Urban Insight is an initiative launched by Sweco to illustrate our expertise—encompassing both local knowledge and global capacity—as the leading adviser to the urban areas of Europe. This initiative offers unique insights into sustainable urban development in Europe, from the citizens' perspective.

The theme for 2019 is Urban Energy, describing various facets of sustainable urban development as regards energy usage, renewable energy and energy efficiency—withe future challenges and opportunities in the new energy landscape.

In our insight reports, written by Sweco’s experts, we explore how citizens view and use urban areas and how local circumstances can be improved to create more liveable, sustainable cities and communities. Please visit our website to learn more: swecourbaninsight.com
REDUCE, REUSE AND REIMAGINE  
– SUSTAINABLE ENERGY  
DEVELOPMENT IN THE CITY

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SMART ENERGY
RE-USE IS GAINING IMPORTANCE IN URBAN DEVELOPMENT, PARTICULARLY IN ADDRESSING GLOBAL CLIMATE CHANGE CHALLENGES AND FUTURE LIMITED FOSSIL FUEL RESOURCES.
Designing and planning the communities and cities of the future will involve not only saving energy, but also developing smart energy-efficient solutions focused on the re-use of energy. Great amounts of energy are currently wasted in our cities. We need to identify creative new ways to reuse this energy.

Energy that can be harvested and reused will be an essential part of the future energy system. There is great potential in Germany to reduce energy consumption, particularly since fossil fuel consumption in Germany’s residential sector is among the highest in Europe. It is possible to achieve an 80 per cent reduction by 2050, over 2008 levels, in final primary energy consumption in Germany’s residential sector if we change the way we reduce, reuse and reimagine energy. The right approach to reducing energy consumption will produce cost savings of up €13.34 billion.

In the UK, energy wasted in the electrical system — before it even reaches homes and industry — costs billions of pounds. Currently, £9.5 billion is lost every year. According to the Association for Decentralised Energy, this is over half of the amount spent on electricity by all UK homes.1

More can be done to develop a more sustainable energy system. Similar to the role of recycling in the waste management sector, an improved re-use of energy will produce great environmental benefits by reducing consumption of fossil fuels as well as reducing the need for renewable energy.

“THERE ARE LOTS OF BENEFITS TO MAKING THE ENERGY SYSTEMS MORE EFFICIENT.”

Waste management became common practice in the mid-70s to decrease environmental pollution and reduce the amount of waste. A well-defined waste hierarchy was established: first, reuse; second, recycle materials; third, incinerate for energy recovery or deposit in landfills. A similar hierarchy can be established for energy: first, prevent use; second, preserve, reuse and recover.

Re-use of energy is possible and is already practised in many contexts. Re-use of energy can be understood as a smart use of excess energy that would otherwise be dissipated unused into the environment — for example, using excess heat from a car engine to heat the car. Re-use of energy comprises clever combinations of different types of energy. As a result, the re-use of energy increases the efficiency of energy usage to face the challenges of climatic change and limited fossil fuel resources.

The smart re-use and recovery of energy is also gaining importance in urban development. Energy generation is one of the main sources of carbon emissions. By phasing out fossil fuels and using our energy more effectively, we can substantially reduce carbon emissions. This would also be instrumental in achieving five of the UN Sustainable Development Goals: affordable and clean energy; industry, innovation and infrastructure; sustainable cities and communities; responsible consumption and production; and climate action. Urban planners and designers throughout the world are already starting to implement technical solutions to reuse energy in industrial and residential buildings.

The re-use of energy is an essential component of sustainable energy development. The journey towards energy re-use starts with a consideration of final energy consumption. Future communities and cities need to consider Waste-to-Energy concepts for supplying residents and industry with energy while also eliminating fossil fuel emissions.
2. WHAT IS “RE-USE OF ENERGY” IN URBAN DEVELOPMENT?
Some communities are already discussing an autonomous energy supply based on renewable types of energies — independent from big energy suppliers. These challenges and ambitions have a strong impact on urban development. In order to make this influence more tangible, we spoke with Robert, an urban developer.

Robert is working on the development of a district in a mid-size European city. The plan is to improve the technical standards of existing buildings and expand the district by converting the area of a former factory. Area residents gathered at a town hall meeting to discuss the pros and cons of the development. One topic dominated the discussion: What can be done to minimise the energy usage and CO2 footprint of the district?

Robert leaves the town hall meeting with a multitude of questions and ideas:
- A mixed zone of housing and offices is planned in the conversion area. How should it be supplied with heat and electricity?
- How can existing buildings (blocks of flats from the 60s and 70s) be improved as regards heat and electricity?
- A small, resident-owned power plant could be constructed in the area. Is this a good idea? If so, what do you suggest would be a good way of producing energy there?
- There are still factories operating in the neighbourhood. Are there any smart solutions to use the factories’ heat to heat the districts’ flats? Which fuel can be used in place of coal, oil or natural gas?
- The meeting participants mentioned condensing boilers, heat pumps, wastewater heat, heat from the subway, combined heat and power plants – but preferably no use of fossil fuels and, if possible, no waste incineration.

Back in the office Robert asks his colleagues Paul and Sonja from the energy and waste department: “Could you please explain to me the contexts in which you would use a particular type of energy, and why?”

Robert’s colleagues are surprised at the variety of questions and innovative ideas. “The residents are suggesting nothing less than the imminent changeover of the energy supply – but here, it is related to the tangible development of an urban district. But there will be no comprehensive solution – it is always situation-specific. Each approach needs to be reflected on as regards technical feasibility, environmental and social impact, and economics. Making a decision on a sustainable solution requires serious consideration of possible opposite effects.”

Paul, a facilities engineer, goes more into detail: “The technology to supply a household with heat and electricity without fossil fuels is available. But a passive building, which no longer needs a heating system, requires a 10 to 30 per cent greater investment. The fuel cost savings repay the higher investment in subsequent years, but the higher construction costs need to be paid upfront when the passive house is constructed. This makes it difficult for families with modest incomes to build or buy a passive house. This also applies to rented flats. With higher construction costs for greater energy efficiency, there is less interest in constructing inexpensive rental flats. As a consequence, there is an increasing housing shortage for people with small or medium incomes.”

Sonja, a chemical engineer, gives another example: “Throughout the year, a factory that produces acrylic resins needs a great deal of heat at 300°C to supply their production processes. The company currently heats up thermal oil with natural gas, a fossil fuel with a small CO2 footprint. It would be possible to eliminate fossil fuels by generating heat using an electric boiler, but generating heat with electricity is costly and would only reduce CO2 emissions if the electricity is generated from renewable energies or nuclear power. Additionally, the factory competes in a market where the product price ultimately counts more than the product’s sustainability.”

Robert is not happy about these statements. Does this mean that all approaches to reducing the share of fossil fuel consumption for energy generation are unfeasible due to economic or social-political reasons? What about the consequences of climate change? If we continue to generate and consume energy without making any changes, the negative economic and social consequences will be much greater than if we accept manageable impairments now.

Sonja and Paul agree with Robert. While the economic and social consequences are relevant in the present and near future, medium- to long-term development needs to be considered when developing an urban district. Sustainable urban development must simultaneously create environmental, economic and social solutions. We cannot immediately change an historically evolved energy supply situation, but we can improve energy production efficiency through the intelligent combination of different technologies. We can reduce consumption of primary as well as renewable energy by reusing excess energy. We already have tools at our disposal to utilise heat from sewage water, subways and electrical grids.

Along with expansion of renewable energies, energy re-use plays an important role in phasing out energy production from fossil fuels.
3. WHICH KINDS OF ENERGY DO WE FINALLY CONSUME?
Our journey to the re-use of energy begins with a short look at the current final energy consumption (Ill. 3), taken from the official energy balances of EUROSTAT. We look at 14 different European countries to show the variety of final energy consumption in different European regions.

Selected countries:
- Denmark, Finland, Norway and Sweden in the north
- Germany, the Netherlands, Belgium and the United Kingdom in the west
- The Czech Republic, Estonia, Lithuania and Poland in the east
- Bulgaria and Turkey in the south

The selected countries differ in economic and industrial structures. They also differ in methods used to generate electricity and heat and in final energy consumption.

But looking at final energy consumption in nearly all selected countries, most final energy consumption can be allocated to transport and to direct consumption of fossil fuel and renewable energy for industrial heating processes and household heating.

With regard to the re-use of energy, this report focuses on the provision of heat, since electricity cannot be used a second time. As shown in Ill. 3 most heating energy is supplied by fossil fuels, followed by renewable energies and derived heat. Derived heat covers the total heat production in heating plants and in combined heat and power plants. Derived heat is generated centrally and consumed decentrally, which provides options for reusing excess heat from electricity production or industrial processes precisely where the heat is required – even in cases where there is insufficient heating demand at the heat generation site. Distribution of energy consumption varies in the countries studied, depending on usage for residential (Ill. 4) or industrial (Ill. 5) heating purposes.

Fossil fuels still predominate in final residential energy consumption, particularly in the UK, Belgium, the Netherlands, Turkey and Germany. In the Scandinavian countries (excluding Norway) and Baltic countries studied, renewables and derived heat dominate the energy consumption for heating. In Belgium, the Netherlands, Turkey and the UK, the use of derived heat is comparatively negligible, due to a strongly expanded natural gas supply.

“IN SUM, WE STILL HAVE A LONG WAY TO GO IN TERMS OF ELIMINATING FOSSIL FUEL IN HEAT GENERATION, ESPECIALLY FOR INDUSTRY.”

The review of energy sources in various European countries also shows that fossil fuel usage for heating purpose is not absolutely necessary, even for countries with low winter temperatures. Especially in Scandinavia and the Baltic States, the use of fossil fuel for residential heating purposes has already been replaced by derived heat and renewable energies.

Fossil fuel plays a more important role in industrial heating processes (Ill. 5). A small share of Industrial heat demand is covered by waste incineration. Renewable energies represent a significant share only in Sweden and Finland.

DISTRIBUTION OF FINAL RESIDENTIAL ENERGY CONSUMPTION FOR HEATING 2016

DISTRIBUTION OF FINAL INDUSTRIAL ENERGY CONSUMPTION FOR HEATING 2016
4. EFFICIENT UTILISATION OF FUEL
4.1 CONTROLLED BUILDING VENTILATION

The re-use of energy starts with changing our habit of opening windows in the morning. Many people ventilate a room with cold outside air. In their view, the room is perfectly ventilated when the temperature has dropped noticeably. But what do we want to achieve with ventilation? We want fresh air with a higher oxygen content or, even better, a lower CO₂ and moisture content. There is no need to simultaneously cool down the room by letting in cold ambient air. A forced ventilation system with a heat exchanger ventilates the room without sending warm exhaust air to the outside environment.

"Depending on ventilation system design, 50–80 per cent of the heat in the exhaust air can be recovered. Forced ventilation also provides a better inside climate."

About 80 per cent of a building’s energy consumption is used for heating and cooling. There is a lot of potential to use this energy more efficiently. As always, though, a feasible solution does not only present advantages. The additional cost for heat recovery forced ventilation systems amounts to €2,000–€13,000, depending on local conditions and equipment, for a typical German detached house with 120 m² living area. Forced ventilation systems, like all technical equipment, also require regular maintenance to avoid wear and the growth of pathogens.

Installing forced ventilation systems in existing apartment buildings, especially those built in the 1950s, is not an easy task due to low ceiling heights and lack of space for installing the necessary equipment. This applies particularly to city centres, with their mature building structures. Another disadvantage concerns our old-fashioned habits. In practise, energy recovery cannot always be achieved by forced ventilation systems because many people are used to opening windows – even though the ventilation system makes this unnecessary.

Nevertheless, the benefits of lower energy consumption and an improved indoor climate outweigh the disadvantages in the long run. It is therefore advisable to consider installation of a forced ventilation system when installing or modernising a heating system.

Forced ventilation systems are a good example of energy re-use, as they extract heat from exhaust air and allow us – in a figurative sense – to use the heat a second time.

4.2 UTILISATION OF FLUE GAS HEAT AND CONDENSING BOILERS

Since the inception of steam generation, flue gas heat generated by fuel combustion has been used to evaporate water into steam and subsequently overheat the steam. However, heat utilisation from flue gas is limited by physics: To ensure sufficient heat exchange in the boiler, the flue gas always needs to have a higher temperature than the produced steam. The flue gas from the boiler still contains energy, which can be used to preheat the combustion air and/or the feed water for the steam boiler.

Preheating combustion air and feed water has been an established practice since the early 20th century. It is mentioned here to highlight its potential use in residential heating systems. Low-temperature gas heating systems have flue gas temperatures of >120°C. To recover some of the flue gas heat, the stack can be constructed with an uninsulated inner pipe for flue gas and an insulated outer pipe for combustion air. Combustion air flows through the outer pipe and is preheated by hot flue gas in the inner pipe. A small fan maintains the flow of combustion air. The recovery rate of this simple construction is an approximately 4 per cent increase in system efficiency for low-temperature heating systems.

The condensing boiler is a further step in reusing flue gas energy. Combustion of a fossil or renewable fuel mainly forms CO₂ and water. The latter is emitted as vapour with the flue gas. Vapour from combustion contains a lot of energy, as water molecules need energy to become vapour above the fluid. This energy is called “evaporation energy.” Part of this energy can be recovered by using a heat exchanger before the stack. The flue gas is cooled below the condensation temperature of the vapour in the flue gas – normally 48°C for oil-fired boilers, 57°C for gas-fired boilers, and 68°C for wood-fired boilers. Cooling can be achieved by preheating the combustion air and the backflow of the heating system.
Flue gas condensation allows up to 15 per cent heat recovery of the fuel input energy. Many industrial processes have temperature demands above 100°C that exceed the temperature level of flue gas condensing. Even in these cases, heat from flue gas condensing can be used to preheat water or other fluids that need to be further heated by other means. Low-temperature heat from the condensate can be utilised as a heat source for a heat pump (discussed below).

To sum up, flue gas condensers in small residual boiler installations are state-of-the-art and significantly increase fuel utilisation efficiency. If frame conditions – such as site-specific heat demand and flue gas acidity and dust load – are taken into consideration as early as the design phase, flue gas condensers can also be operated with high availability and efficiency in biomass and other combustion plants. Ideally, plants with flue gas condensers should be combined with a district heating grid to derive heat. If the plant’s heat generation capacity exceeds heat demand during summer, additional pipes can bypass the flue condenser. If higher temperature levels are required, combination with heat pumps is an option.

“WITH AN IMPROVED REUSE OF ENERGY, SYSTEMS WILL NEED LESS ‘NEW ENERGY’ TO MEET HOUSEHOLD AND INDUSTRY ENERGY NEEDS.”

Condensing boilers in residential heating systems have already proven their feasibility and dominate the heat system market. In larger plants, they can improve fuel utilisation efficiency. Condensing boilers are therefore a reasonable measure for reusing energy.

Up to this point, we have only discussed measures for reusing energy by reducing heat losses and utilising excess heat from combustion process flue gas. Heat can also be extracted during electricity generation. This process is called Combined Heat and Power generation, or CHP.

If the electricity is produced by a gas- or oil-fired motor, flue gas has a temperature of approximately 500 – 850°C. This temperature level allows steam generation. Following steam generation, a flue gas condenser, described above, can utilise the remaining heat.

Electricity generation in a steam turbine also allows the extraction of heat in a CHP process. In steam turbines, the steam in the turbine rotates the turbine rotor, which drives the generator to generate electricity. By converting the thermal energy contained in the steam into rotational energy, the steam expands, i.e. the temperature and pressure of the steam decrease. For pure electricity generation the steam is expanded to pressures below atmospheric conditions to utilise as much steam energy as possible. In a CHP plant, all or part of the steam is expanded to a certain pressure corresponding to the required temperature level for heating purposes. Although slightly less electricity is generated in a CHP process, more total fuel energy can be utilised for combined electricity and heat production.
In terms of steam input energy, efficiency increases from 35 per cent in old coal-fired plants, and from 55 per cent in modern gas and steam turbine plants for pure electricity generation, to more than 85 per cent for combined electricity and heat production. The simultaneous generation of electricity and heat allows much more efficient fuel utilisation, even in the most effective gas and steam turbine plants.

Due to the cost of heat extraction equipment, investment costs for CHP plants are approximately 20 – 25 per cent higher than for a simple power plant. To operate economically, CHP plants normally need a minimum heat demand that allows heat extraction for around 5,000 full-load hours per year. It may be impossible to extract heat from a CHP plant during the summer, when heat consumption in residential areas decreases to about 10 per cent of winter demand. At best, therefore, a CHP plant is operated following heat demand and has a capacity below the maximum heat demand. In winter the required heat that cannot be generated in the CHP plant is produced in a heating plant.

Derived heat comprises extracted heat from CHP and heating plants. Derived heat is an important measure for future energy re-use. Although most derived heat is currently generated by the combustion of fossil fuel, derived heat grids also offer opportunities to distribute heat from sources other than fuel combustion. For residential consumers in particular, excess energy from various alternative sources that are currently not utilised can supply derived heat in future. This makes derived heat an important measure for future energy re-use.

CHP has been well established for over 100 years. Nowadays many CHP plants can be found in industry, for the simultaneous generation of electricity and supply for district heating grids.

CHP plants produce 2.5 – 20 kW electricity and 10 – 40 kW heat and are intended for detached houses. Micro-CHP plants produce 2.5 – 10 kW electricity and 10 – 40 kW heat and are intended for small-family buildings and small and medium-size commercial enterprises. Both kinds generally use gas motors with flue gas heat utilisation to produce heat and electricity.

This may address the issue concerning small individual power and heat generation. Due to funding conditions, district heat is currently primarily generated in biomass heating plants.

In the wake of the large-scale CHP plants mentioned above, with capacities of 100 kW – >100 MW, small CHP plants are gaining importance. Nano-CHP plants generate up to 2.5 kW electricity and up to 10 kW heat and are designed for detached houses. Micro-CHP plants produce 2.5 – 20 kW electricity and 10 – 40 kW heat and are intended for multi-family buildings and small and medium-size commercial enterprises. Both kinds generally use gas motors with flue gas heat utilisation to produce heat and electricity.

CHP is a very useful instrument for optimising fuel utilisation efficiency if there is sufficient heat demand throughout the year. Sufficient heat demand may be prompted by the installation of district heating grids. CHP plants are therefore also an important element for the re-use of energy.

Due to high investment costs, heating networks for derived heat today are mainly suitable for areas with sufficient connection densities of at least 50 GWh/km². Unfortunately, some heat gets lost during transport. According to a study on local heating grids conducted by Energieagentur Freiburg GmbH, losses vary between 40 per cent in old district heating grids or at low connectivity density and <10 per cent relative to the heat input into the network. Network age, maintenance conditions and connectivity density have a significant impact on these losses. In cities with a high amount of connected multi-storey blocks of flats, office buildings, shopping malls etc., losses can be reduced to less than 10 per cent under good conditions. As the Energieagentur Freiburg study shows, under good conditions losses of under 10 per cent can also be realised at low connection densities. Further loss reduction is possible if the heating grid’s overall temperature level can be reduced. More on that later.

As the examples of Norway and Lithuanian show, it is not only pure energy efficiency but also competition with other energy sources such as hydropower (Norway), or politically established economic conditions, that determine the spread CHP plants.
5. WASTE AS A MEASURE OF ENERGY RE-USE
So far, we have only looked at opportunities for optimising fuel utilisation efficiency without looking closely at the fuel. As discussed above, fossil fuel currently predominates in heat generation in many countries. Why not use the energy content of waste as another measure of energy re-use?

Many Waste-to-Energy (WtE) plants are CHP plants that generate electricity and district heat (Ill. 10). In Denmark, a WtE plant in Frederiksberg was already supplying heat back in 1903. Besides supplying heat to residential areas in Germany (plants in Bernburg, Knapsack, Weener), France (soon in Chalampé) and other countries, steam is also supplied to other industries such as the chemical and food industries. The WtE plant in Reutenstadt Savenhagen (Mecklenburg-Vorpommern, Germany) supplies a crisp factory (Fanny Frisch) with steam. This example illustrates a change in evaluating WtE plants. Waste is becoming an interesting alternative to fossil fuels.

Marcin, from the energy department in Poland, explains to Robert, the urban planner, the rationality of waste incineration for urban energy supply: “To compare energy generated from a WtE plant to something tangible, imagine heating water in a boiler. The waste incineration plants operating in Poland generate a total of 585 GWh of electricity – enough to supply 5.3 million homes with electricity and to heat enough water for 23,400,000,000 cups of coffee! What’s more, these incineration plants cover the annual energy consumption for nearly 60,000 homes, assuming 16.35 MWh as typical annual house consumption for central heating and domestic hot water.”

Marcin also describes the path of the waste as it moves through the WtE plant. In a modern WtE plant (Ill. 11) waste is delivered by lorry or rail, weighed and stored in the waste bunker. The waste is incinerated completely on a movable grate at furnace temperatures of >850°C. The hot flue gas from incineration generates high-pressure steam of up to >40 bar and up to 450°C in the subsequent boiler. Air pollutants like nitrogen oxides, sulphur oxides, hydrochloric acids, hydrogen fluorides, heavy metals, dioxins, furans, dusts, fly ashes and other compounds generated during the combustion process are separated from the flue gas in a multi-stage flue gas cleaning process.

The slag from waste incineration, which contains incombustible minerals and metal scrap, comprises 20 – 25 per cent of the weight of the untreated waste and is stored in a slag bunker. Ferrous and non-ferrous elements are recovered in separate treatment steps. After a maturation process to stabilise the remaining slag, it can be recycled as a construction material. Boiler ash and flue gas cleaning residues are collected in silos and, depending on local regulations, disposed of in former mines (Germany), stabilised and disposed of in landfills or, in rare cases, used in construction.

The utilisation of steam from the boiler depends on the particular energy demand at the site. The steam is generally utilised for electricity generation in a steam turbine with a generator. Ill. 10 shows that some incineration plants that deliver only electricity are still in operation in Belgium, Germany and the UK.
In most cases, these plants are located too far from potential consumers to allow for economically feasible heat extraction. A much more efficient use of energy in waste can be achieved by generating electricity and heat in a CHP process, or in particular by generating heat exclusively for industrial heating purposes. A WtE plant that produces only electricity achieves an electrical efficiency of 25 – 33 per cent due to the technical limitations of steam pressure and temperature. Using energy in the waste exclusively for heat generation or in a CHP process increases a WtE plant’s efficiency by up to 85 per cent. Most WtE plants are currently operated as CHP plants (Ill. 10).

Interestingly, waste incineration is also gaining importance in Eastern European countries. In Poland, for instance, where there is a high proportion of coal in the energy supply, the first waste incineration plant was opened in 2000 in Warsaw. It remained the country’s only WtE plant until 2015. WtE plants are now operating in eight cities: Białystok, Bydgoszcz, Konin, Krakow, Poznań, Rzeszów, Szczecin and Warsaw.

Critics claim that waste incineration prevents material recycling. Ill. 11 shows the share of municipal waste being disposed of in landfills, treated in Waste-to-Energy plants or other incineration plants, or being materially recycled.44 Most countries with a share of waste incineration higher than the EU average also have a recycling rate above the EU average. Waste incineration does not prevent material recycling if there is political will supporting sustainable waste management.


III. 13: Waste-to-Energy plants use waste to produce electricity and heat for inhabitants.

“In all leftovers that people throw away ended up in the fuel tank as biogas, carbon dioxide emissions would decrease by several thousand tonnes.”

In terms of health, a common argument against waste incineration is environmental pollution by flue gas. Since the 1990s, waste incineration plants have been equipped with effective flue gas cleaning systems. And since the early 1990s, emission caps for waste incineration plants are equal to or much more stringent than those for other combustion plants. In Germany, for example, the emission cap for dust from WtE plants is 50 per cent lower than for biomass-fired plants, the emission cap for sulphur dioxide accounts for 25 per cent of biomass-fired plants, and the emission cap for nitrogen oxide is 40 per cent of the value for biomass-fired boilers. Further tightening is to be expected.

Implementation of the latest technologies and the need to adapt to stringent legal requirements allow the effective operation of WtE plants with a minimal environmental impact. In future, WtE plants will not only play an important role in waste disposal – they can also provide steam at high pressure and thereby replace fossil fuel for industrial steam generation.

While electricity can also be generated from renewable energies such as wind and sun, WtE plants are able to generate heat even at higher temperature levels above 100°C, which is often required in industry.

As a future energy source, electricity will play a decisive role in the transport sector. And, due to its potential to be converted in other forms of energy (e.g. kinetic energy), electricity is too valuable an energy form to be used for pure heat generation. Heat from WtE plants is therefore a good alternative to fossil fuels, to avoid the transformation losses involved when using electricity to provide heat at requested temperatures exceeding 100°C.

The changing function of WtE plants will also influence the choice of site for new installations. In the past, waste incineration plants were mostly located far away from heat consumers to place them as far as possible from residential areas. Proximity to potential heat consumers will become more important in future. Today and in future, WtE plants are another important element of energy re-use.
BIOWASTE

Not all municipal waste should be treated in a WtE plant. Biowaste, i.e. food leftovers and green waste, has a low calorific value due to its moisture. If biowaste is collected separately it can be composted and recycled as a soil conditioner. Alternatively, digestion of the biowaste offers an opportunity to produce a biogas from the waste to use as energy.

To generate biogas from biowaste, the waste is milled and fermented in an airtight container after adding water. During fermentation, organic compounds in the biowaste are degraded to a biogas and a digestion residue comprised of indigestible organic material (mainly wood). This residue can be composted like biowaste.

Depending on the process, approximately 25 – 40 per cent of the biogas is required to preheat the digestion process during the cold winter period. The remaining biogas can be used directly in a gas-powered CHP to produce electricity and heat.

In 2014, 14.9 Mtoe (million tonnes of oil equivalent) of biogas was produced in the EU, corresponding to 160 TWh, or twice the amount of energy used for transports in Sweden. Currently, a mere three countries (Germany, Italy and the UK) are responsible for over 77 per cent of the EU’s biogas production – so there is great potential for more countries to join this group.

Alternatively, biogas can be purified into a renewable substitute for natural gas. Biogas purification provides options for efficient biogas use in cases where there is insufficient heat demand at the site of the fermentation plant. During purification, CO₂ is separated from the biogas. After purification, the purified biogas can be fed into the natural gas network as biomethane.

LANDFILL GAS

Although landfilling untreated waste is prohibited in Europe, many countries still dispose of most of their mixed municipal waste in landfills. Systems for separate waste collection and incineration capacities may not be in place, due to high investment costs and, in some cases, the lack of political will to establish a developed waste management system. In these cases, when municipal waste contains many biodegradable components and other forms of waste recovery or disposal are not practised, landfill gas can be sourced to recover energy from waste.

“DON’T WASTE THE WASTE. THE HALF A MILLION LANDFILL SITES IN EUROPE ARE POTENTIALLY WORTH A FORTUNE.”

The generation of landfill gas is a natural process which starts immediately after disposing biodegradable waste in a landfill. As opposed to a controlled biowaste digestion process, in a landfill a biochemical decomposition of organic substances takes place under both aerobic and anaerobic conditions. The deeper the process takes place in the landfill’s body, the more it is carried out under anaerobic conditions (digestion). In the end, a landfill gas is produced with the main components methane and carbon dioxide, comparable to biogas produced from biowaste. An active degassing system with perforated horizontal collection pipes is installed to achieve an optimal landfill gas yield. Depending on frame conditions, maximum gas production will be achieved after approximately 15 – 18 years after which gas production declines. Landfill gas is combusted in gas engines to generate electricity and, where possible, to extract district heat.

In Germany and other Western countries, collection of landfill gas was established primarily to reduce methane emissions to the atmosphere, and only secondarily for energy recovery. In other countries, such as Turkey, new landfills are equipped with as many gas drainage pipes as required to collect the greatest possible amount of landfill gas from the start. Here, a landfill’s bioreactor is viewed as a gas resource for operating gas engines. Gas motor heat recovery often fails due to the lack of heat demand, as landfills are normally situated far from residential areas.

Clearly, landfilling untreated and unsorted municipal waste is not a sustainable or desirable way to dispose of the waste. Landfill gas that is not captured causes greenhouse gas emissions and leaching, resulting in considerable harm to the environment. Still, pending the establishment of separate biodegradable waste collection, biowaste digestion and waste incineration, the collection of landfill gas relieves the environment and enables the use of at least some of the energy contained in the waste.
6. SMART ENERGY SYSTEMS
Most opportunities to reuse energy described above require combustion of a fuel. Fossil fuel for heat generation in industry can be partially replaced with waste incineration, but there is currently still a high demand for fossil fuel to supply residential heating systems. Natural gas is gaining importance for residential heating in many EU countries, but the combustion of natural gas also produces CO₂.

To decrease the amount of heat from fossil fuel generated by combustion, alternative solutions are needed for supplying heating systems, particularly residential heating systems. Here, a smart energy system that combines different energy sources is the answer.

Smart energy systems are characterised by intelligent control of production monitoring and forecasting, demand response, price signals, etc. in a highly digitalised and decentralised energy structure. The often highly decentralised production facilities of renewable energy sources such as wind and solar energy fluctuate in production depending on local conditions, and their share of the energy mix is increasing (currently over 50 per cent in Denmark).

Smart energy systems are not limited to the electricity grid but comprise energy transformation and energy exchange across all energy infrastructure networks – electricity grids, district heating and cooling grids, gas grids – and interact across sectors with the water and sewage sector, waste sector and the transport sector.

According to a recent study on the utilisation of excess heat from the London Underground, total excess heat in London (71 TWh/a) is higher than the city’s heat requirement (66 TWh/a). Unfortunately, the temperature level of the waste heat sources is often much lower than the input temperature level of a common district heating grid.

Nevertheless, low-temperature waste energy can be re-used through integration into smart energy infrastructure grids. An important factor in utilising low-temperature waste energy is to decrease the temperature level of district heating networks. Deployment of heat pumps also plays an essential role in integrating smart energy systems. The heating sector is being partially electrified.

District heating is currently generally used directly for space heating and heating tap water. The flow temperature of district heating grids therefore often varies between 70 and 90°C. Looking at the requirements of modern heating systems, ideally in combination with forced ventilation and good insulation, such a high flow temperature will not be required in future. While a floor heating system, for example, manages fine at 35°C, hot tap water requires a temperature of around 50°C. If space heating and tap water heating are decoupled, the flow temperature can be lowered substantially, producing the following benefits:

- Lower percentage of heat loss due to less difference between the temperatures in- and outside of the district heating grid
- Renewable energy sources and waste energy are more efficiently integrated into low-temperature grids
- Improved utilisation efficiency of primary fuels at production facilities (e.g. CHPs) through increased flue gas condensation, CHP electrical efficiency, etc.

Ultra-low-temperature district heating networks only supply around 40°C hot water and utilise a small heat pump for boosting the hot tap water share of total heat demand.
Heat pumps: How they work
The closed circuit of a heat pump contains a refrigerant with a very low boiling temperature. The refrigerant is evaporated by ambient heat, because the fluid temperature in the evaporator is slightly below the ambient temperature. The cold vapour of the refrigerant is then compressed at a very low pressure, but remains vapourised. During compression the vapour heats up above the level required inside the room. In the condenser, the vapour condenses and releases energy to heat up the room. In the next step the fluid is expanded but not vapourated to a temperature below the outside temperature. The fluid enters the evaporator and is re-evaporated, and the cycle starts again.

Some electrical energy is used in the heat pump’s compression of vapour, but it amounts to only 1/3 – 1/5 of the energy used for direct heating of the room. This means that with 1 kW of electricity you can generate 3 – 5 kW of heat.

As described above, heat pumps not only raise the temperature level of heat – they can also cool a building. District heating and district cooling networks are currently separated, although waste heat from cooling chillers is in some cases reused and integrated into a district heating network. In future, district heating and district cooling networks may be the same, i.e. have only one set of twin pipes. Decentralised heat pumps can be connected to the thermal network producing and extracting either heat or cold water, in accordance with customers’ specific demands. The temperature level in the warm and/or cold pipe may even be dynamic depending on the season and consumer demand – balancing heating and cooling.

Large heat pumps in district heating networks are increasingly being used for utilisation of low-temperature energy resources. The largest systems are used in connection with data centres (approximately 50 MW), geothermal energy usage and for various industrial applications.

Supply to ultra-low-temperature areas could also be provided by the return line of an existing large district heating network, thereby increasing the district heating system’s overall system capacity and efficiency.

Various energy sources are also available for the booster heat pump: a share of the 40°C district heating itself, energy re-use of ventilation air, the outside air directly, and other sources such as excess heat from sewage systems, subway tunnels and high-voltage ground cables.

6.3 LOW TEMPERATURE WASTE HEAT

Utilisation of wastewater heat
The sewage/wastewater sector is another area strongly focused on energy re-use by means of heat pumps. Applications are often within the capacity range of 1 – 10 MW. During summer, wastewater temperature is approximately 15 – 20°C and can be cooled to 5 – 10°C. Wastewater temperature is lower during winter (10 – 15°C) and cooling will be to approximately 5°C. The biological processes are temperature-sensitive, meaning that heat pump applications are most suitable at the wastewater plant’s outlet.

Utilisation of subway heat
Utilising heat from subway tunnels is an alternative to utilising wastewater heat.

“Making good use of the heat we find.”

A recent study examined the heat utilisation of the London Underground22 to supply the Caledonian swimming pool and two nearby housing estates. During summer, hot air from a ventilation shaft is extracted and cooled in a heat exchanger by heating the district heating grid’s backflow from 15°C to 20°C.

Utilisation of excess heat from ground cables
The highest-voltage electricity cables, which connect offshore wind farms with onshore electricity grids, are another very interesting source of waste heat. These cables can reach temperatures of 55 – 60°C. If laid as ground cables, this waste heat is discharged into the surrounding soil. The environmental impact of this heat discharge is currently the subject of an intensive scientific and political debate in Germany, delaying utilisation of the highest-voltage cables. Due to the waste heat, the cables need to be laid along a wide route to avoid negative impact on adjacent high-voltage cables in the route. The area above the highest-voltage route can be used for farming, but needs to cleared of trees. This cuts wide swathes through existing forests and interrelated ecosystems.

Recovering the cables’ waste heat (e.g. through water cooling23) is a potential heat source for district heating in nearby areas. The distance between adjacent cables can be reduced, decreasing the impact on forests and interrelated ecosystems. If the heat recovery succeeds at a temperature level of around 40°C and above, the waste heat can be used directly as a low-temperature heat resource for low-temperature district heating, without needing a heat pump for space heating.

The recovery of waste heat from electrical cables is still in the early development phase, but promises to be another interesting approach for re-use of energy.
7. CONCLUSIONS AND RECOMMENDATIONS
In view of global warming, hardly a week goes by without an appeal to abandon energy production from fossil fuels in future. Renewable energies such as wind, hydro, solar and geothermal energy and the utilisation of biomass are gaining importance. Nevertheless, consumption of fossil fuels still amounts to 74 per cent of the EU’s total final energy consumption.

The abandonment of fossil fuels forces us not only to optimise the energy consumption of existing technologies and to develop renewables, but also to search for new energy sources that were not previously relevant to us. These new sources need to avoid the main problems of the existing energy structure: limited resources and negative environmental impact through emissions into air, water and soil. Utilisation of the new resources also needs to be technically feasible and economically affordable. Last but not least, the energy sources need to be accepted politically.

In this view, it is natural to think of energetic recycling, or “re-use of energy”, as analogous to waste recycling in the well-established waste hierarchy of prevention, re-use, recycling, recovery and disposal (Ill. 20). Re-use of energy can be understood as a smart use of excess energy that would otherwise be dissipated unused into the environment. Re-use of energy comprises clever combinations of different types of energy (e.g. heat, electricity) to reduce primary energy consumption.

Considering that fossil fuel consumption for industrial and residential heating still accounts for 38 per cent of the EU’s total final energy consumption, the re-use of energy will play an important role in sustainable heat generation.

In areas with a well-developed gas supply, changing over to a district heating network is a daunting task. There are a few technical solutions available to reduce utilisation of fossil fuel for residential heating purposes. Condensing boilers in household heating systems already recover evaporation heat from water vapour formed during the combustion.

A further step in energy re-use is to prevent heat losses from ventilation. Forced ventilation systems already recover evaporation heat from water vapour formed during the combustion. Forcing ventilation systems can be combined with the other measures of energy re-use mentioned above.

The utilisation of waste heat from the backflow of existing heating grids, CHP plants, wastewater grids, subway tunnels and, potentially, from cooled ground cables can be achieved with heat pumps, ideally in combination with low- or ultra-low-temperature district heating systems with decoupled space heating and tap water heating with additional heat pumps.

In areas with a sufficient connection density, centrally generated heat (e.g. from CHP plants) can be distributed to decentralised consumers via traditional district heating systems. As a further step in reducing heat losses, the heat supply can be based on low- or ultra-low-temperature district heating systems with decoupled space heating and tap water heating with additional heat pumps.

The actual reduction potential of the measures discussed in this report depends on each country’s specific legal and energy market conditions, particularly the price competition between fossil fuels and the cost of reducing and reusing energy. To illustrate this reduction potential, let us look at possible reductions in final energy consumption in Germany’s residential sector across all measures detailed above for the 2018 – 2050 period. Germany has the highest fossil fuel consumption in this sector and is aiming for an 80 per cent reduction by 2050, over 2008 levels, in final primary energy consumption in the residential sector.
A realistic estimation needs to consider that the country’s building inventory will not be completely upgraded to the lowest possible energy consumption. Of a total 18.9 million residential buildings in Germany, 4.1 million are already energetically refurbished. The current energetic renovation rate in Germany amounts to 1 per cent of all residential buildings per year. This means that 189,479 buildings per year, or 6,063,328 buildings during the 2018–2050 period, are energetically refurbished. In our assessment, we assume that final energy consumption for heating purposes for each energetically renovated house can be reduced by 80 per cent over actual 2018 levels using suitable combinations of forced ventilation, condensing boilers, and conventional air/water and soil/water heat pumps.

At the current energetic renovation rate of 1 per cent of all buildings, fossil fuel utilisation can be reduced by 57 per cent of total fossil fuel consumption by 2050 over base year 2008. The reduction of fuel consumption corresponds to a CO2 reduction of 40.4 million t/a compared with 2008. This represents respectable energy savings, but the German target to achieve an essentially climate-neutral building stock by 2050 requires a renovation rate of 1.5 to 2.0 per cent. If the renovation rate of existing buildings is increased to 2 per cent per year, fossil fuel consumption for residential heating purposes in this estimation can be reduced by 62 per cent of total fossil fuel consumption by 2050 over base year 2008. CO2 emissions will be reduced by 66.0 million t/a compared with 2008.

Due to the currently low prices of light oil (€0.05/kWh) and natural gas (€0.06–0.07/kWh), the reduction in fossil fuel consumption will produce fuel cost savings of only around €6.67 billion/year at an annual renovation rate of 1 per cent or €13.34 billion/year at an annual renovation rate of 2 per cent.

Ill. 21–24: By reducing energy waste and reusing energy, we can significantly cut back on global carbon emissions.

Ill. 25: When renewables only account for a small portion of final energy consumption, the important role of energy re-use becomes obvious.

**Re-use of energy for heating purposes in industry**

The re-use of energy is already established in industry. Heat exchangers utilise excess heat from production processes and flue gases to generate steam for production, to generate electricity or to preheat feed water and combustion air. Combined heat and power (CHP) plants simultaneously produce electricity and heat for e.g. district heating grids and achieve efficiencies above 80 per cent. Condensing boilers in CHP and heating plants recover evaporation heat from water vapour in flue gas. The measures mentioned above reduce the usage of fossil fuels – but fossil fuel will still be needed as long as furnaces are not supplied with biomass.

Fossil-free heat and electricity generation is already done at Waste-to-Energy plants. WtE plants can play a key role in future as a substitute for fossil fuels, especially in providing steam for industry. This is particularly true for countries that currently have relatively few WtE plants and a high share of landfill waste disposal. In Poland, for example, only 19 per cent of municipal waste is treated in WtE plants, while 46 per cent is disposed of in landfills. If the share of waste treated in WtE plants is increased to 39 per cent, these plants would replace 4,843 GWh of fossil fuels per year at an efficiency rate of 85 per cent, or 11 per cent of Poland’s total industrial fossil fuel consumption, and CO2 emissions would be reduced by 454,000 tonnes per year.

The energy content of separately collected biodegradable waste can be partially recovered in biowaste digestion plants. Purified biogas from biowaste digestion plants can replace natural gas in industrial CHP plants. Where mixed municipal waste is disposed of in landfills, landfill gas can be collected and combusted in a gas motor.

For heating tasks similar to those in the residential sector, industry can apply all residential heating measures described above.

Investment and operating cost requirements will determine industry’s utilisation of renewables and re-use of energy to a greater extent than in the residential sector.
As a result, the development of gas networks in new urban districts has been shelved in favour of district heating networks.

Areas with existing district heating grids need to be analysed to identify potential ways to reduce heat loss by decreasing flow temperature, while also taking into account the building stock’s capacity to handle lower flow temperatures in the grid.

If heat is needed at temperatures higher than 100°C and if there are no sources of waste heat to satisfy demand, installation of CHP plants is analysed to optimise combustion efficiency.

Waste incineration will be viewed not only as a waste disposal measure, but also as a method of replacing fossil fuel in industrial processes with steam requirements. Due to the technical limitations of steam parameters, the exclusive generation of medium-pressure steam and saturated steam for industrial purposes is gaining importance. This must be considered in site selection for new WtE plants. Future WtE plant sites need to at least allow for CHP operation.

Also, more attention is being paid to developing waste management systems for separate collection of various waste categories to optimise material and energetic waste recycling.

A political approach is needed to compensate for market-related preferential treatment of fossil energy sources. Further development of CO₂ certificates, which have not been very successful to date, is an obvious way of doing this.

Financial support is needed for the energetic refurbishment of existing building stock. In replacing fossil fuels for heating purposes, we still have a long way to go. But clever application of energy re-use, in combination with renewable energies, is an important step towards a carbon-free energy supply.

IMPORTANT PERSPECTIVES IN URBAN DEVELOPMENT

The technology required for re-use of energy is already available, or will be in the near future. Many previously unused energy sources can be tapped in energy re-use. In view of the current levels of fossil fuel consumption, energy re-use will be an essential component in abandoning fossil fuels in future.

The more energy we reuse, the less energy we need to produce.

This environmentally oriented insight is counteracted by commercial framework conditions. As shown by the cost estimate for the energetic refurbishment of residential units, current low fossil fuel prices and the existing building stock designed for individual heat supply are obstructing implementation of energy re-use measures. For sustainable urban development, different approaches need to be taken simultaneously.

To reduce the costs of energy re-use in the residential sector, greater focus will be placed on developing neighbourhoods with multi-family buildings. Installation of forced ventilation systems, heat pumps and district heating grids, and utilisation of waste energy from new sources such as sewage canalisation and subways, is more cost- and energy-efficient in compact development. Insulation measures are more efficient in multi-family buildings, as outer surfaces are small as compared with stand-alone buildings. Compact development also reduces traffic pressure.

Sustainable urban development will also take into consideration potential energy sources for low-temperature district heating grids, starting at the initial planning stage. Commercial enterprises will be integrated into the residential heating system by offering options for extracting waste heat into public heating grids. The construction of residential and commercial buildings allows utilisation of low-temperature district heat for space heating (e.g. with floor heating systems), with hot tap water provided by heat pumps.
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