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Carbon Neutral Aarhus

City Performance Tool – May 2016

Global Center of Competence Cities

The City of Aarhus has the ambition to become Carbon Neutral by 2030, and the work delivered by Siemens using its in-house City Performance Tool has shown that this target is realistic. While it is realistic, it will certainly not be easy as the city will need to further electrify its transport and entice the private sector to do the same.

Executive Summary

The City of Aarhus has the ambition to become carbon neutral by 2030, and the work delivered by Siemens using its in-house City Performance Tool has shown that this target is realistic. While it is realistic, it will certainly not be easy as the city will need to further electrify its transport and entice the private sector to do the same. Aarhus' local co-generation of heat and electricity is a key part of their plan to reach carbon neutrality, and because of this efficient and relatively clean local energy it is less clear what carbon focused actions the city should take or incentivize for its buildings. One option would be to focus only on transport and leave buildings as they are; however, because cities are comprised of buildings, and buildings consume a vast majority of energy in a city, therefore they cannot be ignored. This becomes even more important as buildings, transport and energy together are expected to become smarter over the next 15 years, and achieving the full benefits of a smart city requires upgrades in all three sectors.

The most impactful technologies for reducing carbon in Aarhus are those that increase the scope of public transport and electrify existing services. Building improvements will deliver energy savings, but the carbon savings are less clear because of the local energy mix. However, there are many reasons other than carbon to improve buildings such as operational cost savings, reduced demand on the electricity grid and possibly reducing the need for additional energy generation. If the city does want to improve its buildings then implementing the less invasive automation technologies becomes attractive because these technologies can deliver significant energy reductions without incurring the large costs associated with full building retrofit.

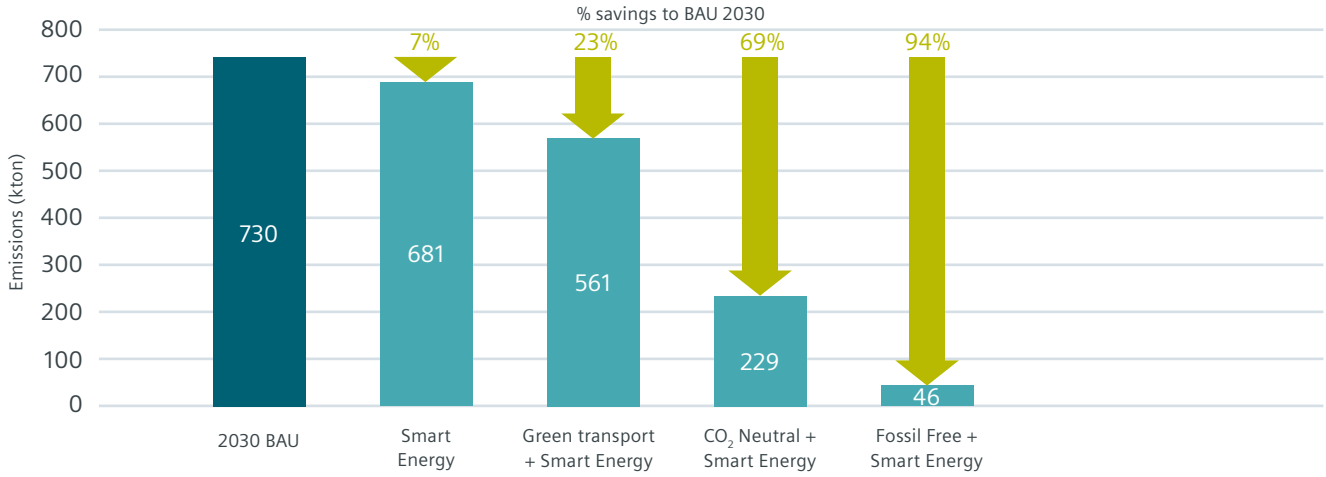
Siemens has partnered with the City of Aarhus to identify not only which technologies would make the most significant carbon reduction, but also to identify the scale at which they would need to be implemented. Siemens has first considered the expected changes to the local heat mix, and the implementation of other key technologies by 2030 that have already been funded in its Business As Usual (BAU) reference case. All of the scenarios will calculate additional carbon reductions from the BAU. The scenarios considered will test varying take-up rates of technologies in both the public and private sectors ranging from Smart Energy (building technologies), to Green Transport, CO_2 Neutral and Fossil Free. Out of the tested scenarios, one of the most ambitious scenarios could deliver carbon reductions of up to 94% – here are some of the key numbers to come out of the Siemens analysis.

- Fossil fuel free approach – 94% CO_2e reduction compared to 2030 BAU

- CO_2 Neutrality – 69% CO_2e reduction compared to 2030 BAU

These scenarios demonstrate that it is possible for the City of Aarhus to reach carbon neutrality and possibly even to exceed it. However, out of the scenarios tested in the study, none actually reduced carbon emissions to zero. These residual carbon emissions are linked to electricity imports, but they are very minor given the scale of the carbon reduction successes.

The tested scenarios also identify an electricity gap between what will be demanded by the public in 2030 and what the City of Aarhus' municipal heat and electricity generation can provide. Today the gap is very small between local production and overall demand; however, in the future, there is a general expectation that electricity demand will increase due



to further electrification of transport, for example more take-up of electric cars. Reducing this gap will require the city to increase its local renewable generation, significantly reduce electricity use in all buildings or purchases carbon offsets. Actions taken by the City of Aarhus to reduce electricity demand in its buildings will help to reduce the demand for clean electricity that the national government will need to provide.

The key result of the CyPT analysis is the identification of the best performing technologies for the City of Aarhus irrespective of when or how much is actually implemented. The most significant results would come from actually changing energy generation away from combustion technologies to renewables such as wind and solar. The next most impactful technologies are those that will reduce the most carbon. These technologies may be those that are simply more energy efficient or switch fuel sources, such as electric cars (e-cars) if the local electricity mix is cleaner than burning petrol. The following points highlight the best performing technologies for Aarhus.

Most impactful carbon reduction technologies

Buildings

Non-residential:

- Building performance optimization
- Building remote monitoring
- Demand oriented lighting

Residential:

- Home automation
- Efficient lighting

See appendix III for technology descriptions.

Due to how the City of Aarhus creates its heat and electricity and how it counts its carbon emissions, building technologies that significantly reduce heat loss actually increase carbon emissions as 'dirtier' electricity from the grid must be imported.

Transport

- City tolling
- Electric buses
- Plug-in hybrid cars
- New tram lines

Overall the most impactful technologies are transport related because of the assumed carbon neutrality of building heat and the associated additional carbon coming from electricity imports.

If we shift our focus away from the most carbon reducing technologies to those that save the most energy (heat and electricity) then these technologies are the best performing.

Most energy savings technologies

Buildings

Non-residential:

- Building performance optimization
- Building remote monitoring
- Building management systems BACS B
- Demand oriented lighting

Residential:

- Building envelope (glazing and insulation)
- Home automation

It is technically possible for the City of Aarhus to achieve real carbon neutrality by 2030 should acceptance and take-up of key technologies happen fast enough. Additionally, the cost of meeting this objective will be shared by both the public and private sectors. The city implementing some aspects of road pricing, provision of charging points for e-cars and the further expansion of electricity based public transport and building owners increasing the degree of automation in their buildings. The shared burden of building improvement would require that all non-residential building owners upgrade building lighting and many of those owners would also need to engage in some form of building monitoring or optimization. All residential owners would need to upgrade lighting and just less than half would need to automate their homes and/or make some improvement to the exterior of their homes (glazing and insulation). Achieving 100% of all owners is an ambitious target, but for the lighting technologies which are for the most part inexpensive bulb upgrades and some sensors the economic case is strong over the next 15 years some people will make this change as part of their home maintenance work and others will require more education and encouragement.

Timings of technology implementation should be based upon where the city has the authority to directly implement change and those in which it must partner with other organizations or levels of government. Those technologies where the city has more direct authority could reasonably be delivered in the coming 3 to 7 years and the other technologies may need far longer lead times stretching to the 2030 target year.

A good climate strategy, smart use of technologies and view to partnership with the national government and other Danish cities, will all be required for Aarhus to deliver zero carbon emissions.

Introduction

The City of Aarhus, is fast on its way to becoming carbon neutral (2030), and right behind this target is another ambition to become fossil-fuel free. These ambitions are very high, but Aarhus is as well positioned as any city could be to make them. It has committed leadership, a track record of delivering greener services – particularly in its municipal energy provision, and a public that understands the importance of carbon.

Aarhus is a modestly growing city (330,000) with a large student community, and it could be described as a progressive carbon city due to the actions it has taken to reduce its carbon emissions. So much so, that part of the issue now facing the city is identifying where it can make further reductions. The major question for carbon progressive cities, such as Aarhus, is how to reduce emissions beyond what are termed the 'low hanging fruit' or the actions that can be done with relatively little investment and do not require any real operational or behavioral change. By and large, The City of Aarhus has already addressed these changes and now they are looking for how to tackle the more difficult carbon emissions. The City of Aarhus recognized in its previous Climate Plan, 2012 – 2015, that "reducing the municipality's own energy consumption is not sufficient. Solutions are required, which encourage us to reduce energy consumption and make the shift to fossil-free energy.' Thus, the city already recognizes the need to broaden the responsibilities for delivering further carbon emissions by reaching out to private businesses and individuals to do their part.

The City of Aarhus is today strategizing how it can take its carbon reduction strategy the next logical step further, towards carbon neutrality in its Climate Plan 2016 – 2020. Siemens is supporting the city in quantifying the results of its carbon actions to date and to then identify the most impactful carbon reduction technologies that the city could deliver. Siemens's has used its City Performance Tool (CyPT) to identify the carbon gap between actions the city is taking today and its goal for Carbon neutrality. The CyPT will also model the impact of 70+ technologies by using real city data to identify the most relevant technologies and the levels of implementation required to meet the reductions.

Siemens has been working very closely with The City of Aarhus' Climate and Environment team, and the scenarios and results presented within this analysis are very much based on what they believe is achievable in the short to medium term and what is required in the future to make the transition to carbon neutrality or fossil-fuel free living.

Aarhus is not starting at the beginning; it has already started to significantly reduce its carbon emissions by shifting from coal to biomass in local heat production.

The City of Aarhus is starting from a good position to meet its carbon reduction ambitions. Its per capita emissions are already lower than the national average due to the energy efficient municipal district heating network, which supplies 95% of total heat demand. The municipal heat network is highly efficient as both heat and electricity are produced through co-generation plants, meaning that electricity is a by-product of heat generation resulting in a far more efficient generation process. Aarhus also generates some electricity from additional local wind turbines and solar installations. All in all, the City of Aarhus as an energy business, operator of public transport and as an owner of multiple buildings accounts for nearly a quarter of the city's total carbon emissions today.

The City of Aarhus: Climate Plan 2012 – 2015, recognized the need for the city to reduce the carbon emissions coming from heat and electricity production, particularly as coal comprised a large part of the local heat energy mix. Today, the City of Aarhus has finalized its plans for eradicating coal from the mix and this one change results in dramatic carbon reductions for the city and creates what is essentially a carbon free building

stock. The city also currently incinerates a large portion of its waste. The city aims to remove plastics from the waste stream, and in the future this waste stream will also produce carbon neutral electricity. The impact of both of these changes is hugely significant as clean energy going into buildings and transport reduces emissions. The result of having a carbon neutral building stock is that carbon emissions within transport grow in proportion and reducing these mean incentivizing people to behave differently, which is much harder to do.

The City of Aarhus took the decision to become carbon neutral with the view that biomass is carbon neutral even though it does produce some emissions across its lifecycle. However, given that Aarhus, like every other progressive city that is targeting carbon reductions, this shift to biomass, while not perfect, will enable the city to remove coal from its heat mix and vastly improve its carbon performance. For this analysis, Siemens will assume that the heat mix is carbon neutral, although it does produce some carbon emissions. The City of Aarhus measures Scope 1 & 2 carbon emissions within its carbon emissions accounting. Scope 1 emissions are those directly created in the city, for example, by burning biomass for heat and electricity. Scope 2 emissions are those created indirectly and are used in our buildings to run our appliances or computers. Scope 3 emissions are those created across the lifecycle of the fuel, for example through transportation of biomass or the mining of coal. The City of Aarhus is very much a carbon progressive city, and in the future it may wish to include Scope 3 emissions within its carbon accounting, which would make it an even more significant global carbon reduction leader.

Introducing the City Performance Tool

European cities stand at the forefront of sustainable development in the world. Global rankings regularly highlight their performance in terms of connectivity, mobility, and reduction of greenhouse gas emissions. Cities like Aarhus are constantly striving to test the cost efficiency of their current infrastructure solutions and explore new, more effective technologies that will help them meet their environmental targets.

To help cities make informed infrastructure investment decisions, Siemens has developed the City Performance Tool (CyPT) that identifies which technologies from the transport, building and energy sectors best fit a city's baseline in order to mitigate CO_2eq emissions, improve air quality and add new jobs in the local economy.

The CyPT model compares the performance of over 70 technologies, giving the City of Aarhus the opportunity to test a variety of technologies simultaneously across the city. The city will then be able to compare in a like for like manner possible city investment projects that would ordinarily fall into different city management silos such as transport and buildings, and never be compared against each other in a quantified manner.

The CyPT model takes over 350 inputs from Aarhus's transport, energy and buildings sectors, which include the energy mix of electricity generation, transport modalities and typical energy, travel and building space demand. We refer to this as a city's energy DNA, which we split into transport and buildings energy demand. How high the energy demand is and how it is split between the transport and buildings sector depends on how people use transport and building space and how the city generates its electricity and heating.

As soon as the DNA is calculated we estimate the CO_2eq emissions and other air quality measures. For the City of Aarhus, the CyPT is looking specifically at carbon reduction. The model measures the impact of technologies on the CO_2eq, baselines of the city with CO_2eq accounting performed at Scopes 1 and 2 levels for the building and transport sectors (Figure 1). This means that we have taken into consideration both direct emissions that are occurring within the city boundaries such as from exhaust fumes but also indirect emissions from the consumption of purchased electricity and heat. Scope 3 emissions that look at the energy required to feed the electricity and heating generation in the city have been excluded.

The model also tests the performance of each technology on two economic indicators. Firstly, the total capital investment needed to deliver the technologies. Second, the total number of gross jobs that could be created in the local economy. These include installation, operation and maintenance jobs, which are calculated as full time equivalent jobs of 1760 hours per year. Manufacturing jobs are not accounted because some of these technologies may be produced outside the city's functional area, with no local benefits to the economy.

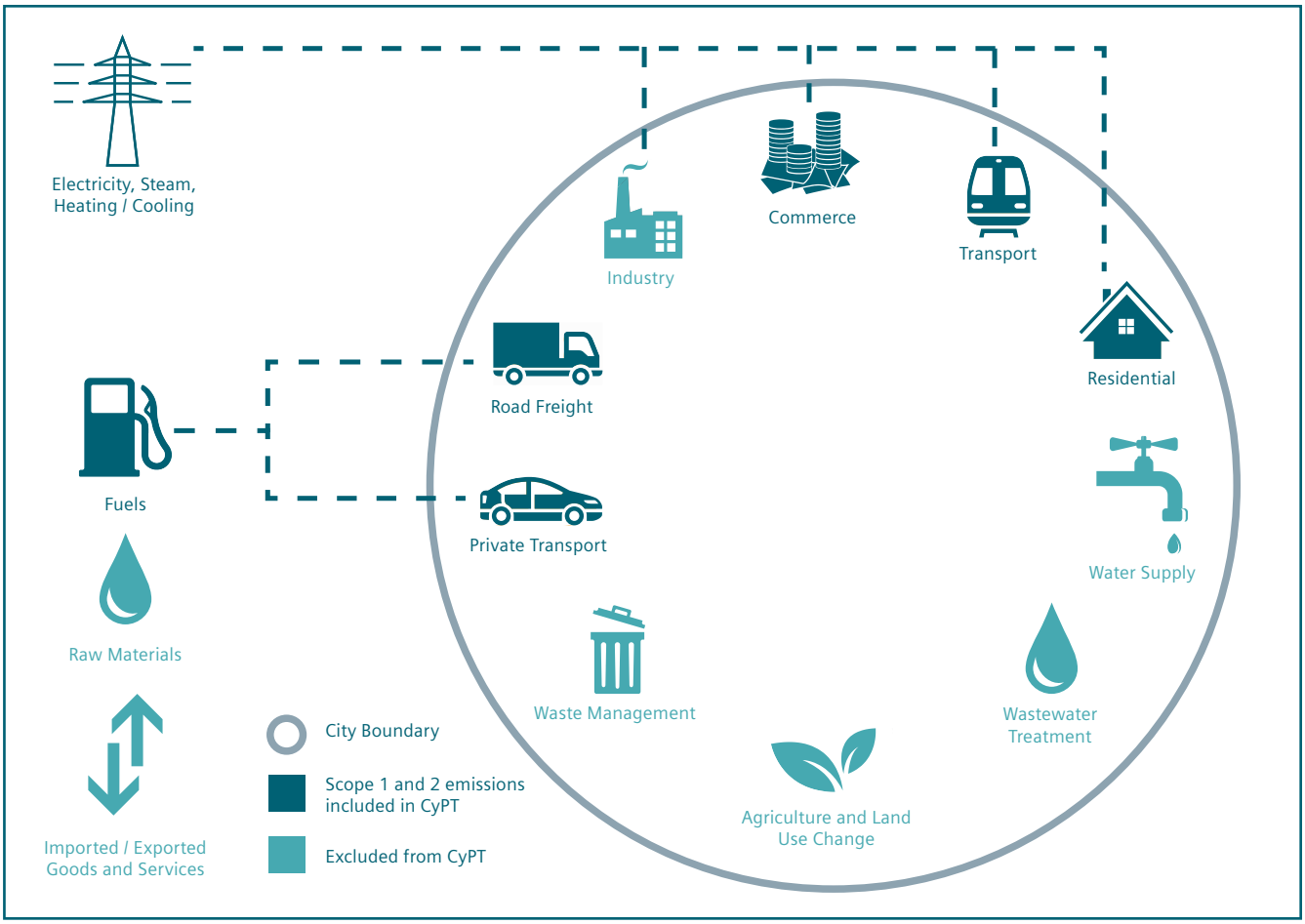


Figure 1: Scope 1 & 2 emissions captured in this study. Icons are for indicative purposes only

Starting with the city's population, energy performance, and emissions baseline, the model estimates the future impacts of technologies along the following three drivers:

1. Cleaner underlying energy mix: Shifting the energy generation mix from non-renewable to renewable energies (e.g., photovoltaics) and/or improving the efficiency of the current, fossil fuel, sources (e.g., Combined Cycle Gas Turbines).

2. Improved energy efficiency in buildings and transport: Replacing existing technologies with more energy efficient technologies. For example replacing traditional street lighting with LED and/or demand oriented street lighting.

3. Modal shift in transportation: Modeling changes in the modal split of the city. For example by creating a new metro line, a city potentially moves passengers away from high-emitting cars and into the subway.

The CyPT model has so far been used in cities such as Copenhagen, Helsinki, Vienna, London, Minneapolis and Nanjing with each city identifying infrastructure solutions that best fit the city's energy demand and production characteristics. The CyPT model requires over 300 city specific data points, and it uses these city specific data points, as well as a wealth of other data about cities and technology. The CyPT first uses this data to create a baseline for the city's carbon emissions today and it shows how they would change by 2030. The model then tests the impact of the 70+ technologies against the expected carbon emissions and gives results in terms of carbon reduction, air quality improvement and job creation

The following diagram illustrates the type of data collected in each sector and the sectors that have the most specific data points.

CyPT data points by sector, Aarhus

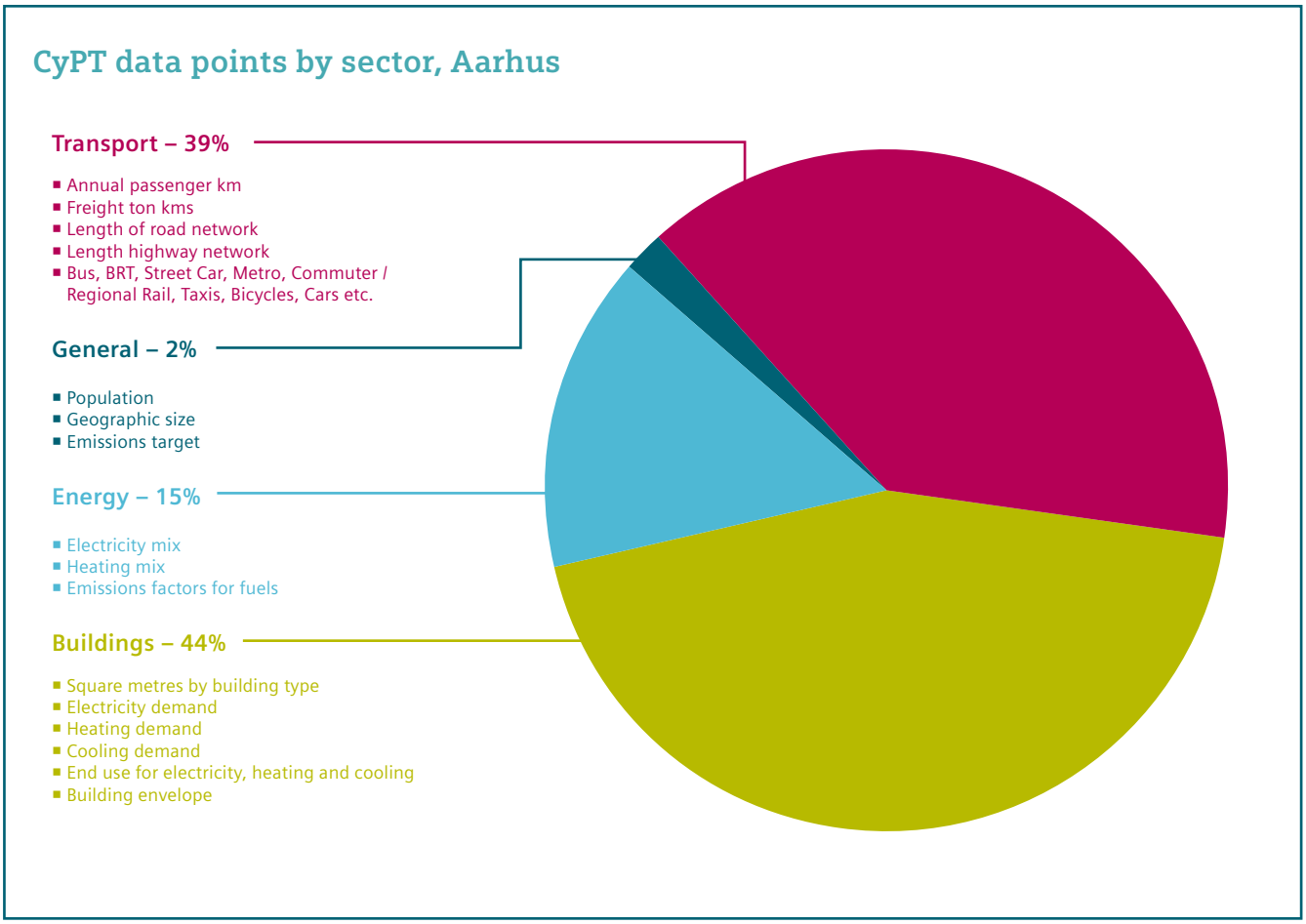


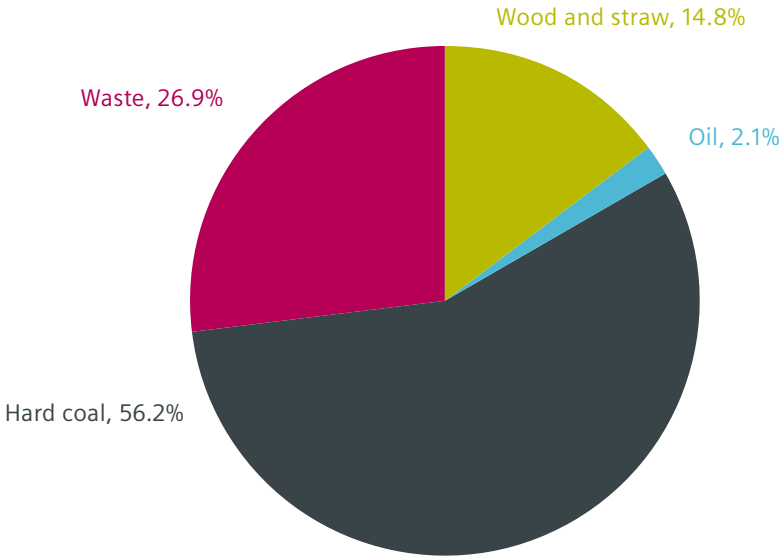
Figure 2: Number of data points by sector used in the CyPT.

CyPT Baseline (2015)

The CyPT model estimates that Aarhus is producing approximately 1.9 million tons (mt) of carbon emissions within the energy utilized by its building, transport and industrial sectors. In 2015 the split between these three main energy users was about 70% buildings, 24% transport and 6% industry. Furthermore, more than 60% of all shipping containers entering and leaving Denmark pass through the Port of Aarhus. These goods are then transported to or from the port on City of Aarhus roads; leading to congestion and poorer air quality.

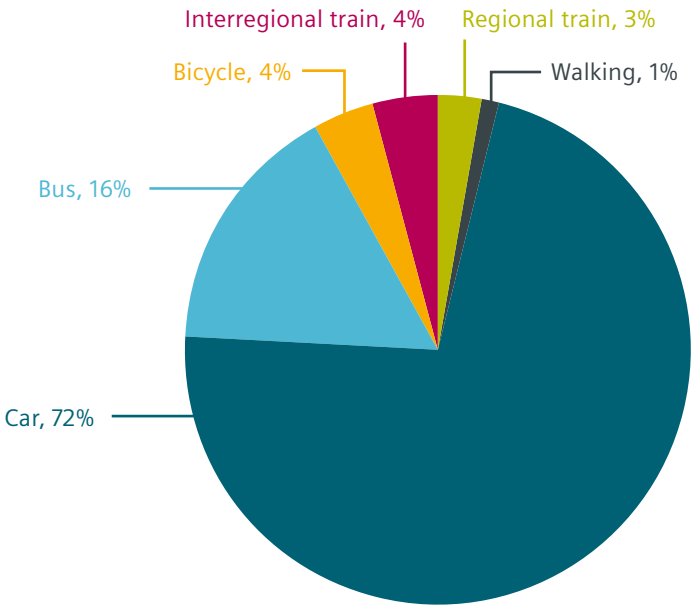
Within the buildings sector, housing was by far the largest carbon emitter (50%), followed by commercial (22%) and public sector (17%) buildings. 95% of the energy for the buildings is generated by co-generation (heat and electricity) plants. The heat/electricity fuel mix today is primarily hard coal (56.2%) with most of the remaining energy coming from biomass or waste. Public buildings were significant users given their relatively smaller footprint and this is because they have a higher energy intensity per sqm than the other building types, which implies more scope for energy reduction. Industry, its buildings and its process were fairly evenly split at 11% and 8% respectively.

District Heating Fuel Mix 2015



Within the transport sector passenger cars were the most significant emitters (67%) followed by road based freight (15%). Despite having a port in Aarhus, the city estimates that most of its freight enters the city and is distributed using the road network. Car based journeys account for 72% of all km travelled and non-motorized transport is about 5% of all km travelled. Today, public transport to and around Aarhus includes inter-regional and regional trains and local buses. The regional trains are not commuter trains but are connections to other urban areas in Jutland. Notably, there is no city center rail connection to Aarhus airport.

Passenger Modal Split 2015



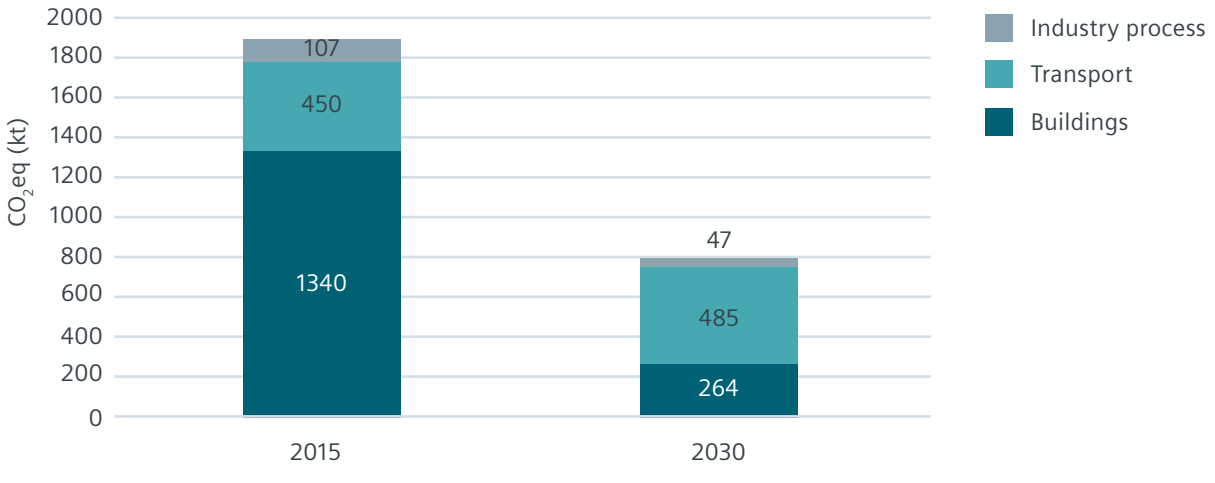
CyPT Business As Usual (BAU) 2030

Utilizing some of the core data described above and through discussions with the City of Aarhus policy-makers and utility managers, the CyPT is able to estimate carbon emissions for Aarhus in 2030.

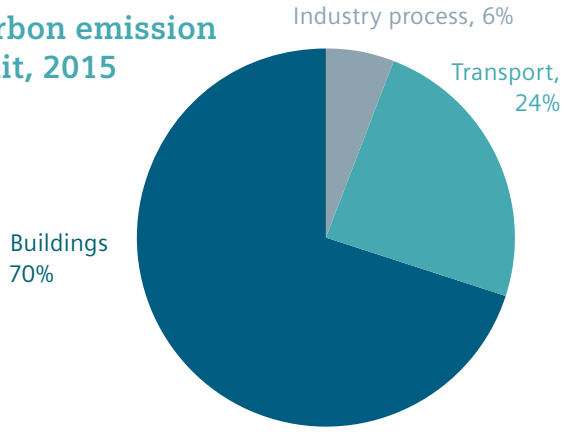
The 15 years between our today's figure (2015) and 2030 are expected to deliver huge changes for the city as the local municipality will green its heat and electricity mix by replacing the 56.2% of coal with biomass wood pellets. The waste will continue to be incinerated as it is today. This change dramatically reduces the scale of Aarhus' carbon emissions by 59% to 777 kton with industry and 730 kton without industrial process emissions. For the purposes of the BAU and in further calculations, emissions from industry processes are not considered as they are beyond the scope of the CyPT analysis.

In the buildings sector, the change is even more dramatic as building emissions will reduce by 80%. The remaining carbon emissions in 2030 are by and large from the transport (60%) sector. Transport emissions are expected to increase because of the new electric tram (2 lines) and an increased number of e-cars (5% of car fleet). Both the tram and e-cars will be emissions free in the city, but they will require additional electricity beyond what the city can generate and this will result in imported electricity and additional emissions because imported electricity is considered to be 'dirtier' than what is produced locally.

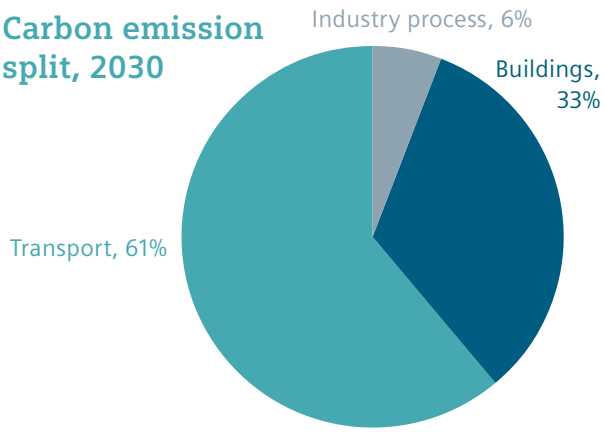
Aarhus carbon emissions



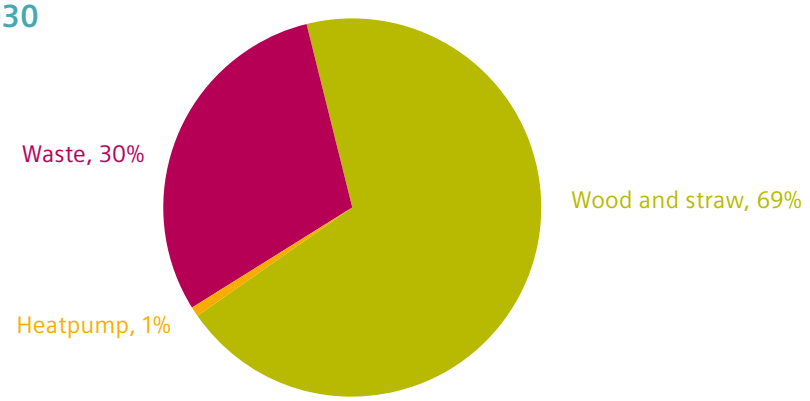
Carbon emission split, 2015



Carbon emission split, 2030



District Heating Fuel Mix 2030

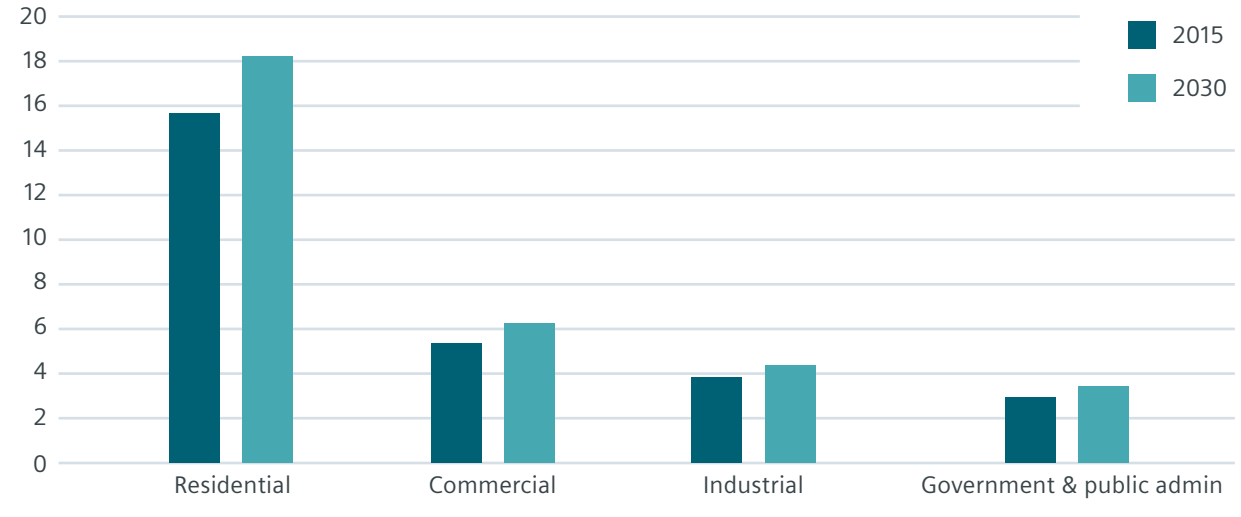


Buildings

The dramatic 80% carbon reductions in buildings come at the same time as the city is expecting its building footprint to increase by more than 2 million sqm in order to accommodate a larger population and local jobs base. In 2030 they will consume 95% of total electricity, but buildings will only contribute 33% of carbon emissions (264 kton).

Overall electricity demand is supposed to increase mainly because of the increasing city footprint, and because electricity production is capped by heat demand, more electricity will need to be imported (61 GWh, +3.5%), thus nudging up carbon emissions. There will also be a gap of 110 GWh, between the energy produced locally via co-generation or city owned renewable generation and overall demand.

Building Floor Space



Transport

Transport emissions are expected to increase by 8% to 485 kton over the years despite assumed energy performance improvements – predominantly due to population increase of 16% to 2030. Also two new tram lines will offer a viable alternative to car transport, and the city is expecting a positive modal shift towards public transport.

Municipal Power Generation and energy gaps

The City of Aarhus co-generates heat and electricity through its municipal district heating company, the Dong Energy owned Studstrupværket and local wind and solar electricity generation located inside of the city boundaries. The city includes this generation in its carbon related calculations. Any gap that is identified in the scenarios considered will be the difference between electricity demand from the city and what is produced via the co-generation and wind and solar farms. In order to bridge this gap to become CO_2 neutral or fossil-fuel free, the city would either need to implement further technologies, increase its renewable electricity (not heat and electricity) or offset through the purchase of credits from external renewable producers.

Scenarios

Siemens is very pleased that results from the CyPT study with Aarhus will be a cornerstone of the new Climate Plan 2015 – 2020. In the case of Aarhus, its Climate Plan is effectively a city strategy and as such it will directly influence policy. Given all of the social, economic and environmental aspects to climate policy, the City of Aarhus wanted to test a variety of possible futures in order to determine where they can most effectively target policy. This aim has resulted in Siemens' testing a number of scenarios stretching from building improvements across the city to actually eradicating the use of fossil fuels. The CyPT has been able to create these futures based primarily on changes to fuel mixes and technology implementation rates.

This analysis first considers the scenarios individually and then builds them up leading towards a more technology driven CO_2 neutral or fossil-fuel free approach to growth. Out of the 70+ technologies within the CyPT, the City of Aarhus wished to consider only the 33 they thought to be most relevant. At the outset all of the technologies were tested to ensure that any technology surprises, a technology that the city was not considering at the outset, would be identified. Our model assumes that today is 2015, the target year is 2030, and that all changes are relative to the aforementioned BAU 2030. For example, if a specific building technology, with an implementation rate of 3%, was selected then this implies that 3% of all buildings install that technology in one year, thus over the 15 years between 2015 and 2030 – 45% of the total building stock would have this technology.

These are the key scenarios analyzed:

Smart Energy

This scenario targets improving the energy efficiency of buildings primarily through automation and highly efficient lighting.

Green Transport

This scenario focuses on shifting drivers towards public transport (new trams and city tolling), electrifying transport (e-bus, on-shore power for ships, and e-cars) and improving energy efficiency through better traffic management (smart traffic signals and lighting).

CO_2 Neutral

This scenario aims at achieving carbon neutrality and assumes that the building heat mix becomes even cleaner by separating out plastics from the waste incineration. As buildings become automatically cleaner from this change, the scenario targets the transport emissions and includes 100% e-electric buses, new tram lines, more e-cars and e-car sharing.

Fossil Free

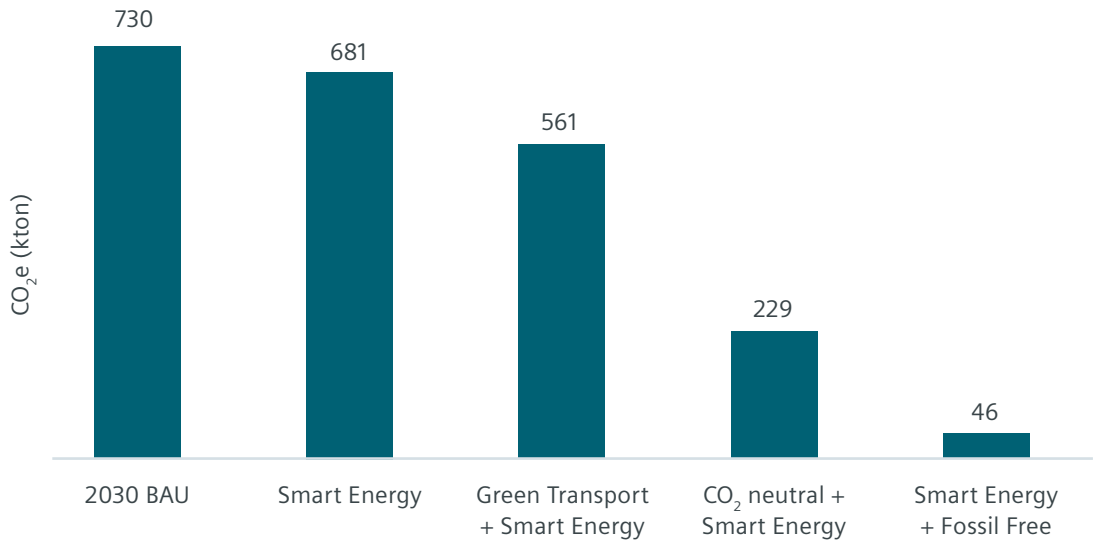
This scenario targets all fossil fuel use within transport and assumes like the CO_2 neutral scenario that the heat and electricity mix is even cleaner than the standard BAU. The technologies selected change fuel types rather than shifting demand towards public transport, and the technologies include additional cycle highways, e-cars, hydrogen cars and full electrification of buses, vessels, rail and trucks.

The chart (opposite) highlights shows the relative degree of carbon reduction across the key scenarios as compared to today's figure.

Municipal Generation

In all of the future scenarios, the amount of external renewable electricity generated from the wind and solar farms remains constant at 104 GWh resulting in a carbon credit of 19 kton. The amount of electricity produced from the co-generation plants is less for the Smart Energy scenario (1,235 GWh), as a reduction in heat demand reduces the amount of electricity produced, and it is constant at 1,585 GWh across the Green Transport, CO_2 Neutral and Fossil-fuel free scenarios. The city may decide to further expand either power generation source, and in all likelihood they will probably expand both, but for the purposes of this study it will remain constant and any shortfalls in provision are identified as gaps.

Carbon Emissions (CO_2e)



Scenario based results

The Smart Energy scenario is testing building technologies that improve the energy efficiency of both residential and non-residential buildings. This is the most expensive scenario because it involves deep renovations that modify the building envelope of nearly half of all buildings.

Smart Energy

(Carbon = -49 kton; electricity demand = - 330 GWh; job creation = 23,000 FTEs; cost of 2.7 bn EUR (most expensive).

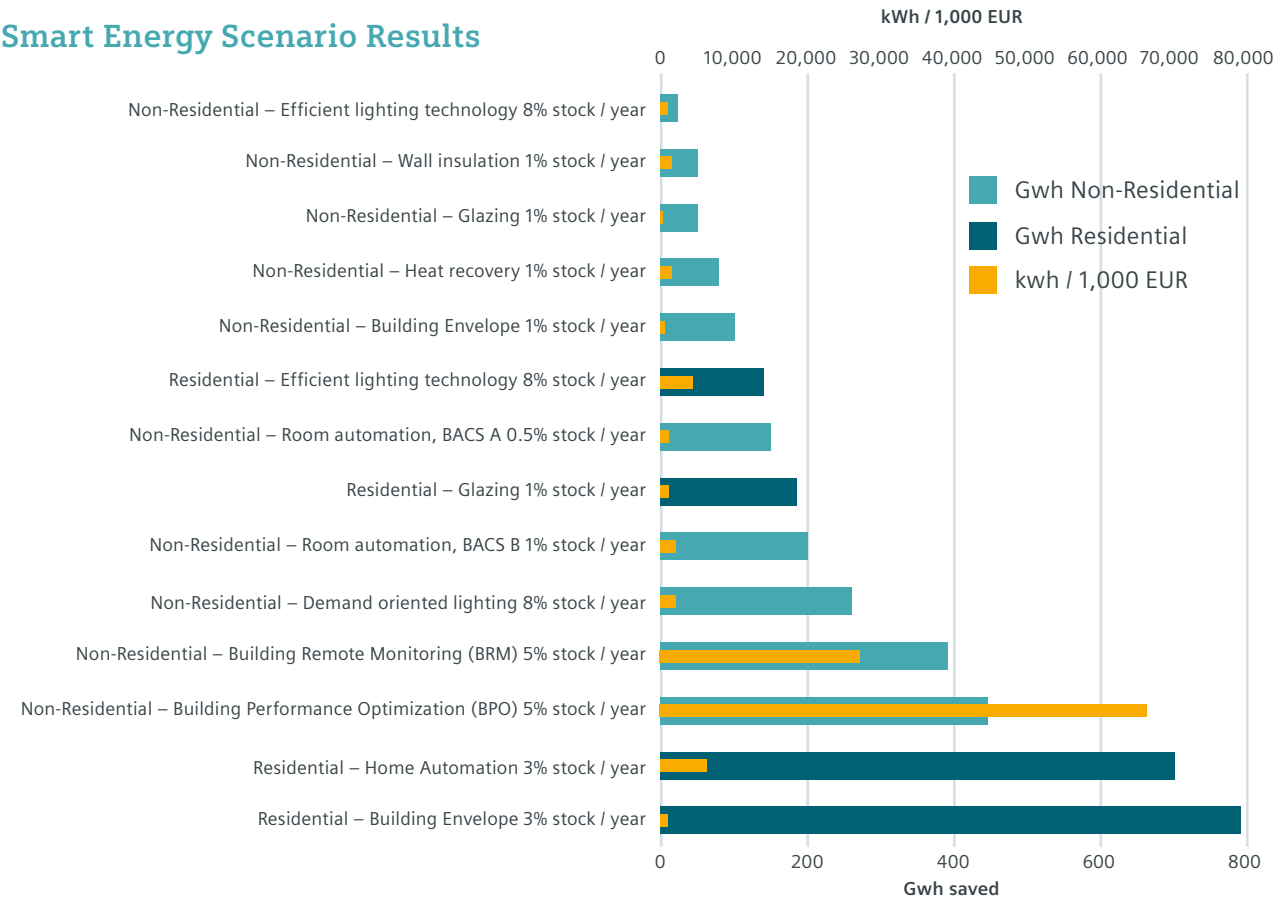
The Smart Energy scenario is testing building technologies that improve the energy efficiency of both residential and non-residential buildings. This is the most expensive scenario because it involves deep renovations that modify the building envelope of nearly half of all buildings. The scenario also includes home automation across all houses, this technology is less invasive and costly, but because it is being rolled-out to all homes it becomes more costly. It is also important to emphasize that because most buildings in Aarhus are privately owned that the cost of this scenario will not be a direct one for the city. The diagram opposite illustrates the technologies that save the most energy and are the most cost effective.

Within the scenario different take up rates have been used for different technologies, and therefore it is key to consider the CO_2e per 1,000 EUR spent in order to best gauge the energy efficiency of any one technology. Building performance optimization and building remote monitoring for non-residential buildings are the most cost effective non-residential building technologies. In the case of residential buildings the only technology that produced a positive carbon performance and appears to be cost effective is energy efficient lighting. As calculated within this scenario, building efficiency improvements that reduce heat loss actually deliver a negative result. This is because of a very particular issue within Aarhus as they calculate that the city produced heat and electricity to be carbon neutral and electricity from the grid is not. As electricity is generated as a by-product, the amount of electricity produced is dependent on heat demand. Thus, any reduction in heat demand through unusually warmer weather or improvement to buildings would result in importing dirtier electricity from the grid. In terms of numbers, the remaining kton of carbon resulting from buildings is 215, which is 49 kton less than the BAU.

Transport carbon emissions remain unchanged from the BAU at 485 kton.

However, in actual GWh of electricity demand, the Smart Energy scenario has a positive story as demand reduces by 330 GWh. The gap in energy generation is 130 GWh.

Smart Energy Scenario Results



Results of the Smart Energy Scenario in Energy Saved and Cost Effectiveness

Residential

The most impactful electricity saver for residential buildings is efficient lighting technology at an 8% annual rate (100% by 2028). In terms of actually saving energy, lighting and building envelope improvements would save the most energy, but lighting and home automation are the more cost effective choices.

Non-residential

The stand-out technology for non-residential buildings would be building performance optimization, and building remote monitoring, both of which save significantly on electricity and comes out as being very cost effective Demand oriented lighting comes out very positively on carbon reduction performance, but this is at a very high implementation rate of 8% of total stock per year, and it is less cost effective then the other two technologies.

Green Transport

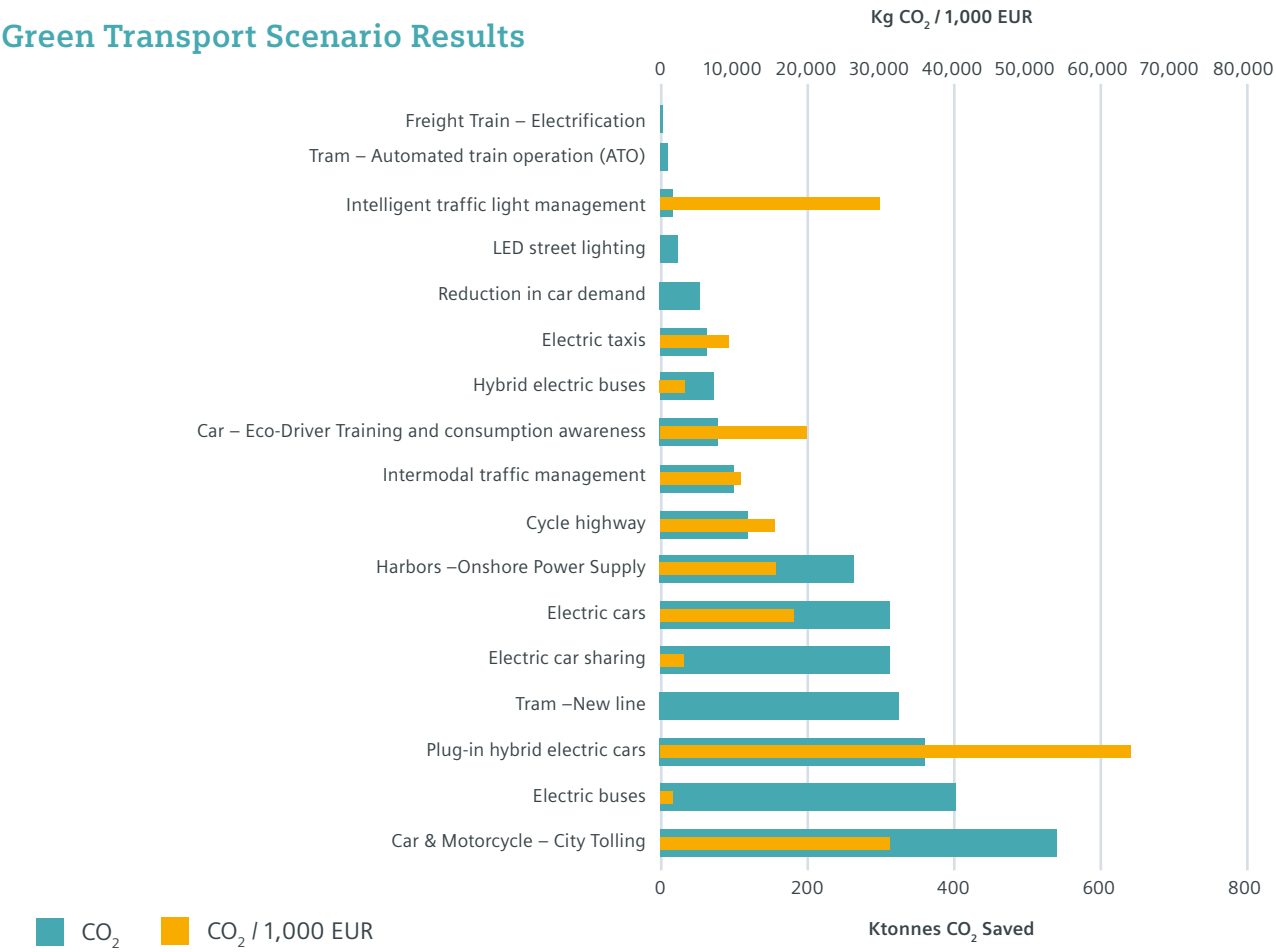
(Carbon = - 120 kton; electricity demand = +122 GWh; job creation = 25,243; cost of 0.97 bn EUR).

This scenario reflects the greening of transport, which occurs through the electrification of transport. The results indeed show a reduction in carbon emissions and an increase in electricity demand due to the addition of three electric tram lines, e-buses (70%), full implementation of on-shore electric power for docking vessels and electric taxis. There are also some transport technologies that would reduce electricity demand such as LED street lighting and intelligent traffic light management, which adds functionality to traffic signals such as timing lights to actual traffic demand versus strict timing or prioritizing road based public transit. Carbon is reduced by 120 kton (-24% reduction in transport emissions) and an increase in electricity demand from 1,799 GWh to 1,921 GWh (+6.7%). In this scenario the gap in electricity production is 232 GWh.

Identifying the stand-out transport technologies (see diagram opposite) requires comparison of both the carbon reduction and the relative implementation level (see appendix). Transport is a more difficult sector to compare technologies against each other from a cost perspective because only the costs to the city are considered. Thus, the purchase of a hybrid car is not a cost to the city, but the purchase of an electric car is as the city would be expected to provide charging points. In this scenario, direct carbon reductions give a better overview of impact.

City tolling (10% reduction in total car traffic), e-bus (70% of total fleet), plug-in hybrid cars (10%) and new tramlines (3 lines) are the best performing transport technologies. City tolling would save over 20 kton of carbon and is very cost effective. However, it is a politically difficult technology to deliver. In some cities, they balance this perception of additional tax by ring-fencing all revenues and investing these directly into public transport projects. From a city cost effectiveness perspective, excluding plug-in hybrids, the most effective technologies are city tolling and intelligent traffic light management (traffic signals).

Green Transport Scenario Results



CO_2 Neutral

(Carbon = -504 kton; electricity demand = +240 GWh; job creation = 30,101 FTEs; cost of 1.1 bn EUR).

This is a very critical strategy for the city as it essentially outlines the technology story underpinning a transition to carbon neutrality. As stated earlier, this scenario utilizes a cleaner heat and electricity mix and it has higher implementation rates for transport technologies. However, the key difference between this scenario and Green Transport is that the implementation rates are higher, high enough to reach a calculated carbon neutrality.

In this scenario, because of the cleaner heat mix the carbon emissions from the buildings sector would drop by 91% to 23 kton, and the transport emissions are reduced by 263 kton (-54%). Because this scenario is targeting CO_2 neutrality there is an increase in electric transport (e-cars (+40%) and e-buses (+30%)) and electricity demand for transport increases from 90 to 330 GWh, an increase of 240 GWh (+260%).

The gap in electricity provision has grown from 110 GWh in the BAU to 350 GWh.

Fossil Free

(Carbon = -687 kton; electricity demand = +89 GWh; job creation = 3,974; cost of 0.4 bn EUR (least expensive).

Aspiring to become fossil-fuel free is a significant step beyond carbon neutrality, and meeting the implied demands of this scenario requires moving beyond full electrification of public transport to the full elimination of all petrol and diesel vehicles (passenger and freight). In this scenario the heat and electricity mix is cleaner, as in the CO_2 neutral scenario, and fuel types have been changed away from fossil fuels, as, for example, residents may purchase alternative fuel cars. Additionally, this scenario does not include the new tram lines and there is no emphasis on shifting transport demand towards public transit.

Combination of Key Scenarios

The Smart Energy and Green Transport scenarios would in all likelihood never be delivered in isolation as they focus on one single sector and meeting carbon reduction targets involves reducing emissions from as many contributors as possible. This section presents results for delivering a mixed scenario approach:

- Green Transport and Smart Energy (carbon reduction of 169 kton)
- CO_2 Neutral and Smart Energy (carbon reduction of 501 kton)
- Fossil Free and Smart Energy (carbon reduction of 684 kton)

BAU 2030 scenario has carbon emissions of 730 kton Technologies and implementation rates for each scenario are included in the appendix.

Green Transport and Smart Energy

This scenario is fairly balanced as it implements both building and transport technologies. However, it is less ambitious in its take-up rates for transport than the CO_2 Neutral or Fossil-fuel free scenarios and results in an overall carbon reduction of only 169 kton. This combination includes the BAU electricity mix, thus is missing the benefits of cleaner power that are reflected in both the CO_2 Neutral and Fossil-fuel Free scenarios. Transport emissions comprise 63% of the remaining carbon.

Electricity demand reductions for this scenario are more impressive (-208 GWh) than carbon reductions (-169 kton) as the energy efficiency benefits of the building technologies are not fully reflected in the carbon results due to the relatively clean heat and electricity mix. The building technologies do offer an electricity reduction of 330 GWh. However, the full electricity demand within this scenario only shows a reduction of 208 GWh as demand for electric transport increases. The electrification gap in this scenario is 252 GWh.

In terms of costs per kton of carbon this scenario is the most expensive, but it is more cost effective when jobs are considered as it does potentially create 48,000 local jobs – most of which are linked to the new tram lines.

CO_2 Neutral and Smart Energy

This scenario aims to reduce carbon through incentivizing a modal shift towards efficient, electrically powered public transport and e-cars, and it is addressing both the public and private sector contributors. Additionally, this combined scenario has the highest implementation rates, and its job creation potential exceeds 50,000 FTEs at a cost of 3.8 bn EUR. As in the previous scenario, the city has invested in three new tram lines and city tolling, which increase costs to the city, but more importantly creates an incentive for a modal shift to more efficient public transport. This scenario differentiates itself as it retains the public transport focus including further electrification of buses. It targets private transport emissions by increasing e-cars from 10% to 50%.

The 501 kton carbon reduction in this scenario is significant and it also has the highest electricity gap - 370 GWh.

Fossil Free and Smart Energy

This scenario aims to reduce fossil-fuels from transport and improve building energy efficiency. This scenario benefits from the cleaner electricity mix than the BAU 2030, and it does not focus on any form of modal shift to public transport. This scenario retains the 50% e-car implementation rate and assumes that the remaining 50% of the car fleet is powered by biofuels or hydrogen gas. The one additional technology in this scenario is the e-highway as electric trucks will remove emissions linked to freight delivery.

Carbon reduction in this scenario is dramatic as it reflects a 94% drop. There are still some remaining emissions and an electricity gap of 219 GWh.

This scenario is the most cost effective in terms of cost per kton of carbon reduced. However, it is asking the private sector to contribute more by renovating their homes and offices, and purchasing alternative fuel vehicles. Additionally, the public will not benefit from an increase in public transport or additional cycle highways.

Industry

There are carbon emissions within Aarhus that are linked to local industry. These emissions are part of the industrial processes happening on-site. There are a number of technologies that could be utilized to reduce the carbon emissions through addressing the internal industrial processes as well as the buildings. Should the city wish to reduce these emissions then a careful study of how energy is generated and utilized on site needs to happen and this is beyond the scope of the CyPT analysis.

Conclusions

The CyPT as a tool is intended to identify the most impactful technologies. It then becomes the role of the Siemens team to put these technologies into perspective in terms of ease of implementation and its relative cost effectiveness. In this sense our first conclusion is the identification of the most impactful technologies, irrespective of the implementation rates used. These technologies are identified as those that best reduce carbon and those that are the most cost effective at reducing carbon.

Development of the City of Aarhus' Climate Plan will be based on finding the best mix of technologies that will balance carbon reductions against the financial ask from both the public and private sectors. Siemens will provide insights on what this mix or ultimate scenario may include. Thirdly, success of any climate strategy will depend upon the city's ability to deliver the results, either by direct action or by influencing others to take action. This influence could be obtained by incentivizing change through financial reward, special benefits like reduced parking costs or by offering an alternative to carbon emitting behavior.

Most impactful carbon reduction technologies

The most impactful technologies for reducing carbon, assuming as Aarhus does, that reducing heat demand in buildings creates a negative carbon result.

Buildings

Non-residential:

- Building performance optimization
- Building remote monitoring
- Demand oriented lighting

Residential:

- Home automation
- Efficient lighting

Transport

Non-residential:

The most impactful carbon reduction technologies include:

- City tolling
- Electric buses
- Plug-in hybrid cars
- New tram lines

Overall the most impactful carbon reducing technologies are transport related because of the assumed near carbon neutrality of building heat.

Most Energy Savings technologies

The following building technologies deliver the most energy savings.

Buildings

Non-residential:

- Demand oriented lighting
- Building performance optimization
- Building remote monitoring

Residential:

- Building envelope (glazing and insulation)
- Home automation
- Building Management System BACS B

Most cost effective technologies

The most cost effective technologies in terms of carbon saved by 1,000 EUR are the following:

Buildings

Non-residential:

- Building performance optimization
- Building Remote Monitoring
- Demand oriented lighting

Residential:

- Efficient lighting
- Home automation

Transport:

- Plug-in hybrid cars
- City tolling
- Intelligent traffic light management

Identifying the optimal mix of technologies

The technology is available for the City of Aarhus to achieve carbon neutrality, fossil-free living or both if implementation rates are high enough. The question is how far to implement and whether the public or private sectors should fund the shift. In terms of actual cost, the fossil-fuel free scenario is the cheapest as its chief target is private transport. Alternatively, the most expensive scenario is Smart Energy, which requires the private sector to deliver wide ranging building improvements and automation. Both of these scenarios are expensive because they are addressing the carbon contributors at scale.

Part of this question of who should pay, is dependent upon other factors not considered directly in the CyPT such as congestion, cost of parking, insufficient cycle lanes or the amount of productive time lost in driving to work or home. Fixing any of these issues means that the city will need to invest in public transit infrastructure and the cost will be a public one. These public infrastructure investments are also generally good for reducing carbon and improve local air quality. However, these technologies do not address the issue of scale, and would rely on people changing their behavior and using public transit and cycle lanes more.

If the city does see a need to address these congestion type issues, then the starting position for the city is to identify a scenario that delivers additional public transit and incentivizes walking or cycling. Alternatively, any scenario that does not require building owners to improve the performance of their buildings because energy is sufficiently carbon neutral loses sight of any of the financial benefits linked to energy savings such as reduced operational costs, possible higher achieved rents and improved comfort.

If the City of Aarhus then takes the more middle ground of investing in both public transit while also asking the private sector to do its part, then the optimal scenario more closely resembles the CO_2 Neutral approach. One possible optimal scenario could be one that targets carbon neutrality, taking only a light touch to buildings and focusing more on mobility. In this scenario, the less invasive and less costly building automation technologies are delivered across the buildings sector. These building interventions are then coupled with the most effective carbon reducing transport technologies – city tolling, e-buses, new tram lines, onshore power, cycle highways and e-cars. These highly effective carbon reducing technologies could also be supplemented by some of the more cost effective technologies such as intelligent traffic light management.

This approach would incorporate the most carbon effective technologies within both sectors and would bring the city much closer to its carbon neutrality target. Some of these technologies, city tolling in particular, may not be possible given national policy and may need to be viewed as a long-term goal whereas delivering e-buses are within the City of Aarhus' authority and could be delivered quickly across the city. The city should focus in the short-term on delivering what it can, while outlining incentives or measures to help implement the more long-term technologies. The following could be one possible time frame.

Short-term

City addresses the key technologies that it can deliver independently while working with national government to create positive incentives for the remaining technologies.

- Buildings: deliver a pilot project that tests room automation and building performance optimization technologies on a range of existing public buildings.
- E-buses
- Deliver tram line 1
- LED street lights

- Retire and replace the oldest vehicles within the city's public fleet with new electric vehicles.

Policy:

Initiate discussions with the relevant port authority and shipping companies to create a plan for transitioning to on-shore electric power in the Port of Aarhus.

Medium-term

City has completed its 70 m EUR public building renovation project and results have been made public with the aim to incentivize building improvements in the private sector. City moves forward with a plan to mandate on-shore power for docking vessels.

- Buildings: further roll-out of automation technologies across the city's publicly owned buildings and houses.
- Incentivize private sector building improvements through education and provide support in pooling buildings together for a possible Energy Performance Contracting type approach, where savings are guaranteed to an end-user and costs are repaid through energy savings.
- Make public data gathered from the automation of buildings
- E-taxi
- Intelligent traffic light management
- Cycle highways
- Line 2 tram
- Fully retire all non-electric vehicles from the city's fleet
- Mandate on-shore power at the Port of Aarhus

Policy:

Implement non-tax related incentives for retiring old cars across the city and replacing them with electric vehicles.

Long-term

City is now able to more fully incentivize e-cars by giving a financial reward for purchasing and allowing these cars to travel within the restricted tolling zone free of charge.

- City tolling
- E-vehicles
- Deliver tram line 3
- Scale-up building automation initiatives for both the residential and non-residential sectors

A Climate Plan that sets out ambitious targets for reducing carbon as well as ideas for how to implement change across the city is vital. By 2020, The City of Aarhus will have already made a huge reduction in carbon emissions through the shift to biomass in the public heat system. However, success

in the buildings sector must be coupled by positive action in transport. Furthermore, the city must also asses how easy it will be to fill the identified carbon gap for each scenario with city-owned renewable power. Siemens has already estimated the number of wind turbines necessary for meeting the electricity gap of 350 GWh in the CO_2 Neutral strategy, – assuming an even split between wind and solar power; Fifteen, 4 MW, wind turbines and 3 km^2 of photovoltaic cells.

The City of Aarhus can also take the opportunity presented through its Climate Plan to publicly share its city data and use it to engage with the very large local student population. One possible future for Aarhus could be to create technology related jobs on the back of the Climate Plan and keep smart young students in Aarhus post-graduation from university. A more affordable lifestyle and a young population are two other main attractors that could be leveraged. Mexico City is one city where the Mayor has created a special City Lab team comprised of recent students who focus on finding ways for technology to help the city operate and improve local quality of life.

There are many options the City of Aarhus can take, and the key point being that it is technically possible to achieve real carbon neutrality by 2030, but that city, national government, and a majority of the public must all agree that is a shared goal and make the required changes.

E-highway and e-bus

The City of Oslo is committed to providing a fossil-fuel free public transport system across the city and into its suburbs by 2020. Buses in Oslo carry 140 million passengers per year and are a cornerstone of local public transport.

Electric Buses in Oslo, Norway

The City of Oslo is committed to providing a fossil-fuel free public transport system across the city and into its suburbs by 2020. Buses in Oslo carry 140 million passengers per year and are a cornerstone of local public transport. Ruter the Oslo transport authority, managed a feasibility study comprising all proven technologies that could meet the 2020 objective. Identification of the best technology would be based upon three key criteria; namely cost, emissions, air quality and ease of phasing in new fleet. The study found that rechargeable hybrid buses (battery operated) provided the best solution as local emissions were zero, they were more efficient than buses run on alternative fuels, and with fast recharging at bus stops could be rolled across 80% of all 64 city bus lines without having to make any changes to timings or routes.

On the lines where some modifications would be needed the changes were minimal. E-buses came out more economically efficient even than diesel buses, this is because the cost of electricity in Oslo is very low and e-bus are very efficient, they can run 3 to 4 times longer on the equivalent amount of power than a diesel bus so fuel costs were less, and charges for local pollution also helped the e-bus result. Ruter estimated that the rechargeable hybrid e-bus would save the company NOK 750 million (80 million EUR) over 10 years and would positively impact local air quality.

E-highway

Trucks are a critical part of freight logistics, and they can be very noisy and damaging to local air quality. Until recently, there were no commercial electric trucks, but today Siemens has launched two E-Highway demonstration projects, in the United States and Sweden.

The E-Highway combines resource-efficient railway technology with the flexibility of road transport. The E-Highway adapted hybrid trucks are supplied with electricity from overhead contact lines via the active pantograph, which can connect and disconnect at speeds up to 90km/h.

While trucks are attached to the system they run with zero local emissions and no noise. This technology has the potential to work very well on specific sections of road where freight traffic is particularly heavy, such as leading to and from a port or major distribution hub and city center.

Appendix I

The CyPT tracks technologies' impact of four indicators.

1. CO_2e Emissions

CO_2e stands for a carbon dioxide equivalency measure that allows for various greenhouse gasses (GHGs) to be expressed in terms of CO_2e as a common unit. Equivalency is determined by multiplying the amount of the GHG by its global warming potential (GWP), where GWP indicates how much warming a given GHG would cause in the atmosphere over a certain period of time (usually 100 years). For example, CO_2e has a GWP of 1, whereas methane (CH_4) has a GWP of 25. Therefore, 1kg CH4 * 25 = 25kg CO_2e[1].

2. NO_x

Nitrogen Oxides (NO_x) most commonly refer to nitric oxide (NO) and nitrogen dioxide (NO_2). Some level of NO_x occurs naturally in the air, but NO_x is predominantly caused by human activity that is harmful to the atmosphere, particularly the burning of fossil fuels. In urban settings especially, NO_x emitted from vehicle emissions can cause significant air pollution[2].

3. PM_{10}

Particulate matter 10 (PM_{10}) describes very small liquid and solid particles floating in the air that measure only 10 microns in diameter (about 1/7th the thickness of human hair). These particles are small enough to breathe into human lungs and among the most harmful of air pollutants. PM_{10} has many negative health impacts once lodged in the lungs, and can increase the severity of asthma attacks, cause or worsen bronchitis, and weaken the body's immune system. The most common sources of PM_{10} include vehicle emissions, wood burning stoves and fireplaces, and dust from construction, landfills and agriculture[3].

4. Jobs (Full-time equivalents)

The CyPT measures the gross number of direct, indirect, and induced jobs created in the local economy by investing in CyPT technologies. These include installation, operation and maintenance jobs, which are calculated as full time equivalent jobs of 1,760 hours per year. Manufacturing jobs are not accounted for, because some of these technologies may be produced outside the city's functional area, with no local benefits to the economy.

1. http://ecometrica.com/white-papers/greenhouse-gases-co2-co2e-and-carbon-what-do-all-these-terms-mean
2. http://www.eea.europa.eu/data-and-maps/indicators/eea-32-nitrogen-oxides-nox-emissions-1
3. http://www.arb.ca.gov/html/brochure/pm10.htm

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Appendix II

Scenarios.

Lever	Smart Energy	Green Transport	CO_2 Neutral	Fossil Free	Unit
Non-Residential – Demand oriented lighting	100%				Building Stock
Non-Residential – Building Performance Optimization (BPO)	45%				Building Stock
Non-Residential – Building Remote Monitoring (BRM)	75%				Building Stock
Residential – Efficient lighting technology	100%				Building Stock
Non-Residential – Room Automation, BACS B	15%				Building Stock
Non-Residential – Room Automation, BACS A	8%				Building Stock
Non-Residential – Efficient lighting technology	100%				Building Stock
Non-Residential – Wall insulation	15%				Building Stock
Non-Residential – Glazing	15%				Building Stock
Non-Residential – Heat recovery	15%				Building Stock
Non-Residential – Building Envelope	15%				Building Stock
Residential – Glazing	15%				Building Stock
Residential – Home Automation	45%				Building Stock
Residential – Building Envelope	45%				Building Stock
Car & Motorcycle – City tolling		10%	10%		Road traffic reduction
Electric buses		70%	100%	100%	Fleet
Plug-in hybrid electric cars		10%			Car fleet

Lever	Smart Energy	Green Transport	CO_2 Neutral	Fossil Free	Unit
Tram – New line		3	3		Lines
Electric car sharing		2	6		Cars / 1000 inhabitants
Electric cars		10%	50%	50%	Car fleet
Harbors – Onshore Power Supply		100%	100%	100%	Vessels
Cycle highway		10	20		km / 100,000 Inhabitants
Intermodal traffic management		70%			Users
Car – Eco-Driver Training and consumption awareness		10%	10%		Drivers trained
Hybrid electric buses		30%			Fleet
Electric taxis		100%	100%	100%	Car fleet
Reduction in car demand		1%			Reduced car use
IED Street lighting		100%	100%		Street lights
Intelligent traffic light management		100%	100%		Traffic lights
Tram – Automated train operation (ATO)		70%			Lines
Freight Train – Electrification		100%	100%	100%	Railway network
Hydrogen Cars				20%	Car fleet
E-Highway				100%	Highway equipped

Lever	Smart Energy	Green Transport	CO_2 Neutral	Fossil Free	Unit
Non-Residential – Demand oriented lighting	100%	100%	100%	100%	Building Stock
Non-Residential – Building Performance Optimization (BPO)	45%	45%	45%	45%	Building Stock
Non-Residential – Building Remote Monitoring (BRM)	75%	75%	75%	75%	Building Stock
Residential – Efficient lighting technology	100%	100%	100%	100%	Building Stock
Non-Residential – Room Automation, BACS B	15%	15%	15%	15%	Building Stock
Non-Residential – Room Automation, BACS A	8%	8%	8%	8%	Building Stock
Non-Residential – Efficient lighting technology	100%	100%	100%	100%	Building Stock
Non-Residential – Wall insulation	15%	15%	15%	15%	Building Stock
Non-Residential – Glazing	15%	15%	15%	15%	Building Stock
Non-Residential - Heat recovery	15%	15%	15%	15%	Building Stock
Non-Residential – Building Envelope	15%	15%	15%	15%	Building Stock
Residential – Glazing	15%	15%	15%	15%	Building Stock
Residential – Home Automation	45%	45%	45%	45%	Building Stock
Residential – Building Envelope	45%	45%	45%	45%	Building Stock
Car & Motorcycle – City tolling		10%	10%		Road traffic reduction
Electric buses		70%	100%	100%	Fleet
Plug-in hybrid electric cars		10%			Car fleet
Tram – New line		3	3		Lines
Electric car sharing		2	6		Cars / 1000 inhabitants
Electric cars		10%	50%	50%	Car fleet
Harbors – Onshore Power Supply		100%	100%	100%	Vessels
Cycle highway		10	20		Km / 100,000 Inhabitants
Intermodal traffic management		70%			Users
Car – Eco-Driver Training and consumption awareness		10%	10%		Drivers trained
Hybrid electric buses		30%			Fleet
Electric taxis		100%	100%	100%	Car fleet
Reduction in car demand		1%			Reduced car use
LED Street lighting		100%	100%		Street lights

Lever	Smart Energy	Green Transport	CO_2 Neutral	Fossil Free	Unit
Intelligent traffic light management		100%	100%		Traffic lights
Tram – Automated train operation (ATO)		70%			Lines
Freight Train – Electrification		100%	100%	100%	Railway network
Hydrogen Cars				20%	Car fleet
E-Highway				100%	Highway equipped

	Smart Energy	Green Transport	CO_2 Neutral	Fossil Free
Waste	No separation	No separation	Separation of plastics	Separation of plastics
Biofuel	No biofuel	No biofuel	20% of fuel is biofuel	30% of cars run on 100% biofuel

Appendix III

Glossary.

Building Levers		
Non-Residential	BACS Class B	Energy-efficient building automation and control functions save building operating costs. The thermal and electrical energy usage is kept to a minimum. It is possible to estimate the efficiency of a building based on the type of operation and the efficiency class of the building automation and control systems (BACS) installed. Energy Class B includes advanced building automation and controls strategies, such as demand-based operation of HVAC plant, optimized control of motors and dedicated energy management reporting. Reduction of CO_2e, PM_{10}, and NO_x are related to thermal and electrical energy savings.
Non-Residential	Building Efficiency Monitoring (BEM)	Building Efficiency Monitoring provides real-time measurement of energy consumption and environmental conditions within an EXISTING building, via a centralized monitoring system connected to a network of field devices (such as meters, switches and sensing devices). Standard energy reports are created to allow benchmark comparison with similar buildings to assess performance and highlight problems (e.g. kWh, CO_2, temperature). Offering monitoring services and performance reports creating awareness and transparency and enable continuous improvement and reduction of overall energy consumption. Reduction of CO_2e, PM_{10}, and NO_x related due to thermal and electrical energy savings.
Non-Residential	Building Performance Optimization (BPO)	Building Performance Optimization (BPO) is a range of services designed to increase the energy efficiency of an EXISTING building by implementing proven building control strategies otherwise known as Facility Improvement Measures (or FIMs). BPO can improve THERMAL and ELECTRICAL energy efficiency in a building in many ways; typically via improved HVAC technology, by adapting the building to suit usage profiles or providing information and analytics for operational personnel. Reduction of CO2e, PM_{10}, and NO_x related due to energy savings.
Non-Residential	Building Remote Monitoring	Building Remote Monitoring (BRM) allows individual building performance to be measured and compared against benchmark values for similar building types or sizes. Energy experts are able to remotely analyze building energy usage, to detect problems and make proposals for improvements. Reduction of CO_2e, PM_{10}, and NO_x related due to energy savings.

Building Levers		
Non-Residential	Demand controlled ventilation	With demand-controlled ventilation (DCV), the amount of air introduced into a space is matched to the actual demand and is ideal for areas with fluctuating occupancy such as open-offices, conference rooms and restaurants. CO_2 levels measured by air quality detectors identify periods of low occupancy and cause the fans to stop or reduce speed (at 50% air volume, the fan power is reduced by a factor of 8!). DCV also provides savings in heating and cooling, by adjusting set point temperatures (economy mode). Reduction of CO_2e, PM_{10}, and NO_x related due to electrical electricity savings.
Non-Residential	Demand oriented lighting	Demand-oriented lighting is based upon presence (or motion) detection: Lighting is switched 'on' when someone enters a given area and deactivates after a pre-defined period of time without movement. It is usually combined with daylight measurement. The largest energy savings can be achieved in buildings with fluctuating occupancy, and when combined with other lighting technologies, it can reduce the lighting energy use within a building by 20 to 50%. Reduction of CO_2e, PM_{10}, and NO_x related due to electrical energy savings.
Non-Residential	Efficient lighting technology	Electricity can be saved by replacing conventional light bulbs for room lighting by more efficient light-emitting diodes (LEDs). LEDs consume up to 90% less energy and have a longer lasting in operation hours and turn off/on cycles. LED lamps are compatible to conventional lamps and can substitute them easily. LEDs provide an equal luminosity at lower specified power. Reduction of CO_2e, PM_{10}, and NO_x related due to electricity savings.
Non-Residential	Energy Efficient Motors and Drives	Analyzing the drive technology in your building (fans, pumps, compressors or process plant) can lead to significant cost- and energy-savings and help reduce emissions. As an example: changing a standard 30kW motor (IE1) to an equivalent energy efficient motor (IE3) can save 3,500 kWh per year, and 2,000kg of CO_2 emissions. Adding variable speed drive technology will ensure motors only draw as much energy as is actually required. Reduction of CO_2e, PM_{10}, and NO_x are related to electrical energy savings.
Non-Residential	Glazing	Applying double/triple glazed window made of two or three panes of glass and a space between them filled with air or insulating gases and reduces heat and noise transmission as well as solar gain from solar radiation through the window. Due to better window insulation less heating and cooling energy is needed inside the building. Reduction of CO_2e, PM_{10}, and NO_x related due to energy savings.

Building Levers		
Non-Residential	Room Automation HVAC+lighting	Room Automation provides control and monitoring of heating, ventilation, and air conditioning within individual zones based upon demand, with options for automatic lighting. An in-built energy efficiency function identifies unnecessary energy usage at the room operating units, encouraging room users to become involved in energy saving, and different lighting scenarios can be programmed. Reduction of CO_2e, PM_{10}, and NO_x are related to thermal and electrical energy savings.
Non-Residential	Wall insulation	Solid wall insulation e.g. made of expanded polystyrene (EPS) can be applied to already existing buildings. Applying the rigid foams to exterior side of walls raises thermal resistance. The insulation reduces the heat gain/loss through the walls and thus minimizes the heating/cooling energy needed. Reduction of CO_2e, PM_{10}, and NO_x related due to energy savings.
Residential	Efficient lighting technology	Significant electrical energy can be saved by replacing conventional luminaires by more efficient lighting fixtures and/or changing magnetic ballasts to electronic ballasts. Further reductions in power consumption can be achieved with the use of light-emitting diodes (LEDs), which also have a far higher lifespan than conventional lighting. LED solutions combined with intelligent light management systems can lower lighting costs in a building by as much as 80%. Reduction of CO_2e, PM_{10}, and NO_x related due to electricity savings.
Residential	Home Automation	Home Automation allows the automatic adjustment of heating, cooling, ventilation and lighting. The adjustment is based on environmental conditions and room occupancy, and it works by applying sensors and actuators as well as control units. Home automation reduces the energy demand of heating, cooling, ventilation and lighting.

Transport Levers		
Freight	E-Highways	Share of hybrid diesel-electric trucks and highways with overhead power lines at target year. As soon as trucks join the eHighway they connect to the overhead power lines and switch into pure-electric mode. Leaving the eHighway, the trucks switch back to using hybrid mode. Energy demand is reduced due to shift of transport to hybrid electric truck and electric transport together with related emissions.
Infrastructure	City Tolling	City tolling is a form of road pricing applied to a geographic area within a city. It would charge drivers for road use and pricing can be flat or dynamic based on distance and likely travel times. Charges could also be used to encourage cleaner vehicles or those that use a particular fuel type. The technology uses number plate recognition software and cameras.
Infrastructure	Intelligent traffic light management	Share of traffic lights, coordinated (green wave algorithms) - Management systems controls traffic speed and volumes and co-ordinates traffic lights to help maintain the flow. Reduced energy demand, fuel consumption and air pollution caused by traffic by reducing traffic jams, stop and go.
Infrastructure	Intermodal traffic management	Share of users integrated at target year equals to person kilometer considered to optimize capacities of the entire traffic infrastructure. Intermodal Traffic Management focuses on interoperable multimodal Real Time Traffic and Travel Information (RTTI) services provided to drivers/ travelers promoting change in mobility behavior from individual to public transport reducing energy demand per person kilometer.
Infrastructure	LED Street lighting	Share of low efficient street light replaced by more efficient light-emitting diodes (LEDs). Saving electricity together with related emissions. Additionally high reduction in maintenance due to longer lifetime (10 years versus 6-12 month) and possibility to dim the light depending on the environmental conditions.
Infrastructure	Low emission zone for vehicles	Share of the city's area, defined as a geographical area with restrictions for vehicles of certain off-gas emission standards.
Passenger	Automated train operation (ATO) Metro	Share of lines operated with ATO at target year: ATO controls or guides optimal throttle of engines, going optimal speed without violating the schedule. Reduced electricity demand per person km due to coasting. The saving potential correlates with the number of and distance between the stations. Reduction of CO_2e, PM_{10}, and NO_x related to lower electricity demand.

Transport Levers		
Passenger	Bike sharing	Number of sharing bikes per 1,000 inhabitants, offered at target year, which results in a shift from all other transport modes equally. The technology will lower energy demand per person kilometer of travel together with related emissions.
Passenger	BRT-Electrification	Share of the Bus Rapid Transport (BRT) bus fleet that is powered by batteries. Battery electric vehicles are "zero" exhaust emission vehicles. Electrification of these buses will reduce local emissions of PM_{10} and NO_x. The technology requires the set-up of a charging infrastructure. The electricity, used for charging, is generated according to the general local electricity mix.
Passenger	Cycling highway	Additional number of cycling highways, increasing modal share of bikes. This lever reduces the modal share of other motorized vehicles and therefore emissions.
Passenger	e-Bus rapid transit new line (eBRT)	Share of Passenger Transport at target year provided by Bus rapid transit: a high performance public transport combining bus lanes with high-quality bus stations, and electrical vehicles. Faster, more efficient service than ordinary bus lines. Results in modal shift from private transport to public transport, shift from combustion engines and reduce energy demand per person km together with related emissions.
Passenger	Eco-Driver Training and consumption awareness (road)	Frequent Training of car drivers to optimize driving behavior and increase fuel economy of fleet average.
Passenger	Electric buses	Share of the vehicle fleet operated by battery electric bus vehicles. Battery electric vehicles are "zero" exhaust emission vehicles. These vehicles will significantly reduce local emissions of PM_{10} and NO_x. The technology requires set-up of charging infrastructure. The electricity used for charging is generated according to the general local electricity mix.
Passenger	Electric car sharing	Number of sharing cars/1000 inhabitants at target year: model of car rental where people rent e-cars for short periods of time, on a self service basis. It is a complement to existing public transport systems by providing the first or last leg of a journey. Resulting in fewer driving emissions due to e-car and shift to non-vehicle travel, such as walking, cycling and public transport.
Passenger	Electric cars	Share of conventional combustion vehicles replaced by battery electric vehicles. Battery electric cars are "zero" exhaust emission vehicles. These vehicles will significantly reduce local emissions of PM_{10} and NO_x. The technology requires set-up of charging infrastructure. The electricity used for charging is generated according to the general local electricity mix.

Transport Levers		
Passenger	Electric taxis	Share of conventional combustion taxi vehicles replaced by battery electric taxi vehicles. Battery electric vehicles are "zero" exhaust emission vehicles. These vehicles will significantly reduce local emissions of PM_{10} and NO_x. The technology requires set-up of charging infrastructure. The electricity used for charging is generated according to the general local electricity mix.
Passenger	Hybrid electric buses	Share of vehicle fleet operated by hybrid electric vehicles at target year. Small combustion engine for base energy demand combined with an electric drive for acceleration and for brake energy recuperation. Energy demand is reduced due to a higher efficiency of the combustion engine, operating at optimum and brake energy recuperation together with related emissions.
Passenger	Hybrid electric cars	Share of conventional combustion vehicles replaced by hybrid electric vehicles at target year. Small combustion engine for base energy demand combined with an electric drive for acceleration and for brake energy recuperation. Energy demand is reduced due to a higher efficiency of the combustion engine, operating at optimum and brake energy recuperation together with related emissions.
Passenger	Metro - new line	Number new metro lines at target year of average metro length, shifting passengers from all other mode according to the transportation performance of existing lines in the city. Public transport attractiveness is increased and energy demand per person kilometer is reduced together with related emissions.
Passenger	Metro-Reduced headway	Reduction of headway by introducing a rail automation system with moving block scheme. The lever increases the capacity of over utilized metro lines significantly. It induces a modal shift from other motorized mode to the metro system.
Passenger	New Tram Line	Light rail systems (LRT) are lighter and shorter than conventional rail and rapid transit trains. LRT systems are flexible and can run on shared roadways or along dedicated tracks. These systems can be configured to meet a range of passenger capacity levels and performance characteristics. They can operate with high or low platforms, and consist of one or multiple carriages. Trams can be equipped with braking energy storage systems to further reduce energy demand.
Passenger	Plug-in hybrid electric cars	Share of conventional combustion vehicles replaced by Plug-in hybrid electric vehicles at target year. Small combustion engine for base energy demand combined with an electric drive for acceleration and for brake energy recuperation. Energy demand is reduced due to a higher efficiency of the combustion engine, operating at optimum and brake energy recuperation together with related emissions.

Energy Levers		
Distribution	Smart Grid for Monitoring and Automation	Increased network performance with intelligent control - Optimization of decentralized energy resources –economically and ecologically. Possibility for bidirectional energy flow, Reduces technical and non-technical grid losses in distribution and corresponding reduced energy generation and related emissions.
Distribution	Smart Metering and demand response	Implementing smart meter devices and a meter data management system providing detailed information about how much energy is consumed at which place which allows demand response and reduction of non-technical losses.
Generation	Photovoltaic	Share of electricity provided by Photovoltaic at target year changing the energy mix and its related emissions provides cleaner electricity for buildings and electric powered transport modes.
Generation	Wind power	Share of electricity provided by wind power at the specified target year. This technology effectively changes and electricity mix and it provides cleaner electricity for buildings and electric powered transport modes.
Transmission	Network Optimization	A well-structured, secure and highly available electricity supply infrastructure. Reduces grid losses; Resulting in less energy generation and related emissions to provide the demanded energy at customer side.
Transmission	Power System Automation and optimized network design	Optimal combination of substation automation and change of voltage levels, power system structures, equipment (lines, transformers), change of disconnecting points, etc. in order to reduce (non-)technical losses, guarantee fast power system restoration after a fault in the network and simplified network operations.

VELOPAK
CYKELBUDET
61 72 16 96
BULLITT

The Crystal
1 Siemens Brothers Way
Royal Victoria Dock
London
E16 1GB

© 2016 Siemens plc.

Kurt Othendal Nielsen – Siemens Denmark
Kurt.o.nielsen@siemens.com

Klaus Heidinger – Global Center of Competence Cities
Klaus.heidinger@siemens.com