in many areas so that it can handle the generation peaks from renewable energy sources. All of this contributes to the fact that electricity will not necessarily become less expensive for the end consumer.

Emissions reduction at electricity demand and generation – "bridge" scenario*



* Additional new applications will compensate energy efficiency in buildings

Source: Wuppertal Institute 2008

Scenarios such as the "target" and "bridge" scenarios introduced here are a valuable tool in determining just how technically feasible it might be to achieve the desired perspectives and concrete development goals. But all theory involves gray areas.

The question remains: How can these goals be achieved in reality and how does one implement the requisite measures? The following chapter demonstrates how, in just 30 years, an existing mixed-use area consisting of residential and commercial buildings as well as a newly developed area can be converted into a city district that is, on balance, nearly carbon free. The

3.0 The model city district – a standard for the future

two hypothetical model developments are based on Neuaubing, an existing district on Munich's western periphery with approximately 10,000 residents, and the directly adjacent, undeveloped area of Freiham-Nord[1].

The study incorporates existing ideas about developing Freiham-Nord, yet it does not create a specific plan for its development. This chapter demonstrates that technologies already exist that could be used to develop, in phases, the approximately 340-hectare area – roughly nine times the size of Munich's Theresienwiese, or about the size of 480 soccer fields – into a true model city district.

This would require the prudent application of building, energy, and transportation technologies. Unlike the scenarios discussed above, this chapter looks at a period of 30 years because current plans anticipate the district's conversion by that time. It is unlikely that a completely neutral carbon footprint can be achieved in three decades. Nevertheless, compared to today's standard, the carbon savings are substantial – due in large part to improvements in the efficiency of electricity consumption, the deployment of electric vehicles, and the consistent use of renewable energies and passive house technology.

An overview of the model city district – nearly carbon-free by 2038: Most impressively, the analysis showed that within 30 years, there could be considerable reductions in the carbon emissions stemming from heating households and providing them with electricity. Indeed, the amount of emissions could decrease from 23,000 tons per year in Neuaubing to 14,000 tons in the two districts combined – despite the expected population increase of 17,000 residents. Consequently, the amount of carbon emissions per resident could be reduced from 2.25 tons per year (which corresponds more or less to the national average), to a mere

[1] The adjacent area of Freiham-Süd, which is designated primarily for commercial use, is not considered here.

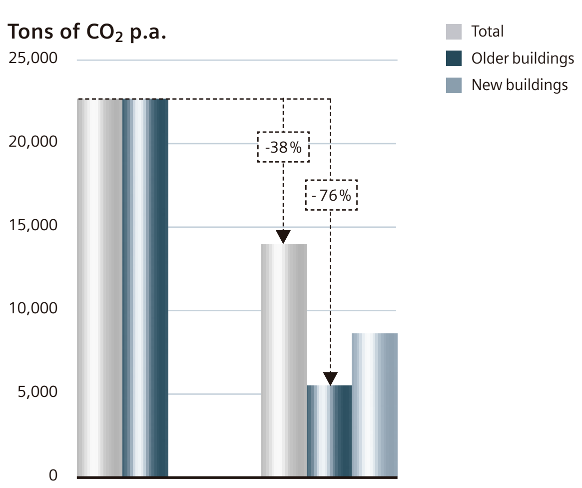
0.5 ton – a drop of more than 75 percent. The transportation sector of this model city district would also contribute to savings by deploying, for example, a greater number of electric vehicles and improving public transportation. Furthermore, a sophisticated delivery system would make much of today's automobile travel unnecessary.

The model district described here could be created by refurbishing Neuaubing's old buildings and developing a climate-friendly district in the adjacent area known as Freiham-Nord. Today, Neuaubing contains about 300,000 square meters of available living space. In 30 years, renovations and new construction would increase the living space of the entire model city district to about 1.1 million square meters.

Today, roughly 10,000 residents live in Neuaubing, which covers about 150 hectares. Many of the existing buildings, which were constructed between 1899 and 2006, are single-family homes and multiple-family dwellings of various sizes, some with as many as nine stories. The remaining buildings include schools, administrative offices, commercial buildings, churches, parking garages, and other garages. Apart from a small number of newer buildings, very few buildings meet even the current energy-efficiency standards. For that reason, there is a great need for energy-efficient rehabilitation.

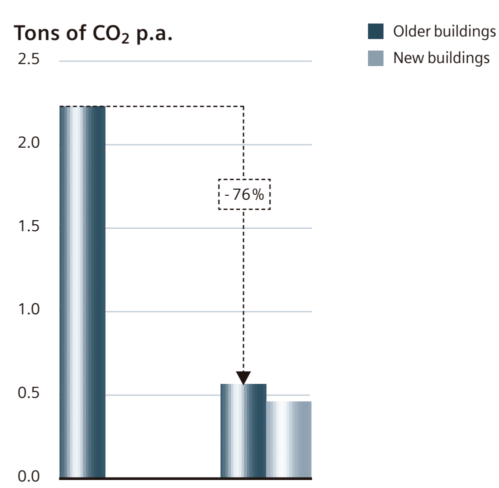
This study assumes that the hypothetical refurbishing of Neuaubing, with the complete conversion of its existing top stories to living space, could be completed in 30 years. To achieve this goal, 3.25 percent of the buildings would need to be refurbished each year – that means roughly 35 buildings, a number that exceeds the mean value assumed for all of Munich in the Scenario chapter. The study also assumes that in the meantime, the top stories will be converted in one third of the buildings. In

Absolute carbon emission of households
(not including transportation)



Source: Wuppertal Institute

Carbon emission of households per capita
(not including transportation)



Source: Wuppertal Institute

the refurbishing and conversion of these buildings, the use of insulation and windows that meet the passive house standard would be a requirement. The houses would also be equipped with central or decentralized ventilation systems with heat recovery. As a result, during the period considered here, the older buildings would require increasingly less energy for heat.

The undeveloped area of the adjacent district, Freiham-Nord, could also be developed within 30 years. The 190-hectare site, which had been used for agricultural purposes in the past, would have predominantly residential buildings under this plan, creating living space for at least 17,000 residents. For the commercial and single-purpose buildings foreseen by this study, the model assumes that they would be used for offices with sophisticated technical equipment. All buildings are to be constructed according to the passive house standard. In addition, they would be equipped with photovoltaic installations to generate electricity as well as solar-thermal systems to help provide hot water and supplemental heat. This study considers Neuaubing and the new residential development of Freiham-Nord a single model city district. It is assumed that the total number of residents in this model district would grow from today's level of roughly 10,000 to about 27,000, primarily due to new residents in the areas of new construction.

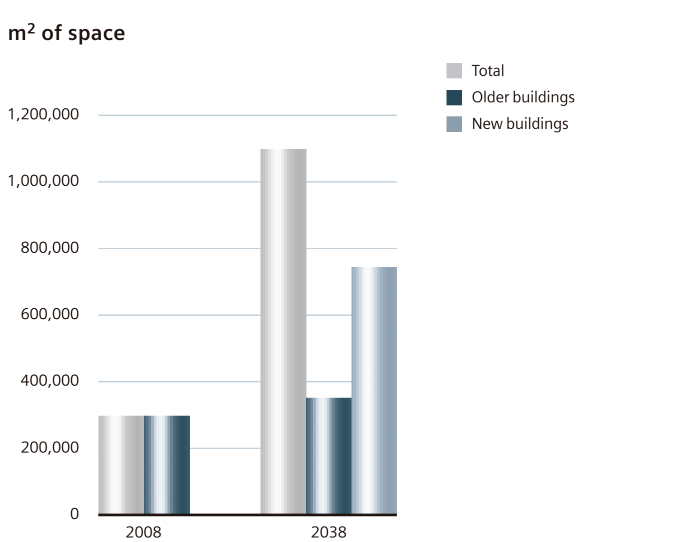
In spite of this steady growth, the heat requirement should gradually shrink. Thus, this study assumes that the amount of energy required to generate heat and hot water in the growing district will fall from 55,600 megawatt hours per year (MWh/a) to approximately 39,000 MWh/a by 2038.

Additional heat will be needed in the area slated for new development, but this will be more than offset by the enormous savings that will occur as a result of the refurbishment measures. In addition, new technologies, or the creation of a geothermal district heating grid in neighboring Neuaubing, could replace the relatively inefficient gas and oil heaters that are generally used for heating today's older buildings. In areas where connecting to a district heating grid is not cost-effective, other options include installing heat pumps or efficient, micro heat and power cogeneration systems. These systems could initially be supplied with natural gas, and later increasingly with biogas.

The amount of electricity each resident of the model district needs will shrink by about half. Admittedly, because of the roughly 17,000 new residents, the total requirements would increase, but that increase is relatively moderate. This will be made possible by efficiency gains through energy-saving electrical appliances and more efficient lighting

The study also assumes that electric and continuous-flow water heaters will be phased out

Development of living space



Source: Wuppertal Institute

by 2038. Ultimately, the electricity needs of the model city district will be determined by the usage in private households. This presents a great opportunity since every citizen can thus actively contribute to saving energy. In Neuaubing, replacing old appliances will dramatically reduce the consumption of electricity. It is assumed that citizens in the new development will, in any case, use more modern and efficient appliances. In the new development, the energy needs for the offices in the mixed-used buildings must also be added.

Although the energy needs in the older buildings will be reduced, the new ventilation systems with heat recovery (installed as part of the refurbishment measures) in these buildings will require slightly more electricity counter – approximately 520 MWh/a more. In the new development, the ventilation systems would create an additional electricity requirement of around 950 MWh/a.

Therefore, the electricity requirements in the model city district would increase overall by 2038, from about 14,000 MWh/a to roughly 21,000 MWh/a. Yet the result would be the same: per-capita consumption would be reduced by half, and that decline, in itself, would be a great success.

The measures summarized below could be implemented to help significantly reduce the older buildings' carbon emissions:

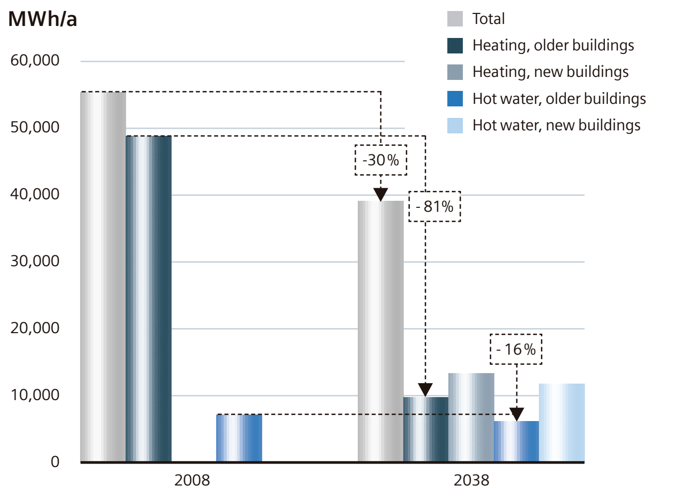
→ Reduction in the energy needed for heat through better insulation of building exteriors;

→ Extensive elimination of fossil fuels used for heat through the connection of a large number of buildings to a geothermal district heating system;

→ Complete replacement of heaters and water heaters that run solely on electricity;

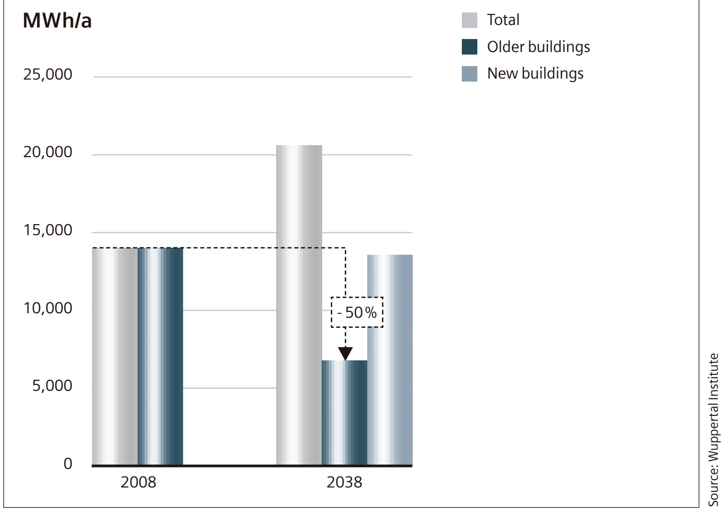
→ Equipping the remaining buildings in the area to be refurbished with gas-powered microCHP systems, wood-pellet heaters, and heat pumps;

Energy requirements for hot water and heating



Source: Wuppertal Institute

Total electricity requirements for private households



Source: Wuppertal Institute

➔ Gradual replacement of household appliances and lighting with more efficient technology.

It would cost approximately €95 million to install new insulation for the exteriors of older buildings, refurbish them so that they meet the passive house standard, and install ventilation systems by the end of the time period that this study covers. Thus this refurbishment would cost just under a third more – or about €40 million – than refurbishing the buildings to meet the 2007 Energy Savings Ordinance standards.

Constructing homes in the new development area according to the passive house standard would cost €83 million more than constructing them to meet the 2007 Energy Savings Ordinance standards. Here, the carbon emissions stemming from the energy use would come almost entirely from energy use in the households since the slight amount of energy needed for heat and hot water in the passive houses would be supplied by geothermal power. By partially using the available rooftop potential for photovoltaic modules, the carbon footprint could be further reduced.

Costs of a carbon-free heat supply: Establishing a carbon-free heat supply would require a large investment. This study calculates that, compared to a corresponding urban district that conforms to the standards of the 2007 Energy Savings Ordinance (and does not take advantage of geothermal energy and district heating), these improvements would require almost €177 million more: €83 million for new buildings, €40 million to refurbish the old buildings, €24 million for a geothermal plant, and €30 million for the district heating grid. Upon close inspection, however, the extra costs pay off.

With a real interest rate of four percent over 40 years, the additional improvements would cost the model city district just under €9 million per year. That cost includes additional expenditures for optimal refurbishment, construction of new buildings that meet the passive house standard, and a district heating grid based on geothermal energy.

Additionally, the operating costs of the district heating systems and the energy costs for the areas in Neuaubing not connected to a district heating grid would add about €2 million more per year. Depending on the price of energy, those €10.5 million per year would be countered by annual energy savings of between €14.5 and €17 million.

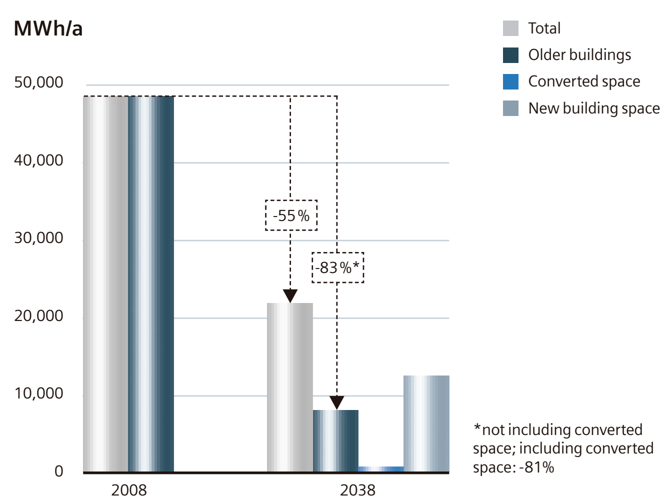
These numbers demonstrate that investments in a carbon-free heat supply not only could lead to a significant reduction in emissions but also could lead to significant financial savings, averaging between €4 and 6.5 million per year over the lifespan of the facilities.

These calculations do not include the costs for basic, non-energy-related renovations that are needed for the older buildings. Those improvements are likely to cost approximately €240 million. Since these expenditures will in any case be necessary to preserve existing living space, they were not considered part of the costs of designing a carbon-free district. Similarly, this study did not include the estimated cost of €1.2 billion to construct new buildings in Freiham-Nord, since that, too, will be done regardless of carbon-free efforts.

3.1 The model city district in detail – heat requirements for the buildings

Residential buildings need heat for two reasons: to raise the ambient temperature in the homes and to generate hot water. In terms of energy efficiency, these two heat applications are very different. Whereas the energy needed to increase the building's ambient temperature can be reduced considerably by refurbishing the buildings and consistent use of passive house technology, the consumption of hot water depends on the behavior of the residents. Those who bathe often require more hot water; those who take short showers use significantly less energy. And the more citizens living in the urban district, the more hot water is consumed. Conse-

The changing energy requirements for heating



Source: Wuppertal Institute

quently, two trends become clear: The model district's usage of energy for hot water will increase, but the energy required to heat its buildings will decline. However, since the energy requirements for heating comprise the lion's share before the refurbishment, the total heat energy needs would decrease dramatically overall.

The linchpin – energy used for heating the spaces: As described in the Scenario chapter, heating Munich's buildings creates the largest share of CO_2 emissions. For that reason, any analysis of the model district must include a plan to reduce the energy requirements for heating. As the calculations demonstrate, simply insulating the exterior of a small, multi-family dwelling constructed between 1958 and 1968 could reduce heating requirements by more than a factor of four.[2] The heat requirement could even be reduced eightfold by installing ventilation systems with heat recovery.[3] From the outset, the buildings in the adjacent new development area would be constructed according to the passive house standard. They would require 10 times less heat energy than older, unrenovated buildings.[4]

These measures, in particular, would reduce the heating requirement in the model district from just under 50,000 MWh/a in the beginning to around 22,000 MWh/a by 2038 – even assuming that both the living space and the population will almost triple in that same time period.

Increasing consumption – hot water: This study assumes that with the influx of new residents during the period, the energy requirement for hot water will also increase, from about 6,800 MWh/a to approximately 17,000 MWh/a. It is important to note the percentage of the overall energy requirement needed to heat water: Currently, the energy required for hot water and heating buildings is 55,600 MWh/a.

[2] from 188 to 43 kWh/m^2 annually; [3] to 24 kWh/m^2 ; [4] to 15 kWh/m^2

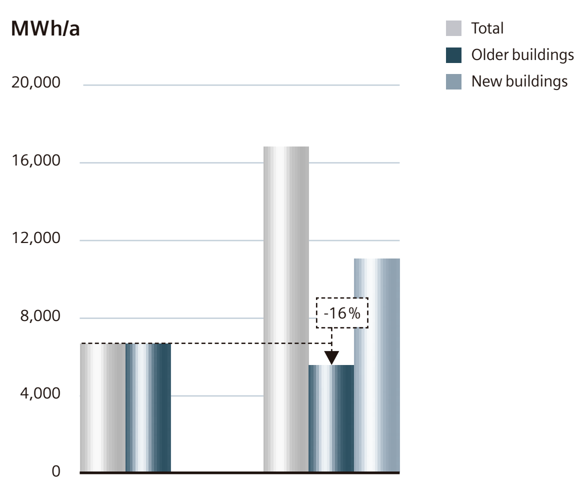
Energy for hot water comprises only 12 percent of that.

Based on these assumptions, the overall energy requirement would decrease to 39,000 MWh/a in 30 years. Because of the massive savings in the energy required to heat buildings, energy for hot water would then constitute more than 43 percent of the total amount of energy used.

The solutions: This study's calculations demonstrate that per-capita heat consumption can be reduced significantly in only 30 years. The following pages explain in detail how currently available energy-efficiency measures can be implemented and what costs can be expected for this.

The first step is to insulate existing buildings, making them largely airtight to prevent heat loss. Airtight buildings require automatic ventilation systems that remove humidity and provide fresh air. This study assumes that such systems will need to be equipped with heat recovery capability. Because few Neuaubing buildings are protected historic buildings, conventional polystyrene or polyurethane sheets could be used to insulate the exteriors. In the future, vacuum insulation panels could increasingly be used.

Energy requirements for heating water



Source: Wuppertal Institute

Large windows and interiors flooded with daylight are distinctive features of modern buildings. Windows are thus a significant factor in refurbishing. Accordingly, the model district will use triple-glazed windows or vacuum windows such as those described above; these windows will ensure compliance with the passive house standard.

Because the buildings in the new development area would be built with good insulation, they would often need less than 10 W of heat per square meter of living space. Thus, the ventilation system could provide much of the necessary heating. Neuaubing's older buildings would require a somewhat greater amount of heat. Thus, there would be additional heat energy requirements in the model district that could, however, be met by using available radiator heaters.

The costs to refurbish older buildings and construct new buildings in the model district: Based on calculations carried out as part of this study, the costs for refurbishing the older buildings will amount to approximately €95 million by 2038. That total accounts for insulating the building exteriors in compliance with the passive house standard and for investing in ventilation systems. Meeting these standards would cost just under €40 million more than refurbishing the district to comply with the 2007 Energy Savings Ordinance. That figure does not take into account future cost decreases that might result from more efficient processes or lower-priced insulation materials, nor does it take into account possible wage increases or inflation. It is assumed that additional "non-energy-related" renovation will also be completed when the buildings are refurbished (renovations such as installing new bathrooms and sanitary facilities or changing the layout of the apartments). These costs, which generally run between €500 and 1,000 per square meter of living space, are not reflected in the calculation. In Neuaubing, additional expenses totaling between €160 and 320 million could be incurred for "non-energy-related" refurbishment by 2038.

This study estimates that constructing buildings in the new development (roughly 746,000 square meters) according to the passive house standard instead of the 2007 Energy Savings Ordinance will cost an additional €83 million, which is about eight percent more than the previously-estimated cost of between €1 and 1.2 billion to construct buildings in Freiham-Nord according to the 2007 Energy Savings Ordinance. The eight percent increase corresponds to about €130 per square meter of living space.

3.2

The model city district in detail – the buildings' demand for electricity

For the most part, the model city district consists of residential buildings. A smaller portion of the district includes commercial office space, shops, schools, or other public buildings. Consequently, private households consume the most electricity overall, and for that reason, they can do the most to reduce the demand for electricity. This study demonstrates that such a reduction is truly possible. The study also considers possible efficiency gains in commercial office buildings.

Overall, there can be considerable efficiency gains in the model city district. The total number of residents will increase to 27,000 by 2038. As a result, the electricity requirement would increase from about 14,000 MWh/a to roughly 21,000 MWh/a. However, gains in energy efficiency, both in homes and offices, will actually reduce the demand per resident from approximately 1,400 kWh to just around 760 kWh per year – in other words, by almost half.

Trading in the old for the new – the model household: A new refrigerator or an energy-saving lamp in the living room might seem minor when compared to the large-scale refurbishment and insulation of an urban district. But the efficiency gains in households can be considerable. If a three-person model household were to replace old, inefficient appliances with new and efficient appliances, the energy savings would reduce electricity consumption by almost 50 percent – from today's approximate level of 3,900 kWh per year to around 2,000 kWh. Such a reduction is already feasible with today's technology and without any sacrifice on the part of the consumer. The study takes into account the expected increase in office and TV/audio applications. Granted, energy-saving equipment is generally still more expensive than conventional equipment. However, energy savings will usually balance out the additional costs over the equipment's lifespan.

Electricity consumption could be cut in half with the across-the-board exchange of major household appliances (stoves, refrigerators/freezers, dishwashers, washing machines, and dryers) for more energy efficient models. After all, in spite of major efficiency improvements, these appliances still account for the highest share of today's total electricity requirement (about 46 percent). Although washing machines have become 34 percent more efficient, dishwashers 36 percent more efficient, and refrigerators 40 percent more efficient over the past 15 years, their size and their numbers have increased, which means that these appliances' overall consumption has remained more or less the same.

As demonstrated by the example of the efficient refrigerator above, a considerable amount of energy can already be saved by using appliances with A++ efficiency ratings. Even though refrigerators are being equipped with additional temperature zones, it seems entirely reasonable to expect their annual electricity consumption to decrease to 160 kWh. The average today is still 390 kWh.

On the other hand, we can expect only minimal improvements in energy efficiency when it comes to cooking and baking with electricity. The efficiency of ovens and microwaves can possibly be slightly improved, for instance by reducing energy consumption in a stove's standby mode. Provided these improvements are made, the model household would see annual electricity consumption of 225 kWh per range, 112.5 kWh per oven, and 60 kWh per microwave, which corresponds more or less to today's level of consumption.

In the model household, energy used in the private home office will also not differ significantly from today. However, some functions will be consolidated so that fewer devices can manage more applications. Presumably, a central server in a house will be commonplace in the near future. This central server will connect all the household equipment into a network, combining the computer, the Internet, television reception, and the telephone system. Flat-screen input devices will be located in various parts of the house. The study assumes that this central server will consume 175 kWh of electricity a year, and that four flat-screen input devices distributed throughout the house will consume roughly 150 kWh. A TV set will no longer be a stand-alone device. Audio applications, however, will require a speaker system that will consume 240 kWh of electricity per year.

Energy saving lamps are already the norm today. And in the future, LED and OLED technology will be prevalent on the market. The extremely efficient energy-saving lamps, LEDs, and OLEDs can contribute significantly to energy savings. However, these efficiency gains will be partly counteracted by additional applications. In total, the expected amount of electricity needed for lighting will be 225 kWh, compared to today's average of 430 kWh. Moreover, additional efficiency gains can be made by installing

intelligent, automated control systems that monitor buildings through a range of sensors. In addition to sensors for room lighting based on whether people are present in the room, there are also sensors that detect a windows that might have been left open unintentionally (allowing cold air to enter). Heating shut-offs for vacation currently exist, and a central switch near the main entrance could operate a whole range of devices and lamps, allowing them to be turned off easily when leaving.

Refurbishing older buildings and meeting the passive house standard in new developments would lead to significant additional changes in energy consumption. For instance, in the model household, hot water will no longer be heated with electricity. Rather, it will be generated through either solar energy or district heating or local heating. That will save an additional 430 kWh in electricity per household per year.

As mentioned above, however, passive homes require central ventilation systems with heat exchange. Efficient 40 W ventilators would consume about 148 kWh of electricity a year. Modern devices with electrically regulated, permanent magnet engines could be used for the circulating pumps; such pumps are required for heating or for circulating hot-water in a thermal solar installation. The devices draw only 5 watts and would consume an additional 26 kWh of electricity per year.

The end of "standby" operation – the model office: Today's office consumes an average of 50 kWh of electricity per square meter per year. Office equipment consumes the largest percentage of that amount (40 percent), followed closely by lighting (35 percent). The ventilation system requires an additional 20 percent, and equipment such as phone systems and coffee makers consume the remaining five percent. That is considerably different from the usage percentages in a private household. But here, too, using more efficient technology can reduce electricity consumption by more than half, to 21 kWh per square meter per year. This calculation even accounts for a slight increase in the amount of office equipment.

In the future, office equipment will presumably look quite different from that of today. In addition, certain functions will be consolidated even though most of the classic functions will remain. Today, computers and machines such as copiers and printers use the most electricity. A considerable portion of the energy used by this equipment comes not from their actual usage but rather the energy consumed when they are in standby mode and even when they are "off."

Inefficient power supplies and unsophisticated electronics create this problem – there is enormous potential here to improve efficiency. At least 50 percent of the electricity can be saved by installing true "off" switches, using more efficient power packs, providing an appropriate "sleep" mode, and using LED and OLED technology as background lighting on monitors.

Lighting is the second largest consumer of electricity, claiming approximately 16 kWh per square meter annually. Many offices today continue to use inefficient lighting that could easily be replaced by modern, energy-saving technologies. Other offices use lighting based on discharge lamps, which already feature a high level of illumination per watt.

But here, too, improvements are possible: 50 percent of electricity can be saved by installing a daylight control system and by optimizing the lighting dimensions. These and other improvements in efficiency may help the model office reduce its energy consumption for lighting to only 8 kWh per square meter per year.

In today's average office, ventilation and air-conditioning systems consume about 10 kWh per square meter per year. It has been shown that these ventilation systems are often oversized, and often use outdated technology. Moreover, the systems frequently operate longer hours than necessary. Consequently, efficiency can be improved by sizing the systems properly, using energy-saving drive motors, and, installing need-based control systems that work with timers and CO_2 sensors. These changes could save 30 percent of the thermal energy and 60 percent of the electricity. Thus, it's already possible today to reduce consumption to 4 kWh per square meter per year; there's no need to wait 30 years.

Because of the extremely effective insulation required by the passive house standard, the model office will not require additional air-conditioning. Nevertheless, if the people and equipment produce too much heat for a given space, alternative air-conditioning technologies, such as the absorption refrigerators mentioned above, could provide that cooling efficiently.

3.3 The model city district in detail – transportation in the model city district

Presumably, a large portion of passenger traffic in 2038 will still use the classic infrastructure systems – railways and roads. Motorized Individual Transport (MIT) will still include cars and two-wheel vehicles. People will continue to walk or ride bikes, and goods will still be transported by air, roads, and railways. Because transportation infrastructures (like settlement structures), have a lifespan of many decades, actions taken today will affect urban transportation and the associated CO_2 emissions for many years. Of course, transportation within the model city district cannot be viewed as separate from the remaining urban area and the surrounding region.

The district's traffic also affects what happens outside the area – for instance, the transportation network affects how goods would be delivered to the model city district. This study takes these interdependencies into account. Prognoses suggest that the number of daily trips in 2038 will not differ significantly from today's number of 3.3. Freight traffic for transporting goods, however, is expected to increase by 2038.

Given these conditions, what could be done in the next three decades to ensure significant reductions in the CO_2 emissions caused by transportation? This study assumes three essential strategic levers:

1. Reconfiguration of settlement structures to facilitate environmentally friendly transportation,
2. Further development of local and regional transportation systems,
3. Significant improvement in vehicle efficiency for cars, trucks, buses, and trains.

1. Reconfiguration of settlement structures:

The new development area in the model district, in particular, could distinguish itself through its compactness. Residential buildings, commercial buildings, trades, and services could all be located in close proximity. This mixed use would

reduce distances and enable people to travel many routes on foot or by bike instead of by car, thus reducing CO_2 emissions, minimizing the amount of noise, and improving air quality. The need for trips to the city center or areas outside the city would be reduced through more local offerings. The district development would include foot paths for increased pedestrian traffic. The model district's road network would also include dedicated, uninterrupted paths for bikes or small, motorized two-wheel vehicles. There would be additional bike paths, separated from the busy streets, as well. These bike paths would provide more direct routes to the inner city and adjacent districts.

2. Further development of local and regional transportation systems: To reduce CO_2 emissions, city improvements must include enhancing the public transportation system. Attractive, short-range public transportation would encourage people who primarily preferred to travel by car to use public transit instead. Commuter trains, trams, and express bus lines could connect the model district to the city center and other Munich districts. Residents could use electric vehicles, for example, to travel within the district to transportation hubs. A modular, short-range public transportation system could also be developed, consisting of small buses using set routes that coincide with busy routes during rush hours; at other times, the buses would run according to need. Such a bus could be requested quickly by phone, Internet or SMS, or passengers could purchase subscription plans.

Travel would be simplified because passengers would receive personalized information before and during the trip. Mobile terminals and stationary equipment would calculate routes, prices, and travel times based on the current traffic situation. Such a system would be extremely flexible, easily accessible, and clearly more attractive than the short-range public transportation systems of today. In addition, it would reduce waiting and travel times.

We can assume that as a result of these improvements, people will switch from MIT to short-range public transportation in the future. The quantity of short-range public transportation vehicles, such as mini or urban buses, will be adjusted to meet demand, thus maintaining high occupancy rates and in turn reducing the CO_2 emissions per passenger.

In addition to optimizing short-range public transportation, other traffic-control measures could be implemented, such as tolls. These measures, however, affect the traffic flow for the entire metropolitan area, not just the model city district.

This study assumes that more flexible short-range public transportation and a "model district of shorter travel distances" will lead to changes in the "modal split," the term that refers to the percentage of trips taken with each mode of transportation. Due to the short distances in the model city district, short-range public transportation will claim a slightly smaller percentage of trips than it does in comparable districts today. The percentage of trips taken by foot and by bike would increase.

By 2038 in the model city district, citizens would use the integrated system of pedestrian paths, bike paths, short-range and long-distance public transportation for 66 percent of all their trips.

Compared to a district on the periphery of Munich, which is used as a reference (data from the year 2002), this would represent an increase of 6.5 percent. Trips taken with motorized individual transportation (MIT) would be reduced accordingly. This modal split takes into account all trips by the district's residents, including those made completely outside of the district.

3. Improvement in vehicle efficiency: Today, Munich residents make about 40 percent of all their trips by car or motorcycle, using gasoline, diesel, natural gas, and liquid gas. For that reason, the potential for CO_2 savings is high. Generally speaking, there are two ways to reduce these emissions:

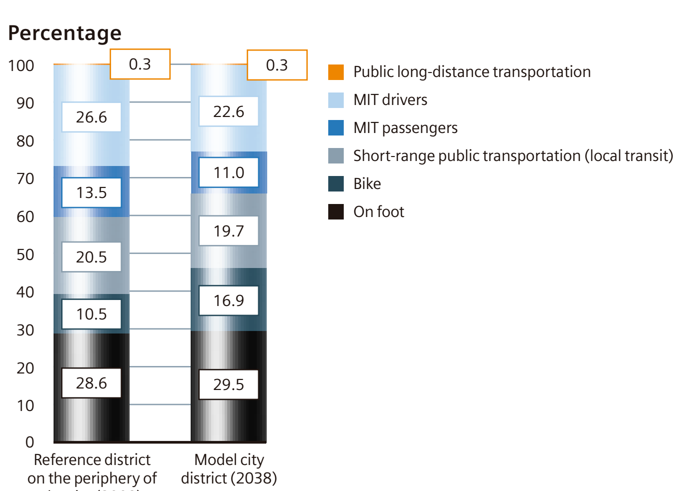
→ By electrifying motorized traffic with battery technology or hydrogen-powered fuel cells

→ By significantly increasing the efficiency of combustion engines.

It is not yet possible to determine which of these two alternatives will prevail in the long run, or whether a combination of approaches will win out. Here, however, the first possibility will be further examined because its efficiency gains have already been discussed above.

Electrifying motorized traffic through battery technology: Electric vehicles have existed for quite some time. However, within the automobile market, this technology has not yet been able to prevail over the combustion engine. That is largely because today's batteries still have limited range, relatively long charging times, and

Modal split: Reference district (2002) vs. model city district (2038)



Source: Wuppertal Institute

relatively low durability. This study assumes that battery technology will improve over the coming years, enabling electric vehicles to become, as a matter of course, part of a diversified fleet in the model district. Moreover, it is assumed that citizens will use small electric vehicles to make their short trips within the district or to Munich's city center. For trips of longer distance, people will be able to use hybrid vehicles and vehicles with combustion engines. Electric vehicles would be used in the city's stop-and-go traffic because they are much more efficient, especially when it comes to the energy needed for getting up to speed. A combustion engine, on the other hand, achieves its optimal performance over long distances, not to mention the fact that the range of a gas- or diesel-power engine is much greater than that of an electric vehicle.

In the model city district, mobility service providers would specialize in offering consumers many different forms of transportation – ranging from hydrogen-cell-powered scooters to small, hybrid vans. Car-sharing would also be an important part of the system. Garages and parking spaces will have charging stations available for electric vehicles. The system will be supplemented by "service stations" where the batteries can either be "filled up" in a short time through a quick-charge function, or an empty battery can be exchanged for a full one. Another advantage of a large electric fleet is that it could connect to the electricity grid and provide electricity when necessary, thereby minimizing the problem presented by fluctuating supplies from photovoltaic sources.

Having different types of vehicles with different ranges and functions would mean that resident must, when purchasing or leasing a vehicle, more carefully analyze what type of vehicle is best for their own personal needs. If they expect to make trips almost exclusively within the city or environs, then perhaps an electric car would suffice.

However, if they need to travel longer distances, then a hybrid vehicle or a car with an efficient combustion engine might be the best choice. Most households, however, have varying requirements. Families would shop in the model city district or in other parts of the urban area. But travel for vacation or recreation is often outside of the immediate region. Because most households cannot buy several different vehicles for the various requirements, hybrid vehicles or flexible rental systems and leasing models will play an important role. It is also conceivable that households will give up private vehicles completely and rent vehicles when necessary. Car-sharing and rental companies already exist, proving that such a system could exist without limiting individual mobility.

More efficient combustion engines: As a result of the vehicle improvements outlined in the Scenario chapter – such as those involving drive trains, gears, and weight – it is technically

possible that, by 2038, the new vehicle fleet will consume on average less than five liters for 100 kilometers.

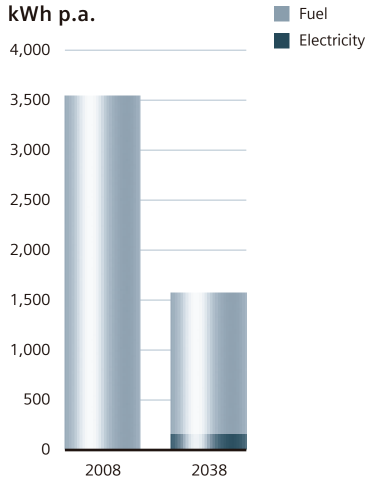
Accordingly, the energy used by MIT in the model city district will decrease. Because of the increase in electric vehicles, a smaller portion of this energy saved will be counterbalanced by an increase in electricity consumption. Using hybrid vehicles in the model city district will account for additional savings.

More efficiency – in short-range public transportation as well: Of course, innovative vehicle technologies for MIT are not sufficient on their own to create a nearly carbon-free transportation system. Short-range public transportation must be made more efficient as well. Today, most of the rail vehicles used in Munich's short-range public transportation system are already electric. Because electric engines are more efficient than combustion engines, buses in the future model district will also be largely powered by electricity.

As described in the Scenario chapter, alternative fuels or hybrid buses could be used during the transitional period. Natural-gas buses in the model city district would also need to be improved for efficiency; they would run predominantly on biogas. There is still considerable potential to reduce CO_2 emissions in rail-bound short-range public transportation (RSPT), which was explained in greater detail in the Scenario chapter. For the purposes of the model city district, it is assumed that those potentials will be achieved.

Challenge of commercial transportation: Of course, commercial transportation – the transport of food and consumer goods, for instance – must be included in any complete analysis of future transportation in the model city district. It is assumed that more goods will

Energy requirement per capita for motorized individual transport



Source: Wuppertal Institute

be transported in 2038 than are today. The traffic created by those deliveries can hardly be isolated to a single district, because any demand created in the model city district would also create traffic outside of the district.

For this reason, it is considerably more difficult to create a carbon-free system for freight traffic than it is for passenger traffic. One option for trans-regional transportation is to use the more environmentally friendly rail system instead of roads. For regional and urban freight transportation, however, that can only be done on a very limited basis.

Therefore, most goods will still need to be transported across the highways in the future – initially with conventional diesel vehicles and later, increasingly, with electric–powered small trucks. Decreasing the extent of the transportation as well as transferring it to the railways would be the easiest ways to decrease emissions. The "CarGoTram" in Dresden, which at hourly intervals supplies parts to an automobile plant in the city center, demonstrates that this idea is at least somewhat viable. Similar concepts include Vienna's "Güterbim" and Zurich's "CargoTram."

Bundling deliveries would also create significant gains. This study assumes that in the model city district, individual companies will no longer deliver all of their goods directly to their customers. Instead, goods will be re-consigned at freight transportation centers on the periphery of the city, where they will be bundled and transported to the model city district, reducing considerably the number of trips required. Additional transport and delivery could be handled by hybrid vehicles and small electric vehicles.

Traffic stemming from shopping trips could also be reduced by using the local transportation system for freight. Today, it is rather unusual for a customer to have goods delivered to his or her home – because of high shipping fees, if nothing else. Generally speaking, buyers pick up their bulky goods, such as a flat-screen TVs or microwaves, and transport them home in their own cars.

In the future, however, it will be common practice for goods purchased in various shops or over the Internet to be bundled into the urban delivery system and delivered directly to the consumer. Advanced IT and communications systems could simplify the complex coordination of delivery requirements, including storage and transportation capacities as well as planning the best routes through the model district. This will include an Internet-based shipping exchange that labels goods with small RFID tags, which can be sorted via radio frequency.

These radio-frequency tags will contain sender and recipient information, which will be conveyed automatically to the merchandise planning and control systems. In spite of all these possibilities, a large portion of goods will still travel over roads for delivery. As with the car, it is therefore imperative to improve the efficiency of utility vehicles.

Achieving the goals through sound traffic management: In addition to the strategies already described, carbon dioxide can be reduced through the intelligent control and management of traffic. Systems to guide drivers to available parking spots and recommend ideal routes in real time, based on conditions, would be a matter of course in the model city district. Moreover, vehicles would be capable of being driven automatically. Cars will collect data from the surrounding area, process that data, and exchange information about traffic or hazards with other vehicles. Because of such smooth coordination, traffic will flow more evenly, saving a considerable amount of energy per vehicle.

Nonetheless, it is also important to consider the following: The less frustrating traffic is, the more attractive travel becomes, which in turn can increase the amount of traffic. With such traffic information systems, CO_2 emissions can only be curtailed if there is a specific emphasis on public and non-motorized transportation and if those forms of transportation become truly attractive alternatives.

3.4 The model city district in detail – heating for the model city district

One thing is clear: The future of the model district's heat supply is multifaceted. In the future, heating will come from a combination of many different heat-generating technologies. This section describes what this kind of heating mix might look like.

In the district of Neuaubing, heat has been generated primarily by three different sources, nearly in equal measure: individual oil-fired systems in residential buildings, gas-operated systems, and a central plant that burns wood chips. This study, however, assumes that in the future, both Freiham-Nord and Neuaubing could exist almost entirely without using fossil resources for energy. This would be possible through the consistent use of geothermal energy, solar-thermal energy, and heat pumps, among other things.

The new development area: The example of Freiham-Nord demonstrates that a consistent low-carbon strategy and design is easier to implement in new development areas than in existing areas. In a new development, it is possible to create a heat supply that is largely carbon-neutral. Consequently, because the power supply would be installed from scratch, Freiham-Nord is well-suited for a district heating system.

Southern Bavaria and the Munich metropolitan area enjoy favorable geological conditions for hydrothermal heating. Thus, the new development area is well suited for the use of geothermal heat, fed into a district heat supply. The great advantage of geothermal energy is that it can provide heat on a continuous basis and, if needed, also electricity – similar to a conventional heat and power cogeneration station. In 2038, the new development's total heat requirement will amount to about 24,000 MWh/a. A geothermal heat station, like the station operating in Munich's Riem district, could supply about 45,000 MWh/a of heat, which would be enough to supply part of Neuaubing's needs as well. The amount of heat available for the older buildings is dependent mainly on whether the future geothermal power plan were to be used only for heat or also for power generation since the latter would require the diversion of a good portion of the heat. This, in turn, is dependent on the temperature of the water in the deep soil layers beneath Munich. Generating electricity with steam requires source temperatures of at least 100° C. According to current data, Munich's source temperature is around 93° C, just short of the required temperature.

Ultimately, however, only test drilling can determine the amount and the temperatures of thermal water available. The prerequisites from the point of view of supplying heat are favorable: Thanks to the passive house standard, space heating could be achieved with a low-temperature district heating grid (based on the LowEx principle) with a low-flow temperature. As a result of the low flow and return temperature, heat losses will be minimized. The electricity yield in the power plant will increase.

Of course, the arrangement would only make sense if all the buildings in the new development were connected to the district heating grid. That would make it unnecessary to construct an expensive natural gas network. Biomass that accumulates in the district, such as wood, agricultural waste, or garden debris, could be distributed to the neighboring urban districts not connected to the geothermal heating grid.

The older buildings – it's all in the mix: As previously mentioned, it is more complicated to supply Neuaubing because supply structures, such as natural gas networks, already exist. Therefore, the mix of heat sources is particularly important when refurbishing older buildings. The percentage of buildings that could use geothermal district heating would depend, on the one hand, largely on how many could be connected in a cost-efficient manner. Another consideration, however, is how geothermal energy would be used in the future – solely for heat generation or also for electricity generation.

A geothermal heating plant could supply heat not only to the new development area but also to the one third of Neuaubing's buildings currently being supplied by the wood-chip-fired heating plant. The advantage: The district would be largely unaffected by price increases in wood fuel. This study also assumes that expanding the heating network will allow geothermal energy to supply approximately half of the buildings currently being supplied with heating oil. The residents, however, will first have to be convinced of the advantages of district heat. Overall, the geothermal plant could supply 31,500 MWh of district heating – 24,000 MWh to the new development area and 7,500 MWh to the older buildings.

A geothermal plant requires a high initial investment, but has low operating costs. There-

fore, it is important to achieve high capacity. However, the following must also be considered: The hot water requirement remains roughly the same throughout the year. The heating requirement for buildings, however, is restricted to several months during the winter and the shoulder seasons.

In this context, there are three primary strategies for operation:

➔ Supplying all the necessary heat energy (hot water and heating) via a geothermal plant (without storage): Such a plant must be designed on a large scale. Therefore, there would be significant costs for drilling the wells and for the pumps.

➔ Supplying all the heat necessary for hot water, and part of the heat necessary for heating the buildings: The geothermal plant would generate enough heat for the base load requirement. The peak load would be covered by a peak-load cauldron (e.g., biomass).

➔ Supplying all the necessary heat (hot water and heating) via a geothermal plant (with storage): Suitable storage options include deep, aquiferous layers in the ground (aquifers). These aquifers could store hot water until the hot water is fed back into the system, acting as a buffer during peak periods.

A detailed analysis must be conducted to determine which of these three strategies would ultimately make the most sense economically.

However, below are a few basic calculations regarding the cost effectiveness of a geothermal plant for the model city district. This study takes into account the development and operating costs of the plant as well as the costs of expanding the district heating grid. The cost to develop the geothermal plant is estimated at about €24 million, which results primarily from the cost of drilling. With a real interest rate of four percent and a plant lifespan of 40 years, that would amount to annual capital costs of around €1.2 million in addition to about €300,000 in personnel and maintenance expenses. The cost to distribute the heat depends largely on the density of the settlement. These investments would be made primarily in the new development area and in a section of the older district (about one sixth of it) that would be connected to the existing district heating system. According to current

calculations, providing district heating supply to both areas would require an investment of around €30 million. That would include house connection lines in addition to the actual geothermal plant. In order to keep the costs as low as possible, it would make sense to install the networks as cost effectively as possible during the new construction or when refurbishing the older building. The network expansion would result in annual capital costs of about €1.5 million. On the basis of these assumptions, heating costs could be expected to be approximately €119/MWh for households in the model city district. To a large extent, these costs would remain constant over the time period because more than two-thirds of the expenses come from the capital costs of the geothermal plant and the district heating grid. This cost would therefore be comparable to the costs for other heat-supply systems: Fuel costs generally amount to about €80/MWh, and additional costs associated with the natural gas connection or the oil tank amount to roughly €30/MWh. It is presumed, however, that fuel costs will increase in the future. If energy costs rise slowly over the next 30 years, as is assumed in the "low-price path," then geothermal district heating would cost around 11 percent less than oil or gas on average. If, on the other hand, the costs of energy rise more quickly, as is assumed in the "high-price path," then geothermal district heating would cost about 23 percent less than heating with fossil fuels on average.

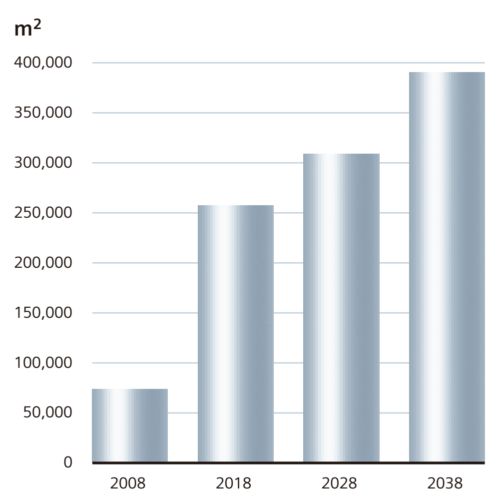
As to Neuaubing's future mix of heat sources: This study assumes that it is not cost-efficient to construct an additional heating main for the buildings already connected to the natural gas network. However, in order to minimize the emission of carbon dioxide, in addition to being refurbished to comply with the passive house standard, these buildings could be equipped with solar systems for heating water and for heating support (solar-thermal system). In this manner, solar energy would account for as much as 70 percent of the overall heat requirement (heating and hot water). In the event that shade or an unfavorable northern orientation made a roof surface unsuitable for a solar installation, another option could be to convert the conventional natural gas furnace to a gas heat pump, or to a micro heat and power cogeneration plant. Those changes would save energy and reduce CO_2 emissions by an additional 20 to 30 percent. Moreover, it would make sense to add more and more biogas to the mix with the fossil fuel, natural gas.

Unlike natural gas heating systems, oil heaters are not connected to a supply network. For that reason, connecting to the district heating network appears to be cost effective in many cases. After all, no duplicate infrastructure would be built since the existing local heating network would only need to be expanded in order to include additional buildings. This study assumes that about half of the buildings heated with oil could be connected in this way. Another sensible alternative that is virtually carbon-neutral is the use of pellet heaters (boilers or furnaces) which could, in particular, replace oil heaters. The space currently occupied by the tank could easily be used to store pellets. Ideally, solar plants for heating water would supplement the pellet systems. This would save approximately 30 percent of the fuel. In the summer, when the heat requirement is low, this pellet system could be turned off completely.

3.5 The model city district in detail – electricity for the model city district

First things first: At least 100 percent of the annual electricity requirement for the model city district could be met by locally produced photovoltaic electricity. Even if this change could not take place throughout the entire urban area of Munich, these numbers demonstrate the potential of renewable energy. The roof surfaces available in the model city district offer sufficient space for the required number of photovoltaic modules. Among the factors the study took into account were the typical capacities of 10 different house types with different roof orientations, shapes, and slopes. As previously mentioned, using additional geothermal

Potentials for solar roof surfaces



Source: Wuppertal Institute

energy for generating electricity depends on the thermal water temperatures available.

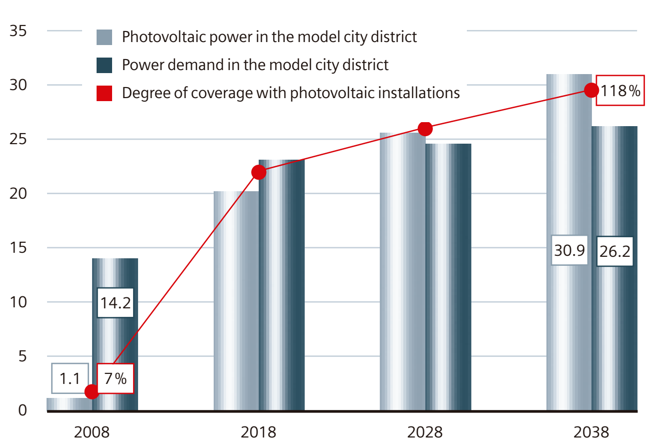
Using this data as a basis, the study analyzed the different possibilities for expanding photovoltaic installations. It also took into consideration dormer windows and such variations that would prevent an entire roof surface from being usable space. It was assumed that over time, photovoltaic power systems would be installed on all the available and suitable roof surfaces in the new development area. The results are impressive: By the end of 2038, when the development and construction in Freiham-Nord would be complete, the photovoltaic systems could supply 40 MWp of power. That would be sufficient to meet the model district's entire demand for electricity. As early as between 2018 and 2028, photovoltaic energy in the model city district could achieve 100 percent coverage, and by the end of 2038, it could even achieve 118 percent coverage. That is quite substantial when compared to today's figures. Even though Munich has very good solar radiation conditions compared to the rest of the country, only about 12.3 MWp was installed in the entire urban area as of the end of 2006. That amounts to about 9.5 watts installed capacity per capita. At the end of 2006, the figures nationwide were around 32.8, and in the state of Bavaria even 88 W per resident. Of course, obtaining a large amount of solar energy requires sophisticated forecasting, measurement, and control systems, appropriate telecommunications systems for data communication, and storage batteries. After all, solar-generated electricity fluctuates over the course of the day. The challenge in photovoltaic integration lies – in addition to proper power storage management – in managing and controlling the recovery, which is considerable. Therefore, adequately managing power storage and recovery is crucial to photovoltaic integration. With this kind of large scale, considerable

fluctuations in output will occur at different times of the day or with changing weather. Thus, to achieve the ambitious expansion of photovoltaic systems expected in the model city district, network technology will need to be improved and expanded.

Costs of photovoltaic systems in the model city district: One pillar of the model city district concept is the comprehensive use of solar energy produced by photovoltaic power panels. The study assumes that available roof surfaces will be directly equipped with photovoltaic installations during construction or refurbishment. Because photovoltaic systems will be employed on a large scale, it is to be expected that the cost of planning, purchasing, and installing such systems will be less than in individual building projects. Assuming a maximum utilization of available surfaces, photovoltaic power plants with an average peak output of around 40 MW could be installed. That corresponds to a little more than 1 MW per year on average. The prices for photovoltaic power plants are currently (in 2007) between €4,000 and €5,000 per installed kilowatt of peak output. This study, however, anticipates that larger markets and improved processes will considerably reduce the production and systems costs for photovoltaic systems over the coming years. Here, a total cost of at least €70 million is calculated for the 40-MW system. That price corresponds to around €1,750 per KW of peak output.[5] However, the greater part of that sum would need to be invested before 2020. After that point the expansion will become considerably more cost effective. The photovoltaic power plants will be financed with the diminishing support prescribed by the Electricity Feed Act. As part of that law, the investor receives significant compensation for the plants installed during the first years – in other words, when the costs of photovoltaic systems are still rather high. Later, more affordable systems will accordingly be given less support. On average, a 4-kW system costs investors around €18,000. An investor who installs a system in 2009 will receive guaranteed compensation of €0.43 per kilowatt hour fed into the system over a period of 20 years. A good system at an average site in southern Germany, with optimal orientation and no shade, can expect an annual output of 4,000 kilowatt hours of solar energy. With that amount of generation, the investor will realize about €34,000 over those 20 years. Because operating costs, the meter-reading fee, and replacing the inverter costs very little, the investor will have a considerable net return. Thus, the investment in a solar installation pays off.

Trends for power demand and photovoltaic power generation

Power generation and demand in GWh p.a.



Source: Wuppertal Institute

[5] When calculating the investment sum, it is assumed that no reinvestments would be required before the completion of the model city district. This is a rather optimistic assumption given an overall construction period of 30 years.

Best Practice

Malmö

Fortunately, low-carbon urban districts are being created or planned all over the world. One of the pioneers is the Swedish city of Malmö, which as early as 10 years ago began constructing an environmentally friendly new development with 3,000 apartments for about 10,000 residents.

Malmö's city government and the private energy provider Sydkraft set themselves a goal of supplying the new development quarter, Västra Hamnen, with 100 percent of its electricity and heating from renewable energies or from refuse incineration by 2010. The development is near the central railroad station, between the Baltic Sea and a park. As a result, it is easily reached on foot or by bike. Two bus lines were created to further reduce the amount of motorized individual transportation. The buses run every six minutes. Electricity is supplied primarily by wind turbines and photovoltaic power plants. Their output is so high that they manage, on balance, to supply the entire area 100 percent. However, because of load fluctuations due to the weather and the time of day, Västra Hamnen is also connected to the public electricity grid. The district draws heat primarily from a deep geothermal well. The well provides water, which is only about 15 degrees, from deeper, water-bearing rock layers (aquifers). Using heat exchangers, the temperature is increased to more than 60° C with heat pumps and the energy from solar-thermal plants. In the summer, the deep cool water is pumped through the district's buildings for cooling purposes. Ultimately, geothermal energy provides about 85 percent of the necessary heat energy, and solar-thermal energy provides the rest.

The Reichstag (the parliament building) in Berlin also uses water-carrying aquifers for heating and air-conditioning purposes as well as for a seasonal heat reservoir. In the summer, excess heat is pumped into the deep aquifer layers. That heat comes from a heat and power cogeneration plant powered by vegetable oil and from solar installations on the roof of the Reichstag and adjacent buildings. Because the heat does not escape from the large water reservoir quickly, there is still enough energy available in the winter to pump it back to earth's surface and heat the Reichstag. Similarly, the building is cooled in the summer with water from a second "cold" aquifer layer.

To answer the question of whether mankind will be able to pursue a sustainable course in its efforts to develop energy-efficient infrastructures, one must look to the cities. Overall, it is the cities that produce the lion's share of CO_2 emissions. At the same time, because of the concentration of technical knowledge in the cities, they are also hotbeds of innovation where new ideas and solutions are generated. With this in mind, this study points to ways that modern, energy-efficient technologies can be implemented on a broad scale, and how sustainable urban development can be accomplished. Sustainable development, however, comes with a

4.0 Outlook

price. In a city such as Munich, citizens and industry will need to invest considerable sums over the coming decades to make the city CO_2-free. But it is already apparent that many of these investments will pay-off through energy savings. A further benefit is that the local economy can mobilize opportunities and develop expertise, bringing competitive advantages for the city in the future as an attractive place to do business.

It is an enormous task to transform a metropolis into a nearly carbon-free urban center. In order to succeed, the goal of becoming carbon-free must be assigned a high priority in the overall development of the urban infrastructure, including city planning, building construction, transportation systems, and energy supply. And the same holds true when it comes to investments from the private sector. On the one hand, this is the responsibility of the decision-makers, the city government, the energy providers, and the urban planners. But equally important is the involvement of the population and investors, along with a clear commitment on their part to energy efficiency. It is likely that such a profound transformation in the way energy is produced and used can only be achieved through a political framework that promotes high efficient, low-carbon technologies. Just as important is the raising of awareness among the population. Energy efficiency will become truly appealing when it pays off. Therefore, it will be important to ensure that the benefits and financial rewards of investing in efficient technologies become more transparent and widely known. At the same time, as some technologies are still relatively recent, future technological developments and more efficient production will likely decrease their cost, and thus increase their use. When all of these factors are aligned, the scenarios outlined in this study can indeed become a reality.

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Electricity requirements: Claus Barthel
Electricity grid and decentralized power generation: Frank Merten

Picture editing: Judith Egelhof, Irene Kern, Publicis Pro, München

Photography: Kurt Bauer, Simon Katzer

Photo credits: Nagy/Presseamt München (2/3, 8/9); Osram (20/21);
Landeshauptstadt München Baureferat (21), Stadtwerke München (41)
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Layout: Rigobert Ratschke, Seufferle Mediendesign GmbH, Stuttgart
Graphics: Jochen Haller, Seufferle Mediendesign GmbH, Stuttgart
Printing: Bechtle Druck&Service, Esslingen

Printed in Germany

Order no.: A19100-F-P135-X-7600

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