Integrated City Strategy for CO_2 Emission Reduction, Resource Efficiency and Climate Resilience

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Low Carbon Future Cities

A Sino-German Cooperation on an Integrated Climate and Resource Proof Urban Development

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Authors:

Johannes Venjakob, Clemens Schneider (Wuppertal Institute)

Contributors:

Mathieu Saurat (Wuppertal Institute)

Tom Fischer, Marco Gemmer, Jiang Tong (China Meteorological Administration (CMA) National Climate Centre (NCC))

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Project Co-ordinators:

Daniel Vallentin, Chun Xia, Wuppertal Institute for Climate, Environment and Energy

Contact

Johannes Venjakob // Wuppertal Institute for Climate, Environment and Energy // Johannes.Venjakob@wupperinst.org

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Summary

The Low Carbon Future Cities project (LCFC) aims to develop an integrated urban low carbon adaptation and circular economy strategy to harness the potential for CO_2 mitigation in urban areas by engaging cities and stakeholders in both China and Germany in an integrated approach.

The challenge of combining mitigation, adaptation and resource efficiency is the focus of WP3. The analysis is based on the development of low carbon scenarios that describe how low carbon development, which significantly reduces greenhouse gas (GHG) emissions and enforces carbon neutral development, is possible for the city of Wuxi in the coming decades. Two possible pathways have been developed: firstly, the Low Carbon Technology Scenario (LCTS) and, secondly, the more ambitious Extra Low Carbon Scenario (ELCS).

The consideration of the future importance of air conditioning systems in the building sector provides the link to the adaptation dimension. In selected areas of the ELCS (the energy and building sectors) the impact on stock-flow and material inputs are also analysed.

The analyses in this report build on the previous work in the project, especially on the development of the Current Policy Scenario (CPS), which describes a business-as-usual development pathway.

Selection of mitigation technologies

The basis for modelling technology-driven low carbon scenarios is provided by a comprehensive database developed by the Wuppertal Institute on behalf of the environmental office of the city of Düsseldorf and the German Association of Cities (Deutscher Städtetag) in 2010.

It contains 150 technologies, qualitatively assessed in terms of economic aspects, required framework conditions etc. Taking into account different stakeholders in Wuxi, a local selection of specific technologies has been made, which will play a central role in the derivation of scenarios. The sectors considered are:

- Power generation, heating and cooling;
- New buildings and building stock;
- Transport;
- Industry.

In a further step, appropriate policy instruments, which are necessary for the successful implementation of the chosen technological strategy, were identified. Successful

implementation examples from the European context have been evaluated.

Low Carbon Technology Scenario (LCTS)

The assumptions and the modelling indicate a rapid decrease in CO_2 intensity (CO_2 emissions per unit GDP). However, absolute CO_2 emissions will remain more or less stable from 2020 to 2030 and then decline again from 2030 onwards.

While the CO_2 emissions per GDP decrease due to structural changes in Wuxi's local economy, the carbon intensity per capita stagnates. This is an improvement compared to the development in the Current Policy Scenario (CPS) but still demonstrates the need for intervention. The initial level of per capita emissions is already very high compared to other Chinese regions and bearing.

In the LCTS Wuxi's economy experiences a fundamental structural change over the next decade, becoming less energy intensive. However, industry in general remains the main driver of CO_2 emissions in Wuxi. It is still essential to develop strategies to make industrial energy use CO_2 neutral in the long-term.

Energy savings in all sectors and electricity generation from local renewable sources are key elements of the LCTS and contribute to the development described.

Absolute direct CO_2 emissions from fuel use in the industry sector begin to decline from 2020. These CO_2 reductions can be explained by energy efficiency, i.e. a lower specific demand for energy carriers, as well as the shift from coal to natural gas.

The building stock in the LCTS experiences some reduction in electricity demand, achieved by using newer technology to make air conditioning more energy efficient.

After 2020 the purchase of best available technology (BAT) household appliances leads to a relatively sharp decline in electricity demand at household level. The reductions in energy demand that are achieved by efficiency gains are not negated by new appliances and/or the more extensive use of appliances.

Some technological changes are assumed when modelling the future development of Wuxi's transport sector, resulting in changes to CO_2 emissions. The total emission level is lower than in the CPS.

The modelling results of the LCTS illustrate that the demand for electricity in 2050 is 22% below the level of the CPS. Conventional coal power generation is projected to peter out. The overall efficiency of Wuxi's power plants is projected to increase in the coming decades. The potential for local renewable electricity production is limited. The share of renewable energies in the total installed power generating capacities (MW) is significant, whereas the share in electricity production is predicted to be only 3% in 2050 due to the high industrial electricity demand in Wuxi. As a consequence of the modernisation of Wuxi's power plants, emissions from electricity generation and CHP plants will be 60% below the level of the CPS by 2050.

Extra Low Carbon Scenario (ELCS)

The results for the ELCS show that it is possible to reduce Wuxi's CO_2 emissions to a lower level than illustrated in the LCTS. This is based on the assumptions that the implementation of new mitigation technologies, which are not in use today, will be enforced and that the amount of imported renewable electricity will increase significantly.

As the city of Wuxi is one of China's industrial heartlands, it seems justifiable and necessary that in the long-term Wuxi will require a high share of imported electricity and, correspondingly, consume a high share of national resources.

Despite fostering energy efficient technologies in all sectors, the total final energy demand is projected to increase by approximately 45% in the coming decades. This increase is most obvious in the industrial sector because of growth in production. However, the relative growth is even higher in the field of housing due to rising living standards and the rapid increase in the use of electrical household appliances, e.g. air conditioning systems. The development of energy demand in the transport sector is equal to the projection illustrated in the LCTS.

In comparison to the LCTS, the most obvious technological change affects the production of steel. Here, new low carbon technologies are projected to be implemented in the ELCS in addition to the technology outlined in the LCTS.

When considering the building sector, it is evident that as floor space increases, so does the move towards a more energy-intensive lifestyle (such as in industrialised countries), causing an increase in electricity demand. It must be stressed, however, that due to the growing market penetration of low energy and ultra low energy buildings the increase in energy demand is considerably lower compared to a scenario that would provide the same comfort for inhabitants but with lower energy standards for residential buildings.

A key driver for the further reduction of energy-related CO_2 emissions in the ELCS, when compared to the LCTS, is the extended production of electricity from renewable sources. This results from the increase in imported electricity from renewable sources to meet the demands of the energy-intensive industries.

Resource utilisation in selected sectors under the Extra Low Carbon Scenario (ELCS)

The ELCS relies much less on domestic electricity production than the LCTS. Imported electricity increases, but importantly comes mainly from renewable energy sources, while Wuxi's domestic electricity and heat production shifts from coal to a gas-dominated fuel mix. However, the related total material requirement does not increase correspondingly due to the lower material footprint of renewable energy technologies.

Additionally the shift to natural gas for domestic production and to renewables for imports, away from coal in both cases, suggests that Wuxi will decrease its energy-related water footprint both within and outside the city.

Overall, the ELCS leads to development with a radical reduction in greenhouse gas emissions and direct/indirect material and water requirements.

Under the assumptions made in the ELCS, a general downward trend in the construction sector can be observed in the coming decade, before an upward swing kicks in for a short period. After 2025 construction activity declines (in rural areas) or stabilises (in urban areas). The projections show that by 2050 the urban building stock will more or less stabilise with regards to material flows. By that time, the material stock in urban residential buildings will have increased by about 70% compared to 2010. This is the result of the growth in urban population and the increase in their living space requirements. Simultaneously, the amount of materials trapped in rural residential buildings will decrease by almost half.

This overall growth in the construction sector means that the environmental pressures from the demand for construction materials and disposal of building waste will continue to be significant in the ELCS.

Implications of the low carbon scenarios for the adaptation to climate change

The annual number of heating degree days (HDD) in Wuxi has decreased by approximately 20 between 1961 and 2009. This trend is projected to further continue in the future. By 2050, HDDs are expected to decline by a further 11 days and in 90 years' time the prediction is that there will be less than 15 HDDs.

The number of annual cooling degree days (CDD) has increased by about 10 during the observed period for the 26°C standard (e.g. for particular types of buildings such as hospitals, children's nurseries etc.). The number of CDDs per year is projected to increase by about 20 by 2050.

Many of the new residential areas are built from scratch. In order to provide a climate change adaptation option that reduces GHG emissions, several technological requirements could be taken into consideration. Efficient adaptation requires a structural change in the provision of cooling devices and installations.

If all measures including energy efficiency, adaptation and R&D were stringently implemented up to 2050, the annual energy costs for air conditioning could be stabilised; however urbanisation, increased living standards and climate change will put additional stress on this sector.

1 Introduction

The Low Carbon Future Cities research project aims to develop a climate protection strategy for a German and a Chinese pilot region/city, integrating aspects of adaptation to climate change as well as tackling questions regarding the resource efficiency of technology-driven climate protection strategies. The Chinese pilot study focuses on the city of Wuxi, a city with between 4 and 6 million inhabitants located 120km north west of Shanghai.

Earlier scenarios and modelling produced by the research project dealt with the investigation of the status quo of GHG emissions and the resulting "business as usual" development up to 2050 (see report on WP2 "Integrated Status Quo and Trends Assessment in Wuxi"; http://www.lowcarbonfuture.net/de/dokumente/12/). This research demonstrated an obvious need for action and, therefore, it forms the basis for the modelling and scenario approach in WP3. The modelled scenario pathways within WP3 focus on illustrating possibilities, starting points and timeframes for more climate-friendly future development than that which is projected in the Current Policy Scenario (CPS).

Tackling the LCFC problem dimensions - mitigation of GHG emissions, adaptation to climate change as well as improvements in resource efficiency - requires the application of a suitable and advanced technology portfolio that is adjusted to the specific framework conditions in Wuxi. The aim of WP3 is to identify, specify and analyse these technologies and integrated options as a basis for modelling low carbon scenario pathways.

The starting point for this identification and assessment of suitable technologies is a comprehensive mitigation technology-matrix elaborated in former research projects by the Wuppertal Institute. In a first step, technologies relating to the problem dimension of GHG mitigation were selected and prioritised by experts and decision-makers in Wuxi. In a second step, the resource impact of the technologies for selected sectors was assessed in a resource check to reveal undesirable side-effects of the mitigation strategy. Thirdly, synergies with strategies for adaptation to climate change in the building sector were investigated.

To highlight the challenges of climate-friendly development in Wuxi, some of the key findings in WP2 are summarised here.

The starting point for the modelling of the status quo and the evaluation of a likely long-term trend scenario is a GHG inventory based on the Intergovernmental Panel on Climate Change (IPCC) sector classifications as well as Wuxi municipal city government's Low Carbon Plan, which targets a 50% reduction in CO_2 by 2020. The key findings of this trend analysis are:

- The policy measures in place will not lead to absolute emissions reductions, as economic growth will offset any GHG reductions related to the GDP.
- The trend over the last few years of declining per-capita emissions, resulting from improvements in energy intensity, is not expected to continue because the Low Carbon Plan's targets concerning CO_2 intensity are not sufficiently ambitious to maintain this development.
- Energy intensive industries do not face enough pressure to reduce their GHG emissions, due to overall structural changes in economy towards less energy and emission intensive fields of industry.
- The potential for energy efficiency and use of renewables will be only partly exploited by 2020. Beyond 2020, there are currently no powerful policy drivers in place to further exploit the potential.

Overall, the objectives of the Wuxi Low Carbon Plan should be seen as an important starting point that will put Wuxi on track for a more ambitious local climate policy agenda, which is needed to reduce the city's emissions to the required level to comply with the IPCC's 2 tonnes CO_2 per capita target.

2 Preparatory work and background information for the climate protection scenarios

The so-called “Technologiematrix Deutschland”(Technology Matrix for Germany) establishes the thematic basis for deriving climate protection scenarios. The Technology Matrix was developed by the Wuppertal Institute in previous research projects.

The database includes about 150 mitigation technologies, which have been evaluated according to a standardised assessment scheme, taking into account technology-specific parameters such as mitigation effects, economic aspects, availability of the technology etc. (see chapter 2.1 for detailed descriptions). Crucial information can be extracted from the database estimating how far (with regard to temporal availability and maturity) the different technologies can be taken into account within the modelling of the climate protection scenarios and the derivation of implementation strategies. Detailed information to assess the mitigation impact of different technologies can also be generated from the database, as well as comparisons to reference technologies (regarding economic aspects, required system changes etc.).

The Technology Matrix assesses the considered technologies from an industrial country’s point of view. Furthermore, the database focuses on technologies within the scope of a municipal decision-maker. It covers the following sectors:

- Electricity, heat and cooling;
- Buildings;
- Transport;
- Energy infrastructures.

The industry sector is not part of the existing database, as in European industrialised countries the implementation of specific technologies in branches of industry does not come under the auspices of municipal decision-makers and municipal climate protection strategies. It is apparent that some modifications to the original database structure are necessary to apply it to the development of scenarios focusing on Wuxi – a city in an emerging economy like China. The modifications required to establish a Wuxi-specific selection of mitigation technologies are described following a brief methodological introduction to the assessment scheme.

2.1 Assessment scheme for mitigation technologies

The focus of the assessment is on technologies that are relevant in urban areas. Technologies such as those that are related to the central electricity generation and distribution system were not taken into account here, as they are typically beyond the scope of urban infrastructures. Technologies are categorised according to the potential width and depth of their energy and GHG mitigation potential, their availability and costs etc.[1].

As a first step, the mitigation potential of each low carbon technology (LCT) is estimated in order to provide a scale of the potential relevance of all LCTs within a low carbon strategy. For the purpose of this estimate, the mitigation potential is defined as the product of the depth and width of an LCT. By *depth*, we characterise the relative order of magnitude of the energy or emission reduction that can be achieved in comparison to a standard or reference technology. In one particular case, energy savings of a passive house would be around 80% of the energy of a conventional new building. In order to provide an ordinal ranking of the technologies, we define four groups of technologies according to their relative mitigation potential (depths). The first group delivers net/zero savings vs standard technology. Such technologies are only considered for use when they are needed as enabling technologies for others with greater potential. The second group of technologies delivers moderate savings (up to 33% vs standard technology). The third group delivers 33 to 66% savings. The fourth group offers high savings of between 66 and 100% vs standard technology.

The second dimension of the potential is its *width*. This is the size of the potential of the LCT with regard to how widely it can be applied in the respective market or technology segment. We distinguish between niche and low-width technologies that cover less than 33% of the respective segment, medium-width technologies that can be applied to between 33 and 66% of the segment and high-width technologies that potentially cover more than 66% of the segment.

As it clearly influences the strategy for introducing a LCT to the market, we qualitatively describe in a separate category whether system changes need to be introduced in order to make use of an LCT and, if so, what these changes are.

In addition to rating their potential, we characterise the LCTs according to their life cycle costs. Such characterisation is, however, problematic for a time span as long as 40 to 50 years (and this is the timespan we are working to with a road map of 2050 in mind). Innovation will lead to significant changes in the cost of LCTs and the cost of fossil fuels and external

[1] The following description of the assessment scheme has been elaborated within the research project "Sustainable Urban Infrastructure: Munich Edition – paths toward a carbon-free future" (Lechtenböhmer et al. 2011)

energy system costs will also change greatly in the decades to come. Therefore, the economic aspects of the LCTs should be seen from a dynamic perspective. We mirror this with two estimates, one for the current situation and one for the future, when the respective LCT is expected to have reached a certain level of maturity. We also provide the estimated date when the technology will have reached this mature status.

Given the long time frame, exact costs cannot be estimated. Consequently, we do not provide hard quantitative estimates such as those given in the marginal abatement cost curves (MACs) that were developed by McKinsey (McKinsey 2009), E.ON (E.ON 2006) or others. Instead, we group technologies into three main categories with regard to their comparative life cycle costs vs standard technologies. Technologies in the first category lead to increased life cycle costs vs a standard technology. We regard this as significant if the estimated increase is equivalent to at least one third (and up to two thirds) of the standard technology's life cycle costs. The second category of technologies has, or promises, life cycle costs that are approximately (+/-33%) equivalent to standard technologies. Finally, the third category consists of technologies that provide life cycle costs that are significantly (more than a third) lower than those of standard technologies.

For the total life cycle costs, investment is typically a very important factor. However, as many technologies discussed here will require initial capital investment but result in a reduction in energy costs, the expected development of future energy prices is even more influential. With potentially high future fossil energy prices, the life cycle costs of the LCTs are often lower than those of standard technologies. For assessment, we assume an annual real increase in the price of electricity of 1% per year from a current level of 20 ct/kWh to 32 ct/kWh in 2050, and for fuels in the range of 1.5 to 2.5% (i.e. from 8 ct/kWh to a level of between 16 and 26 ct/kWh). We do not explicitly take external costs, or CO_2 prices, into account. However, it can be assumed that LCTs - by definition - have lower external costs, and particularly lower CO_2 mitigation costs.

2.2 Wuxi-specific technology selection

To make the existing technology database and the incorporated assessment scheme suitable for the LCFC project context, some adjustments were necessary.

The first step of the modification was to adopt the sectoral structure of the database to the sub-model structure of the Wuppertal Institute's energy model (see chapter Model Description in WP2 report). Therefore, the resulting structure of mitigation technologies within the research project is divided into the following areas:

- Mitigation technologies for power generation, heating and cooling;
- Mitigation technologies for new buildings and building stock;
- Mitigation technologies for the transport sector.

Further adjustment was necessary, as potential contributions by the industrial sector to climate protection had to be considered within the LCFC project context. Appropriate strategies need to be developed as the industry sector is a major emission source in Wuxi. However, as described above, only technologies that come under the auspices of local decision-makers are included in the original technology database. In industrialised European countries like Germany this excludes technologies in the industrial sector as technology implementation in this sector depends on entrepreneurial decision making. The situation is different in China with a centralised government where (in principle) political intervention is possible - including in industrial processes.

Therefore, for the identified key sectors in WP2, best available technologies, which have the potential to significantly reduce CO_2 emissions compared to the status quo within the particular industrial sector, have been investigated. In the LCFC project context, it was not possible to fully adapt the assessment scheme to Chinese conditions and evaluate the technologies accordingly. Instead, the best available technologies have been described based on their current status quo in Germany and the EU. This description takes into account both necessary support schemes and barriers to the implementation of the technologies. This information can be used as an important input for a low carbon roadmap. In addition, appropriate examples for technology implementation from the European context have been examined in order to illustrate the general fields of application.

Another key criterion in selecting appropriate technologies for mitigation strategies in Wuxi are the status quo conditions and local potential of renewable energies, climate conditions, efficiency improvements etc.

For example, it is important to understand features of Wuxi's building stock, with regard to air conditioning systems, average home size etc. to derive appropriate strategies and policy measures for the building sector. For the modelling of the future energy sector, however, it is essential to understand the local and regional potential for renewable energy sources. Detailed studies investigating this potential have not been carried out within the LCFC project. Instead, for the process of selecting appropriate mitigation technologies, local experts were consulted in order to adequately reflect the specific situation in Wuxi. This process typically encompassed three stages of coordination with local experts.

The first step in the technology selection was based on a review of published information and an analysis of relevant statistics. Experts from the Wuppertal Institute and Tshinghua University were involved in this process. The work of WP2 formed an important basis for that first step.

This pre-selection (including the existing assessment of the technologies from an industrialised country's perspective) was submitted to the partners of the Wuxi Low Carbon Development and Research Centre (WCC) for validation.

After re-examination by the expert team from the Wuppertal Institute, a further plausibility check was provided by WCC but this time with the involvement of local representatives from the relevant city government departments.

Based on this approach, it was possible to derive a consolidated technology list for climate protection pathways for the city of Wuxi. However, it must be emphasised that more in-depth studies are needed to gain a deeper understanding of the potential of key technologies and the local conditions in Wuxi in order to achieve more solid scenario outcomes.

2.3 Consolidated list of mitigation technologies and appropriate policy instruments

The process described above led to the establishment of a consolidated list of key technologies (see table 1), which should generally be taken into consideration when developing low carbon scenarios for the city of Wuxi. To what extent the different technologies have been integrated into the modelling is described in chapter 3.2. A detailed review and mitigation assessment of all 'Wuxi-suitable' technologies, following the described method (see chapter 2.1), is shown in Appendix 1.

The overall target of the research project is to develop a highly integrative approach and derive comprehensive strategies that can be offered to the decision-makers at municipal government level. Even if the scenario analyses are strongly driven by the availability of individual mitigation technologies, the added value of the research project is the derivation of a suitable road map that shows which policy instruments could be used in order to successfully implement the technologies.

Based on this overall objective, policy frameworks were formulated (for the selected technologies that are available and suitable for deployment in Wuxi) that successfully promoted GHG mitigation in the relevant sectors in other countries or cities, particularly the EU. An overview of these policy instruments can be found in Appendix 2.

Table 1: Consolidated list of mitigation technologies for the Wuxi low carbon scenarios

Selected Mitigation Technologies for Power Generation, Heating and Cooling
Combined Heat and Power
Micro CHP
Industrial CHP
Innovative Cooling Supply
Passive cooling (ventilation by night, soil etc.)
Combined power heat cooling by utilisation of industrial waste heat (absorption-type cooling systems)
Photovoltaic and Solar Heat
Roof construction
Facade integrated
Free space construction
Solar collectors
Biomass
Solid biomass - co-combustion in coal-fired power plants
Solid biomass - utilisation in CHP plants (ORC, Steam turbine, Stirling engine, wood gasification)
Liquid biomass - utilisation in CHP plants
Biogas / biomethane - utilisation in CHP plants
Heat Pumps
Electrical
Gas
Selected Mitigation Technologies for New Buildings and Building Stock
Passive House and Plus Energy House Design
Residential & commercial, new buildings
Individual Technologies for Innovative Building
Utilisation of daylight
Lighting (LED, daylight sensors etc.)
Ventilation system with heat recovery and innovative air conditioning
Selected Mitigation Technologies for the Transport Sector
Vehicle Technologies
Electric vehicles with accumulators
Natural gas optimised engines
Infrastructures
Supply infrastructure for electro vehicles / plug-in hybrids
Supply infrastructure for gas vehicles
Light signals with LED technology
Optimisation of public transport flow
Technology Strategies for Selected Industry Sectors
Cross-Cutting Technologies
Efficient motors and burning systems
Waste heat recovery (from flue gas)
Increase use of biomass and waste

CCS for industrial applications
Industrial CHP
Iron and Steel
Coke dry quenching
Increase use of scrap steel (recycled)
Cement
Increase use of clinker substitutes
Shift to NSP technology (new suspension preheater), rotary kiln with pre-heater and pre-calciner
Low carbon cements
Chemistry
Bio-based chemicals (feedstock change)
Energy saving production (e.g. ammonia, urea)
Fine chemicals and new (enzyme) catalysts

3 Modelling low carbon scenarios

Scenario analysis enables policy makers to identify strategic areas for action and provides a basis for decision-making. In contrast to the modelling in the Current Policy Scenario (CPS) (see WP2) the modelling in WP3 has a more normative character. It aims to reveal the need for action to achieve certain ambitious targets and to identify windows of opportunity. For this reason, the LCFC team modelled two low carbon scenarios, which differ in their ambition level. These two scenarios depict the different development pathways for different sectors, leading to a more variable range of options for deriving a sophisticated roadmap and strategic recommendations for policy makers.

Both scenario pathways create an image of Wuxi in 2050 that is more climate-friendly than the development projected in the CPS. The key assumptions and framework conditions of the scenarios are described in the following chapters.

3.1 Amendments to the city energy system model

The city energy system model developed by the Wuppertal Institute in WP2 was amended in some respects. WP3 accounts for specific low carbon technologies, which could not be taken into account explicitly in an econometric industry model such as the one used in WP2. The modelling in the LCTS and ELCS is much more differentiated in terms of energy-intensive industrial processes. This process-sharp modelling approach allows for the evaluation of individual technologies, which is highly relevant for deriving strategic approaches in the roadmap. The effective production capacity and the age of the manufacturing plants in Wuxi were evaluated in more detail, with local statistics forming the basis for this. As a result, specifications for the industry sector are possible.

The building model used in WP2 and in the LCTS is inadequate for analysing specific building types such as Ultra Low Energy buildings. A weakness of the modelled trends of the building sector in the LCTS was that they were based on the extrapolation of data (for energy demand in buildings per square metre) from local buildings statistics. This results in inaccuracies, because it does not reflect the successive improvements in building standards. The LCTS was used as a driver for change at the 2012 Stakeholder Forum with the municipal government in Wuxi. As a result of discussions with government experts and the LCFC project team during the forum, the project team decided to refine the analysis of this sector. Accordingly, a stock flow model for per capita floor space of residential buildings was developed, which allows for the analysis of demolition, refurbishment and construction of new buildings and for the energy demand of different building types. The extended modelling approach enabled the

LCFC team to make assumptions about the distribution of market share for specific building types and to model the stock change of the building sector.

3.2 Basic assumptions – Low Carbon Technology Scenario (LCTS)

Basic assumptions strongly determine the pathways in the scenarios and, as a result, their projected outcomes. It is necessary to distinguish between assumptions that are valid for the complete scenario set and assumptions that are specific to single scenario pathways. In this section, assumptions that apply to the LCTS are presented. Differences and similarities to the CPS as outlined in WP2 are explicitly highlighted.

The political framework as laid out in the Wuxi Low Carbon City Development Plan and its inherent measures for the key sectors considered in the LCFC project determine the development until 2020. Furthermore, the basic assumptions of the CPS are also valid for the LCTS. Basically, these are: continued growth of the urban population and of Wuxi's economy, together with a structural change towards the tertiary sector, while maintaining the industrial base (see table below – from a WP2 report - for further details).

Table 2: Basic socio-economic data for all scenario paths

	Unit	2009	2020	2030	2040	2050	2009-2050 % growth p.a.
Permanent Population	1,000	6,245	6,731	6,598	6,325	5,826	-0.2%
GDP	Mill. RMB_{2005}	452,175	1,138,622	2,300,540	3,758,442	5,360,192	6.2%
Of which: Primary Sector	Mill. RMB_{2005}	8,481	14,217	17,970	21,186	23,775	2.5%
Of which: Secondary Sector	Mill. RMB_{2005}	256,933	615,347	1,143,216	1,659,976	2,116,632	5.3%
Of which: Tertiary Sector	Mill. RMB_{2005}	186,761	509,057	1,139,355	2,077,280	3,219,784	7.2%

Source: Calculation of population by CER/WI according to the development in Jiangsu Province in: Wu (2008)

The derived vision of Wuxi in 2050 within the LCTS consists of the following elements:

- In 2050 Wuxi will still be a prosperous city. The economy will have been confronted with demographic problems but the productivity will have improved.
- As it is today, Wuxi will still be an important industrial centre for the Chinese economy.
- However, the economy will have been shifted structurally towards the tertiary sector and less energy-intensive industry.

The existing energy-intensive industry will face challenges as it will be required to renew the production capacity almost completely from 2030 to 2040. In the LCTS, the industry decides to remain in Wuxi, although no additional potential for renewable electricity and hydrogen production exist. The assumed quantity of industrial production corresponds to the CPS pathway. This stresses Wuxi's importance as an industrial centre for energy-intensive products. Physical production of energy-intensive products such as steel, cement and fertilizers, as well as paper and caustic soda (or chlorine), remains stable. As it is assumed that China's levels of steel, cement and fertilizer production will be lower in 2050 than today, Wuxi's share will increase. Production of paper and caustic soda, however, will grow in China, resulting in a lower share for Wuxi. Between 2030 and 2050, the energy-intensive industrial plants in Wuxi will be completely equipped with (today's) best available technologies. Energy and feedstock will be partly changed from coal to natural gas.

The development in construction activity (in quantitative and qualitative respects) is the same in the LCTS and the CPS. Therefore, the development of floor space and improvements in building envelopes are the same in both scenarios. The development of energy demand for household appliances is triggered by (1) the establishment of an equipment standard, corresponding to an overall Asian standard as assumed in the CPS, and (2) the energy efficiency of household appliances. In the LCTS the efficiency of appliances will be improved significantly after 2020 by using best available technologies (BAT).

The service sector was modelled very roughly due to a lack of data. As a result, the development of the overall efficiency level was derived from the development in the household sector.

When modelling the transport sector in the LCTS (and ELCS), the CPS assumptions about traffic growth, modal split and car availability were adopted as they already point towards quite ambitious targets. It is assumed that by 2025 the share of households with cars will have reached the assumed saturation rate of 30% (30 cars per 100 inhabitants) compared to a saturation rate of about 50% in Germany. The development of person and tonne kilometres (persons x kilometres and goods x kilometres) is also the same as that in the CPS.

The assumptions on vehicle technology, however, differ from the CPS. It is assumed that (1) electric mobility will be systematically promoted by the city government and (2) that energy-efficient vehicles will be widely used.

In the LCTS Wuxi's power plant stock will be modernised with new power plants within the city's territory to meet the city's electricity demand. Imported electricity is avoided due to a significant increase in local production. From 2020 onwards, local potential for electricity production from renewable sources will be developed. The modelled installation of new plants is driven by the expectations of future local demand for electricity. Combined heat and power (CHP) plants are driven by the needs of the industrial sector (average power and heat ratio of 0.43 CHP coefficient for all plants approved).

3.3 Key technologies – Low Carbon Technology Scenario (LCTS)

Table 3 lists key technologies for CO_2 mitigation for each key sector in Wuxi, chosen for the LCTS from the consolidated technology list (see table 1). Furthermore, it indicates at which stage of the scenario timeframe the technologies come into play and how they are envisaged to develop in the scenario period. The contribution that each technology can make in terms of compliance with the aspired long-term CO_2 mitigation target is assessed as low, medium or high.

Table 3: Key technologies in the Low Carbon Technology Scenario (LCTS)

Sector	Technology	Year	Development in Modelled Period of Time	Relevance of Technology in the Specific Sector	Key Technology?
Households	Efficient air conditioning systems	Effective immediately	Refurbishment of stock, new acquisition only at highest efficiency standards	Medium	
	Highly efficient household appliances	From 2020	Consequent new acquisition of best available technologies	High	Yes
Tertiary Industry	Efficient air conditioning systems	Effective immediately	Refurbishment of stock, acquisition of new facilities only at highest efficiency standards	Medium	

Transport	Electric vehicles	From 2020	From 2030 PHEV and BEV, 60% market share in 2050; 30% of stock	High	Yes
Industry	BAT for new or replacements of manufacturing plants	From 2020		High	Yes
	Increased use of scrap steel (recycling) in electric arc furnaces	From 2020	Increase of share to 65% in 2050	High	Yes
	Direct iron reduction for steel production based on natural gas	Capacities available	Stabilising share (today about 50%)	High	Yes
	Usage of granulated cinder ("Hüttensand") as a substitute for Portland cement	Effective immediately	Existing potential is exploited; potential declining due to decreasing oxygen steel production	High	Yes
	Retro-fitting of membrane processes at existing production plants; at a later stage, replacement of old production units with new plants operating with oxygen consumption cathode technology	Effective immediately and from 2030	Conversion immediately, new construction from 2030	High	Yes
	Heat-recovery	Effective immediately	Conversion of existing manufacturing plants if economically efficient, technology is considered at new plants	High	Yes
	Efficient pumps	Effective immediately		High	Yes
Generation	Photovoltaic	Effective immediately	350 MW, 1,500 MW until 2030, 1,800 MW until 2040	Medium	Yes

	Wind power (6MW)	From 2020	Until 2035 installed capacities increase up to 330 MW in agricultural areas	Low	
	Biomass-gasification of waste	From 2020	Until 2030 installation of infrastructure	Low	
	Industry CHCP	Effective immediately	Until 2050 installed capacities increase (8 times) up to 7.7 GW	Medium	Yes
	Micro CHCP in tertiary industry	Effective immediately		Low	
	Natural gas plants	Effective immediately	Installation of additional capacities and gradual substitution of coal plants (17 GW in 2050)	High	Yes

3.4 Key results – Low Carbon Technology Scenario (LCTS)

With regard to CO_2 emissions, the applied sectoral assumptions lead to a rapid decrease in CO_2 intensity (CO_2 emissions per unit GDP). However, absolute CO_2 emissions increased significantly at the beginning of the 21st century, will remain more or less stable from 2020 to 2030 and will then decline again from 2030 onwards.

Figure 1: Development of carbon intensity in Wuxi, 2005-2050

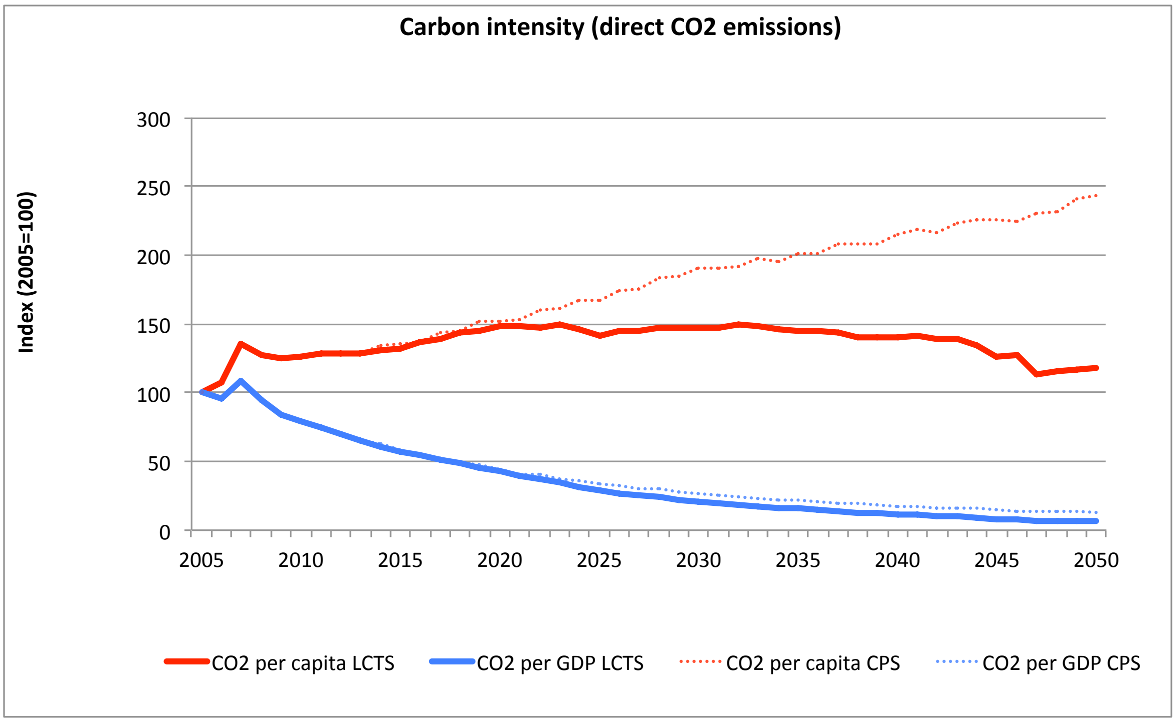


Figure 1 illustrates the development of Wuxi's carbon intensity. While the CO_2 emissions per GDP decrease in both scenario pathways, due to structural changes in Wuxi's local economy the carbon intensity per capita stagnates at a high level during the whole period. This is an improvement compared to the development in the CPS but still demonstrates the need for intervention. The initial level of per capita emissions in 2010 (12.3 tonnes per capita) is already very high in relation to other Chinese regions and to the IPCC's recommendation of 2 tonnes per capita in 2050 as a global average.

Figure 2: Direct CO_2 emissions of sectors, 2005-2050

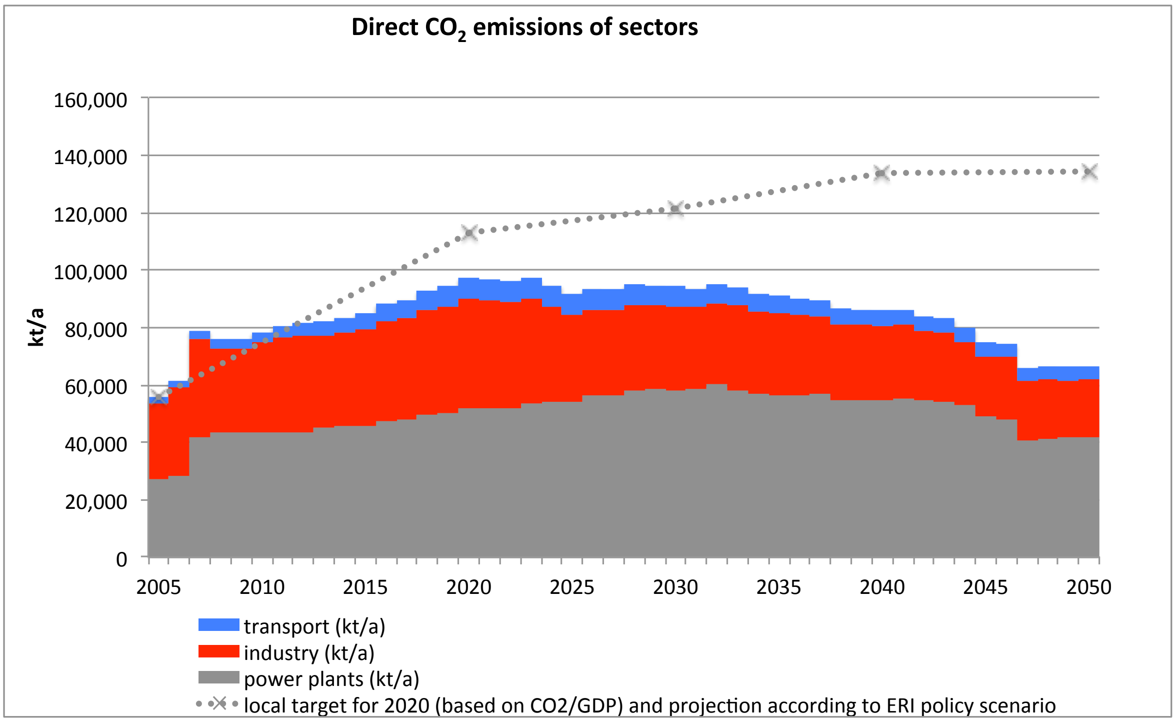
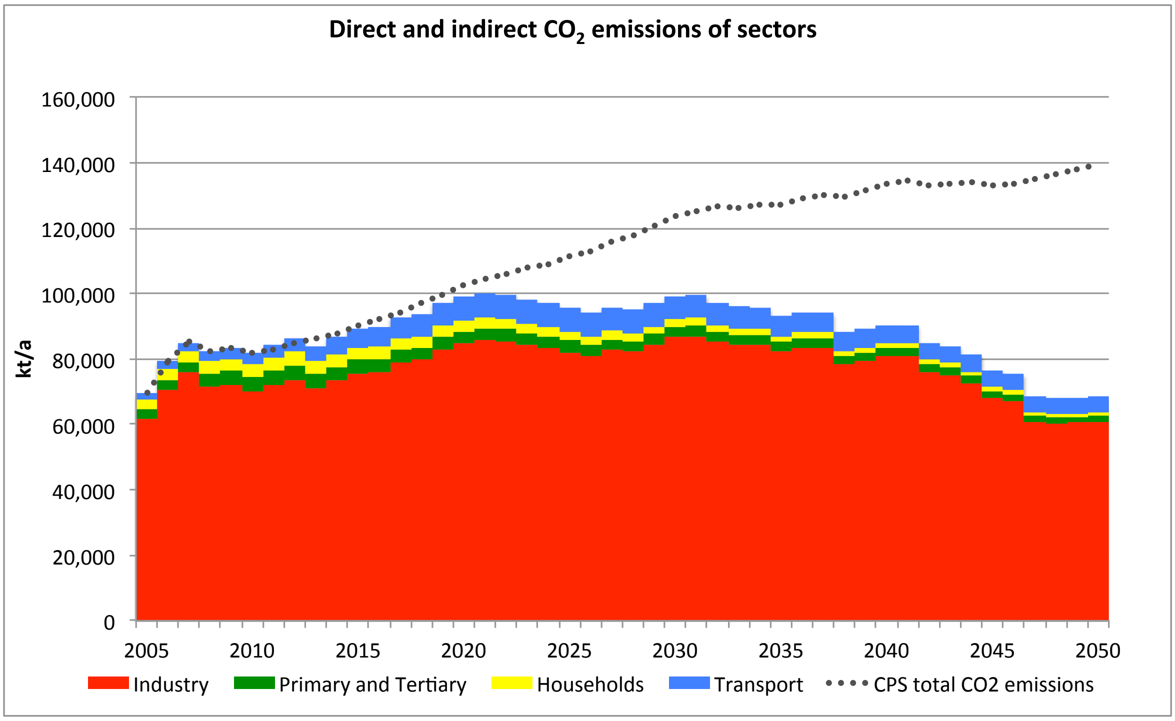


Figure 3: Direct and indirect CO_2 emissions of sectors, 2005-2050



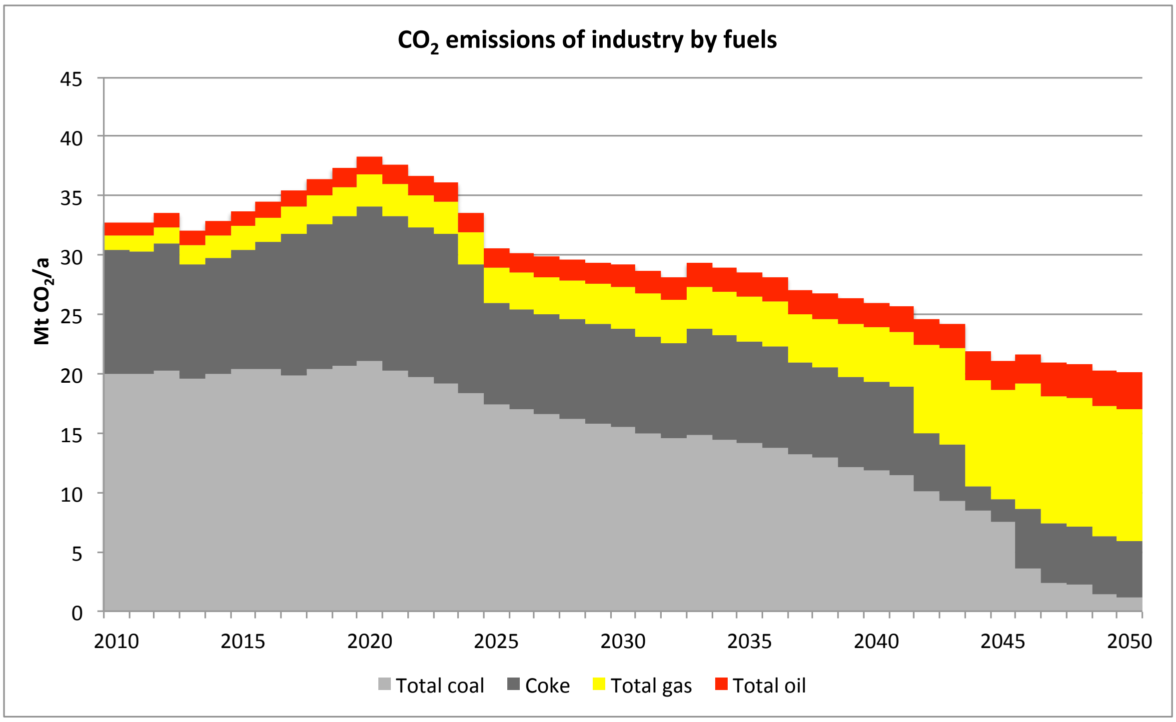
As described above, it is assumed that Wuxi's economy will experience a fundamental structural change over the next decade towards less energy-intensive industry. But, as Figure 3: shows, industry in general remains the main driver of CO_2 emissions in Wuxi. It is still indispensable to develop strategies to switch the energy use in industry to CO_2 neutral sources in the long-term, as will be outlined in the ELCS (see below).

Energy savings in all sectors and electricity generation from local renewable sources are key elements of the LCTS and contribute to the described development. It must be stressed, however, that local potential for technical measures is not sufficient to establish CO_2 neutral development. Therefore, CO_2 intensive industries and electricity production, as well as the high electricity demand of local industries, are responsible for persistent high absolute emission levels in 2050. This is illustrated below in further detail.

3.4.1 Industry

Figure 4 shows that absolute direct CO_2 emissions from fuel use in the industry sector begin to decline from 2020 onwards. The CO_2 reduction can be explained by energy efficiency, i.e. a lower specific demand for energy carriers, as well by the shift from coal to natural gas.

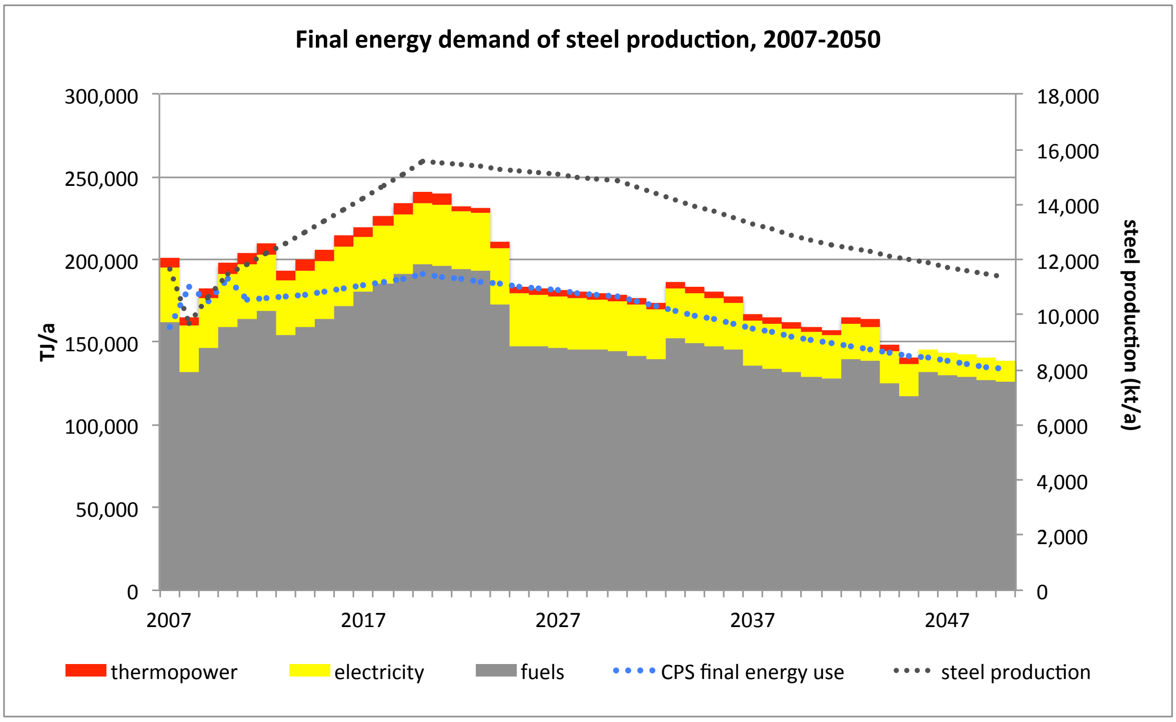
Figure 4: CO_2 emissions of industry by fuels, 2010-2050



The steel industry is the greatest industrial consumer of coal and coke. Figure 5: shows that the strategies outlined in table 3**Fehler! Verweisquelle konnte nicht gefunden werden.** lead to a development in fuel use which is quite similar to the long-term econometric modelling in the CPS. However, in the short and mid-term, substantial energy efficiency improvements will be quite difficult to achieve, as the production capacity of Wuxi's industrial plants will gradually reduce after 2020 and the replacement of old facilities is projected to take time as the existing industry plants are still relatively new.

The investment cycle for several steel production processes as assumed in the LCTS is shown in annex 3 (separate document).

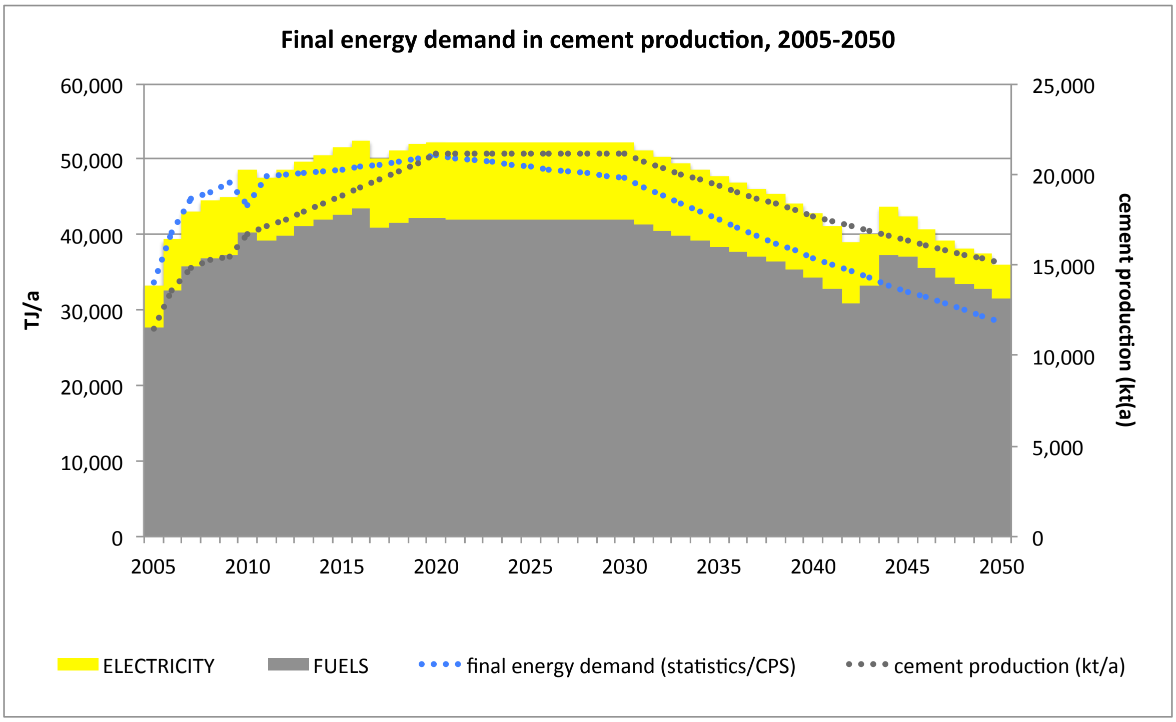
Figure 5: Final energy demand of steel production, 2007-2050



The modelling of the investment cycle of Wuxi's cement industry (see annex 3) delivers similar results to the steel industry. As the plant stock is still relatively young, it will only be upgraded from 2030 onwards. In the mid-term, blast furnace slag use increases to some degree but the feedstock slag will diminish due to structural changes in the steel industry. As the specific energy demand for producing cement out of limestone in a kiln (Portland cement) is much higher than using slag (which is not baked but only ground - unlike cement clinker) specific energy use (relating to overall cement production) may even rise again in the long-term[2].

[2] In the CPS the relationship between steel and cement production could not be analysed, with the result that the energy demand for cement production in the LCTS is higher than stated in the CPS.

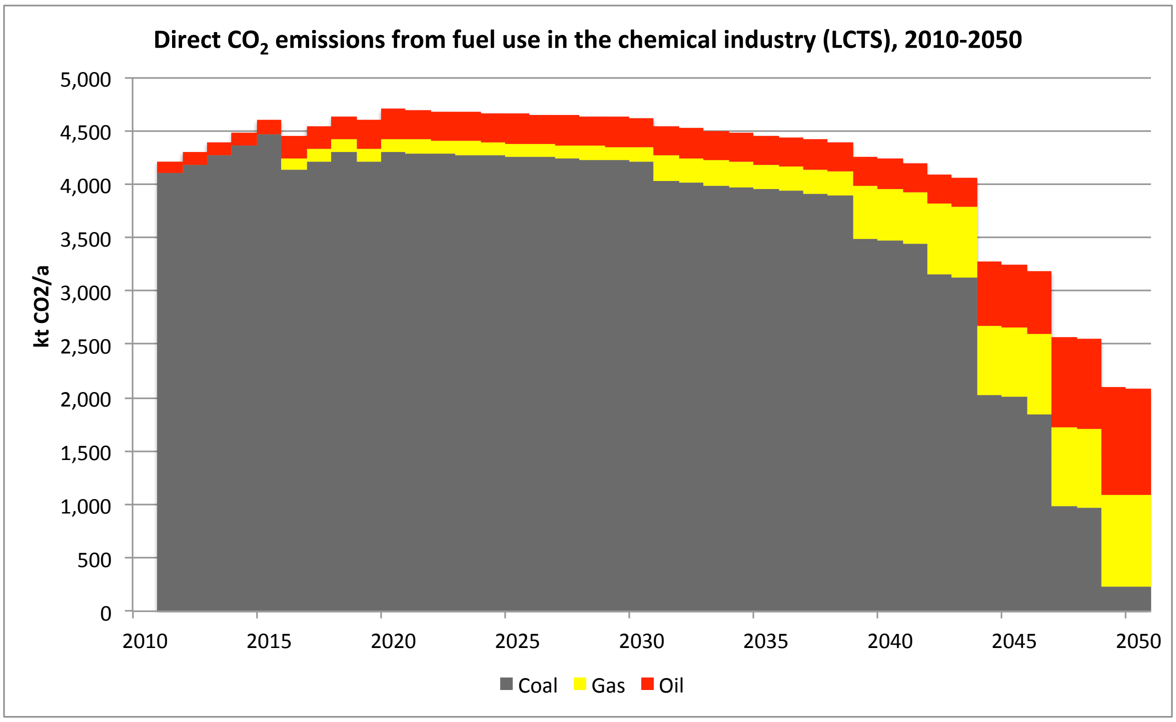
Figure 6: Final energy demand in cement production, 2005-2050



Wuxi's chemical industry produces a broad range of chemicals comprising organic and inorganic chemical products as well as high-value chemicals (see WP2 report).

The feedstocks are oil and coal as well as natural gas (to a lesser degree). All organic chemicals may be produced from coal, oil or natural gas, but the feedstock requirements of specific processes differ. However, using coal as a feedstock for producing organic chemicals is more CO_2 intensive than using oil or gas. In the LCTS the feedstock base shifts to natural gas (see annex 3 for further details) resulting in lower emission levels. In the production of inorganic chemicals, energy demand and electricity demand in particular are reduced by using BAT (especially in chlorine production).

Figure 7: Direct CO_2 emissions from fuel use in the chemical industry (LCTS), 2010-2050



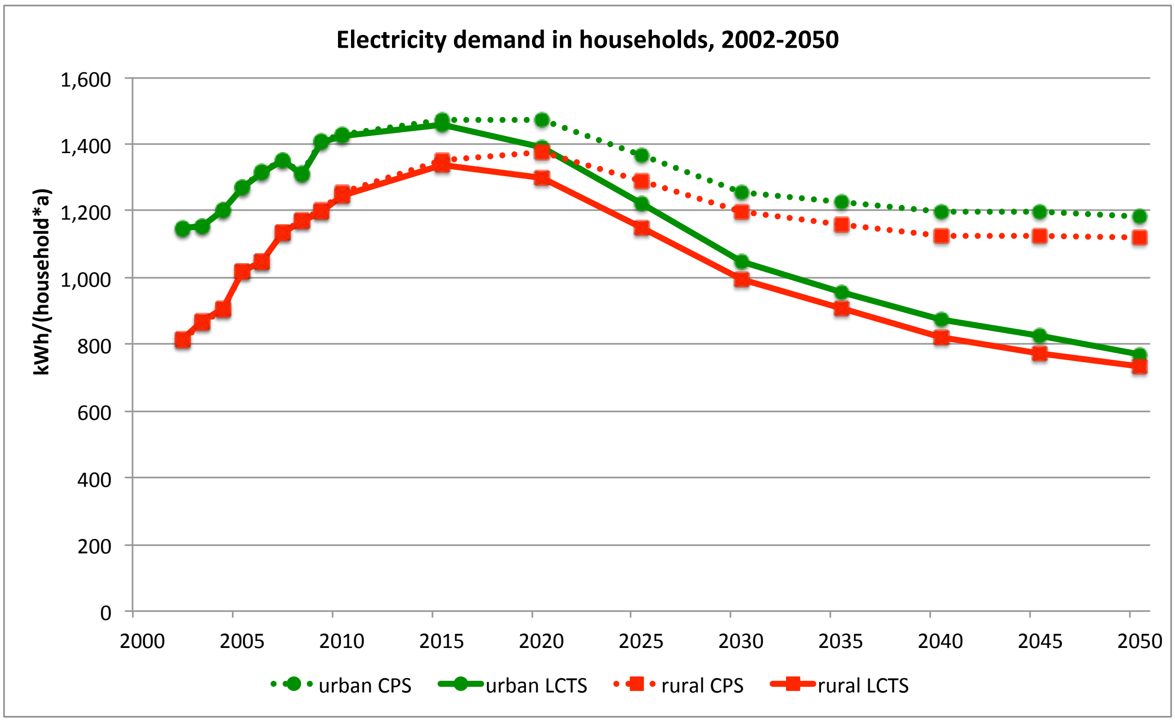
3.4.2 Buildings

The building stock in the LCTS is the same as in the CPS; reduction in electricity demand is achieved by replacing the air conditioning.

3.4.3 Household appliances

After 2020 the purchase of BAT household appliances, especially lighting, fridges, washing machines, etc., leads to a relatively sharp decline in household electricity demand. It is assumed here that the reduction in energy demand achieved through efficiency gains is not offset by the use of new appliances and/or by the more extensive use of appliances. The different types of household appliances currently used in rural and urban areas will become more similar in the future. The types of appliances are discussed in further detail in the WP2 report.

Figure 8: Electricity demand in households, 2002-2050



3.4.4 Transport

As described above, some technological changes are assumed when modelling the future development of Wuxi's transport sector, resulting in changes of CO_2 emissions by fuel as illustrated in Figure 9. The total emission level is below the level in the CPS. Within the projected pathways the importance of diesel rises as freight transport continues to grow.

Figure 9: CO_2 emissions, transport sector by fuel, 2005-2050

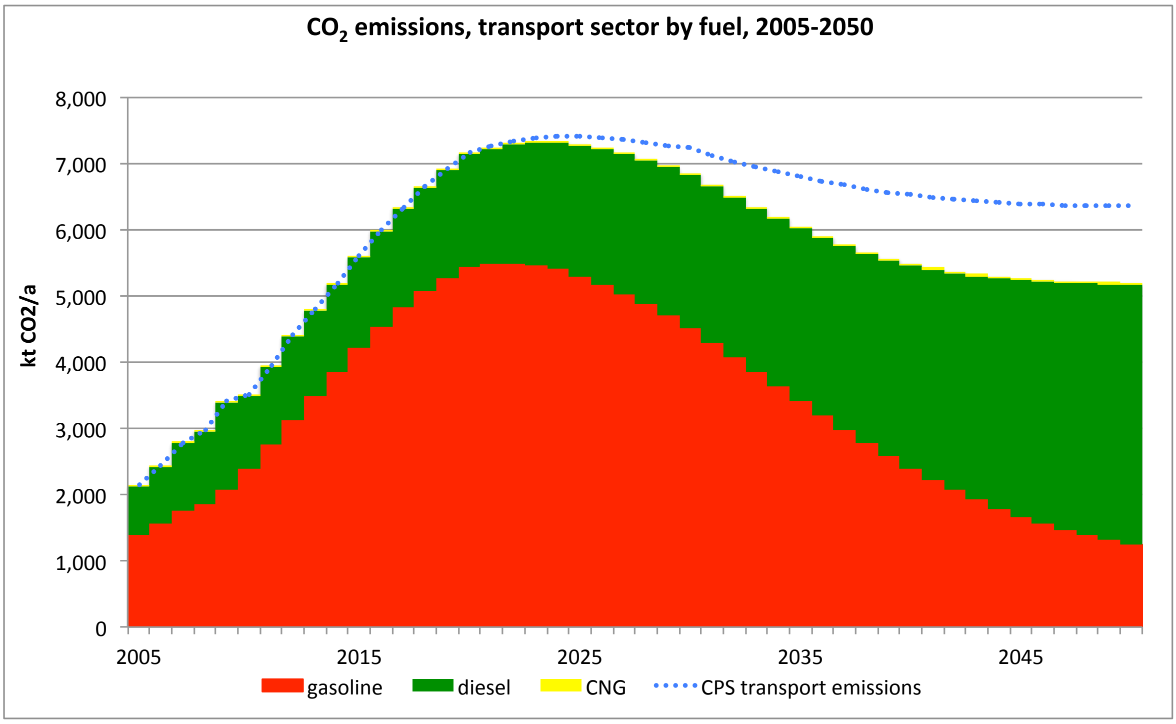


Figure 10: CO_2 emissions, transport sector by scenario, 2005-2050

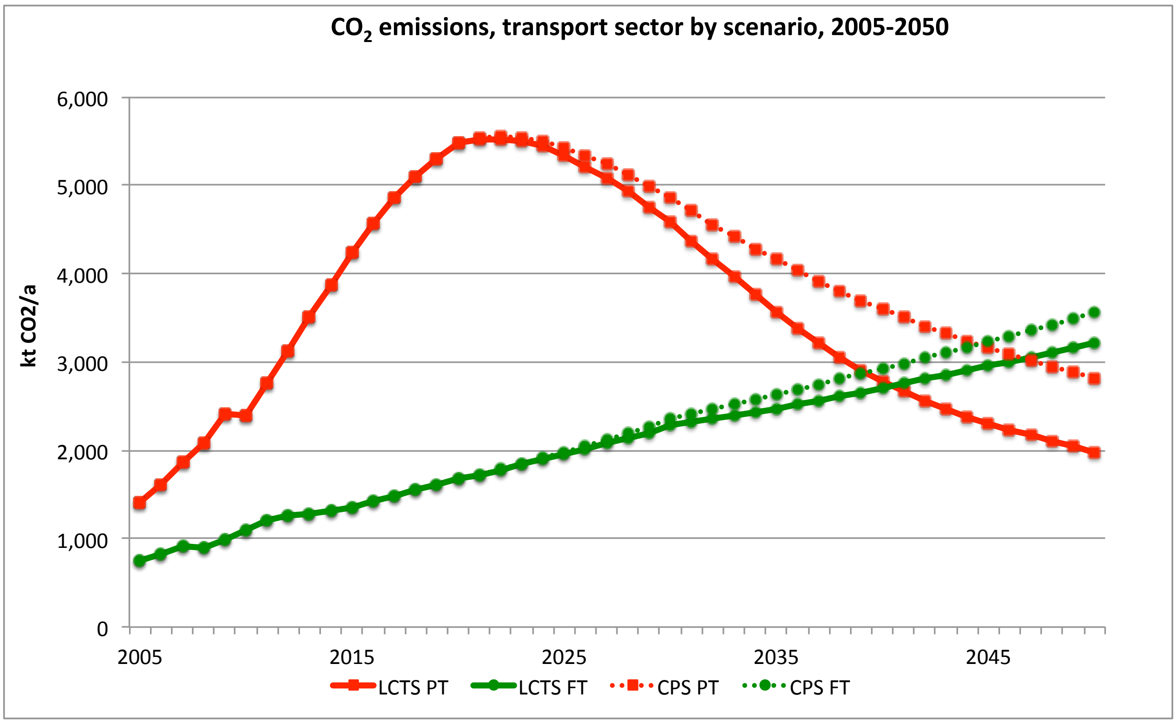


Figure 10: illustrates that both scenarios predict an increase in CO_2 emissions from freight transport. The increase in the LCTS is almost as great as in the CPS as electric mobility is

taken into account as a key strategy here. The difference between the two pathways is more evident, because the LCTS assumes a higher share of electric mobility in passenger transport. It must be stressed, however, that the local electricity mix, still with its high shares of fossil-based power production, reduces the potential for electric mobility to reduce CO_2 emissions. Both scenarios indicate a decrease in direct CO_2 emissions from 2020. In the transport sector, other non-technical measures – especially for freight transport – are necessary. These are measures which need to be addressed at national level but call for support at local level. With the transport sector's emission level reaching ca. 1 tonne CO_2 per capita by 2050, this would 'use up' 50% of the IPCC's target of 2 tonnes CO_2 per capita for transport alone.

3.4.5 Power/heat

The modelling results of the LCTS illustrate that demand for electricity in 2050 will be 22% below the level of the CPS. In Figure 11: the development of installed capacities for power generation is outlined: conventional coal power generation is projected to fade out and eventually cease by 2047 (supercritical coal power plants were installed in 2007 and are supposed to have a 40 year lifespan). The overall efficiency of Wuxi's power plants is projected to increase in the coming decades, as it is assumed that from 2012 only CHP plants and combined cycle natural gas turbine power plants (CCGT) will be installed. Local potential for renewable electricity production is limited; however, biogas can be produced from municipal waste and from agricultural residues like wheat and rice straw and can be fed into the gas grid.

The area for wind power plants is assumed to be 2,800 ha (2% of Wuxi's arable land). With the (optimistic) assumption of installing 6MW plants and achieving 2,000 full load hours per annum, 330MW of wind power could be achieved by 2035. In the LCTS, 5,000,000m^2 of photovoltaic modules are installed by 2035 on residential buildings – with 1,000,000m^2 also installed on public buildings by 2020 (already taken into account in the CPS). The share of renewable energies in the total power generating capacities (MW) is 8% whereas the overall share of renewables in electricity generation is projected to be 3% in 2050. Due to the high industrial electricity demand in Wuxi local potentials for renewable electricity generation are insufficient to meet demand.

Figure 11: Capacities in local electricity generation, 2010-2050

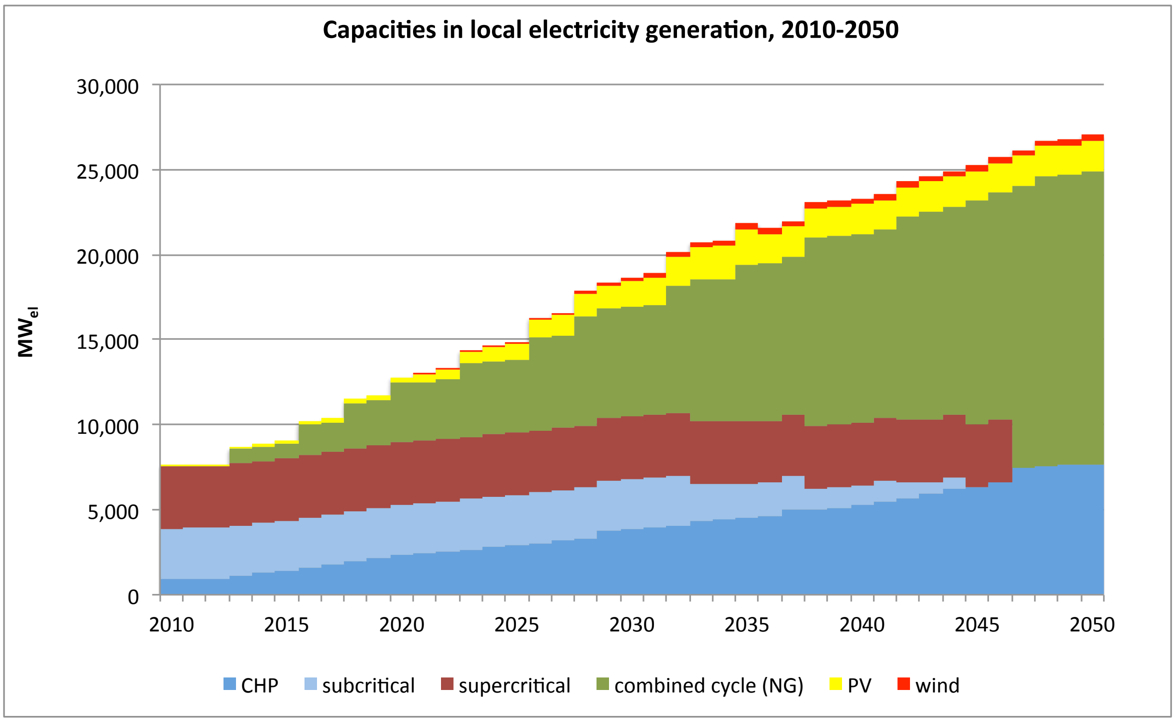
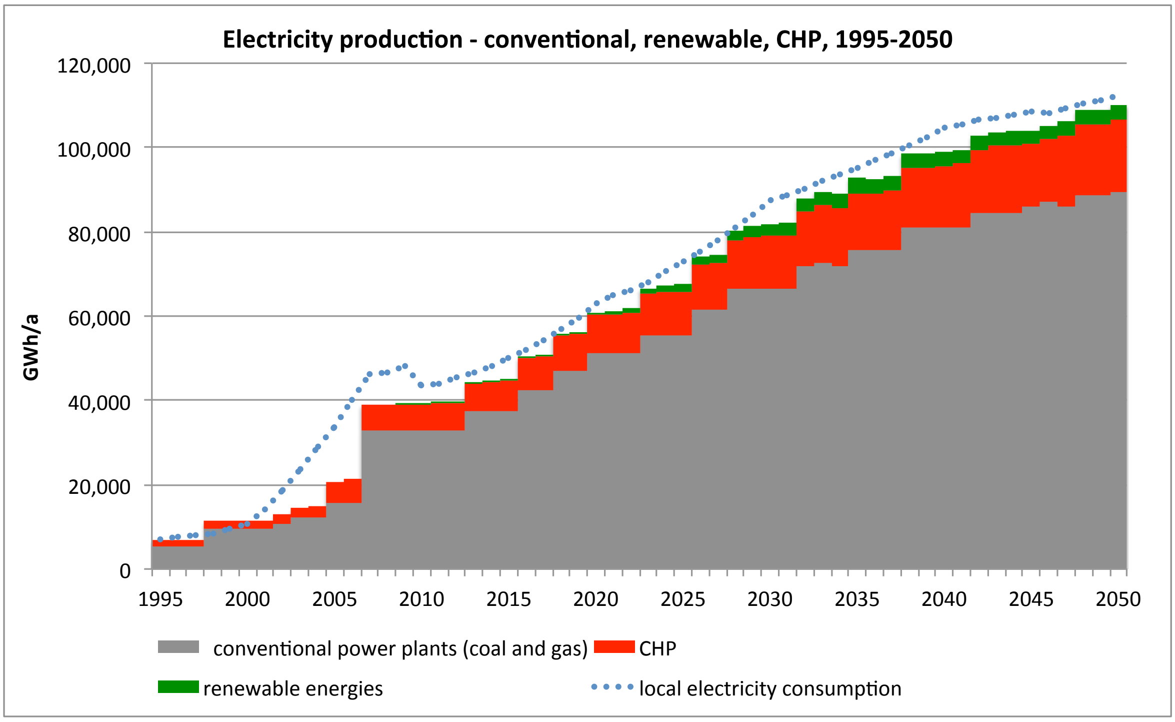


Figure 12: Electricity production - conventional, renewable, CHP, 1995-2050

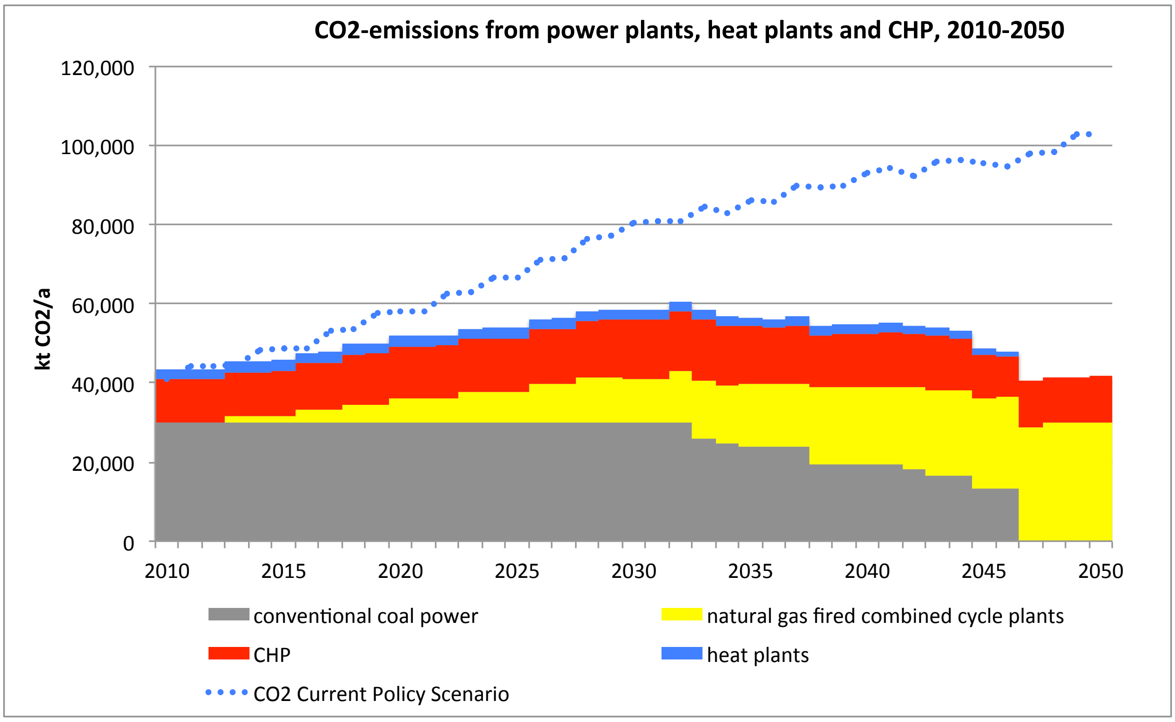


As a consequence of the modernisation of Wuxi's power plants, the emissions from electricity generation and CHP plants will be 60% below the level of the CPS by 2050. The emission factor is significantly lower than it is today. The gas power plants provide the electricity to cover base load demand in this scenario. The economic viability of this assumption is, however, yet to be evaluated.

Furthermore, it must also be emphasised that the proportion of renewable energy in electricity generation is still far too low (see Figure 12:). The shift to gas is only one of many steps towards a low carbon economy.

The accelerating decline in emissions from coal power around the year 2035 can be explained by the huge capacities installed between 2000 and 2007, which will be withdrawn from the grid by 2047.

Figure 13: CO_2 emissions from power plants, heat plants and CHP, 2010-2050



3.5 Basic assumptions – Extra Low Carbon Scenario (ELCS)

Although the development as it was modelled in the LCTS clearly differs from the CPS in some sectors, the reduction in CO_2 emissions still remains insufficient for facilitating low carbon development, calling for further measures.

Therefore, a more ambitious scenario pathway was modelled for selected sectors.

In the Extra Low Carbon Scenario (ELCS), carbon capture and storage (CCS) was introduced as an important additional technological solution for the industrial sector. Another important difference in the modelling of the industrial sector was the assumption of a much higher share of electricity generated by renewable sources. Importing this energy (electricity and hydrogen) is the only option for meeting industrial base load energy demand. An alternative would be to relocate the industries elsewhere in China, where more renewable electricity and/or hydrogen are available, which would lower the infrastructure costs. However, as it is important to protect Wuxi's industrial sites, this alternative is not currently an option. To account for emission levels fairly, the respective emissions would still have to be allocated to the city of Wuxi. Whichever option is pursued, the overall emission reduction effects are the same.

As outlined in section 3.1 an additional modification to the previous modelling was carried out for the analysis of the building sector. This significantly improves the results for the building sector but also means that it is not valid to compare the results for this segment with the other two scenarios. In relation to the projected total emissions, the modelling results are not affected significantly as the city's emissions are still dominated by industry.

One further assumption is related to the per capita floor space demand. In the ELCS it was assumed that per capita floor space growth after 2030 would be lower than in the CPS and LCTS. This assumption affects not only residential energy demand but also the energy demand for cement production and the resource flows outlined in Chapter 4.

One could imagine needing to alter assumptions on transport, too. However, the assumptions made in the CPS on car stock and modal split are already ambitious.

3.6 Key technologies – Extra Low Carbon Scenario (ELCS)

The key technologies of the ELCS are basically the same as in the LCTS (see table 3). Of course, the aforementioned new assumptions for industry and building must be reflected in the implementation of specific technologies. The following table provides an overview of those technologies used in addition to the LCTS.

Table 4: Key technologies in the Extra Low Carbon Scenario (ELCS)

Sector	Technology	Year	Development in Modelled Period of Time	Relevance of Technology in the Specific Sector	Key Technology?
Households	Ultra-low and plus energy buildings	From 2020	Increasing market shares (new buildings only): 44% in 2030; 100% in 2050 Specific energy consumption of ultra-low energy buildings is 74% to 90% lower compared to a reference building	High	Yes
Industry	Iron ore production via smelt reduction and CCS	2047	Share of 17% in steel production	High	Yes
	Designing new blast furnaces as "CCS ready"; later: retrofit of blast furnace with top gas recycling/CCS	2017/ 2037	2000 kt production capacity	High	Yes
	Direct reduction of sponge iron with hydrogen as reductive	2042	4000 kt production capacity	High	Yes
	Lower cement production in Wuxi compared to CPS and LCTS (lower local demand and lower exports)	2021	2043: -45%; 2050: -80% compared to CPS and LCTS	High	
	Gradual phasing out of ammonia production in Wuxi (moving to areas with "cheap" renewable H2)	2039	2048: production capacity 0 kt compared to 520 kt in the same year in the LCTS	Medium	
Generation	Combined cycle power plants (natural gas)	Effective Immediately	Installation of high additional capacities and replacement of coal-fired units (peak: 9 GW 2034-2041; 2050: 5 GW)	High	Yes
	Import of renewable electricity	2033	Increase to 73 TWh in 2050, share of 60% in electricity supply	Very high	Yes

3.7 Key results – Extra Low Carbon Scenario (ELCS)

The results of the calculations for the ELCS show that it is possible to reduce Wuxi's CO_2 emissions to below the LCTS level if it is assumed that new mitigation technologies, which are not in use today, are enforced and that the amount of imported renewable electricity increases significantly. As the city of Wuxi is one of China's industrial heartlands, it seems justifiable and necessary that in the long-term Wuxi will require a high share of imported electricity and, correspondingly, consume a high share of national resources.

However, further in-depths studies are required to assess and map potentials of different renewable energy sources in the adjacent municipalities and regions in order to specify sources of potential electricity imports to Wuxi.

Figure 14: Direct CO_2 emissions by sector, 2005-2050

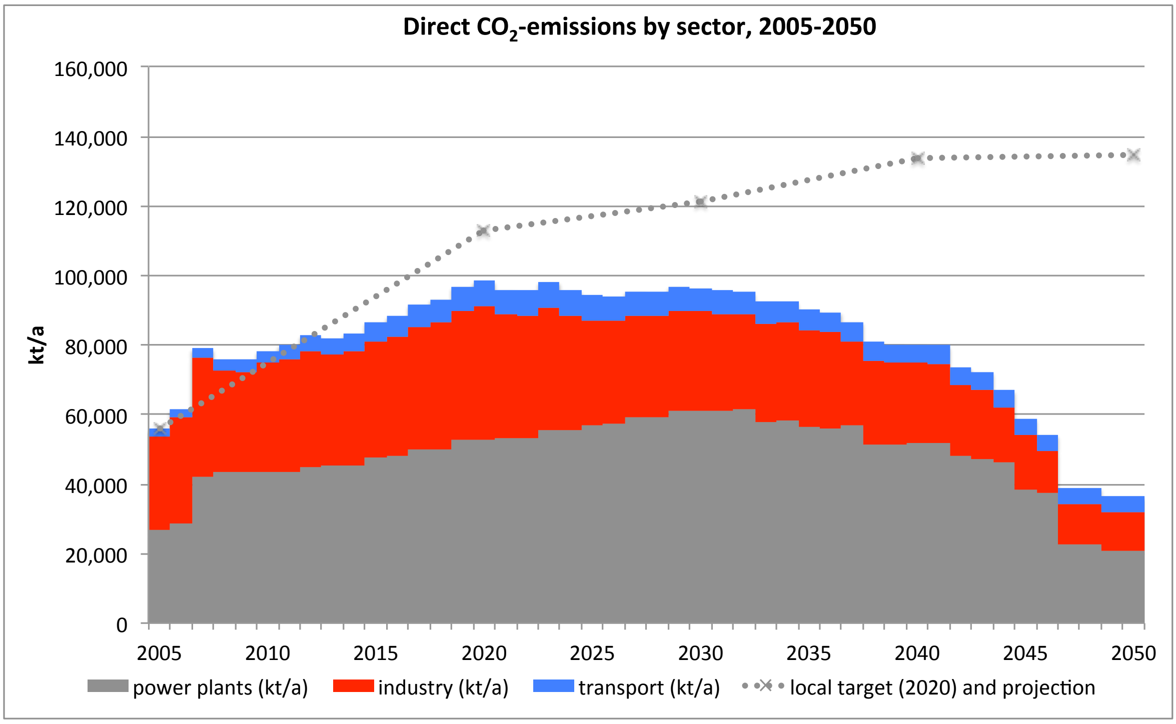
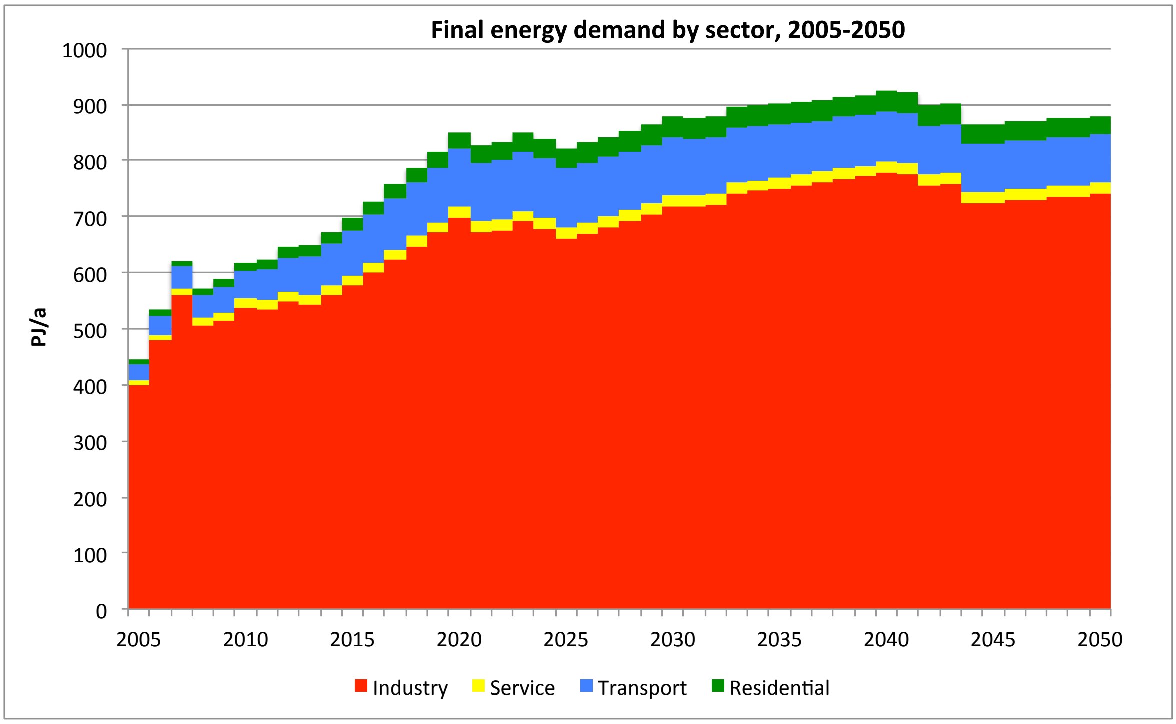


Figure 15: Final energy demand by sector, 2005-2050



Despite fostering energy efficient technologies in all sectors, Figure 15: demonstrates that the total final energy demand is projected to increase by approximately 45% in the coming decades. This increase is most obvious in the industrial sector because of growth in production. However, the relative growth is even higher in the field of housing due to rising living standards and the rapid growth in the use of electrical household appliances, e.g. air conditioning systems. The development of energy demand in the transport sector is equal to the LCTS, i.e. growing by 80%, as both scenarios apply the same basic assumptions for this sector. The assumption set has remained unchanged because assumptions on modal split in passenger transport (in the CPS) and on new drivetrains (LCTS) are already very ambitious.

3.7.1 Industry

In comparison to the LCTS, the most obvious technological change affects the production of steel. Here, three new low carbon technologies are projected to be implemented in the ELCS in addition to the technology portfolio of the LCTS:

(1) Direct reduction of iron via hydrogen is one option, which leads to considerable levels of hydrogen consumption in Wuxi and to a respective CO_2 reduction compared to conventional processes. It is assumed that hydrogen can be provided via electrolysis using electricity from renewable sources. To use this option, however, electricity or hydrogen would have to be imported or the industry would have to move to another area with greater potential for renewable electricity production (which is not currently an option).

(2) Carbon capture and storage (CCS) in connection with top gas recycling (retrofit of one blast furnace designed "CCS ready" in 2017) and

(3) smelt reduction process with CCS .

Figure 16: Final energy use in Wuxi's steel industry in the ELCS, 2007-2050

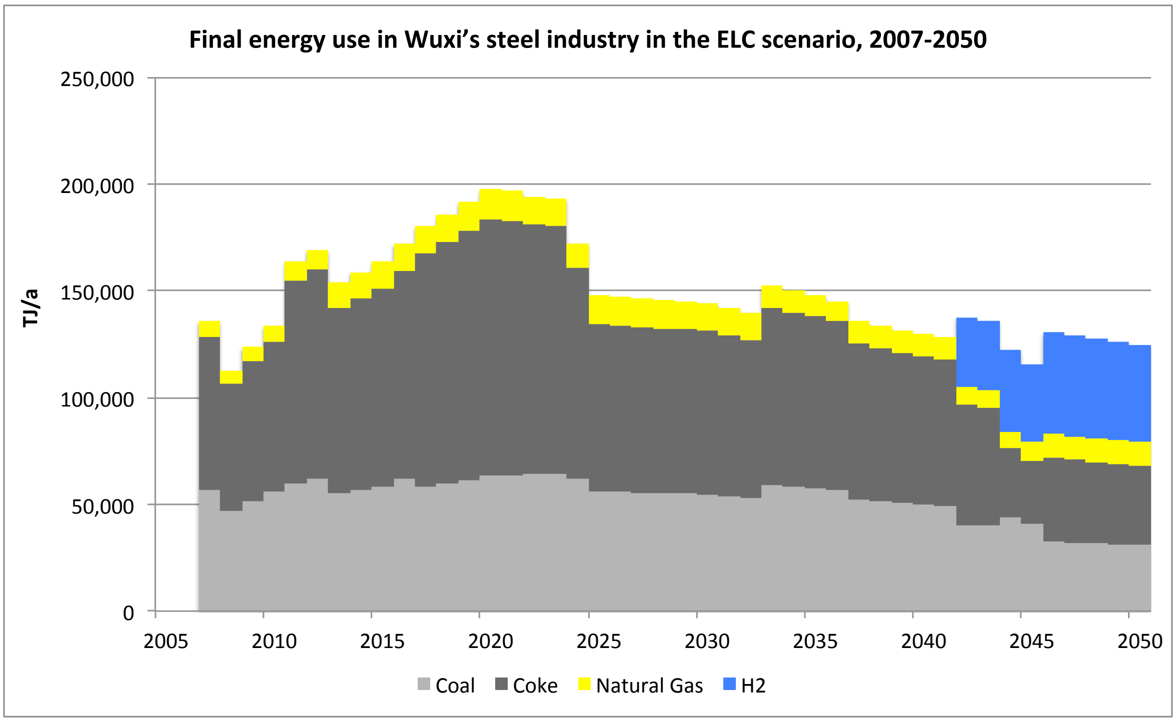
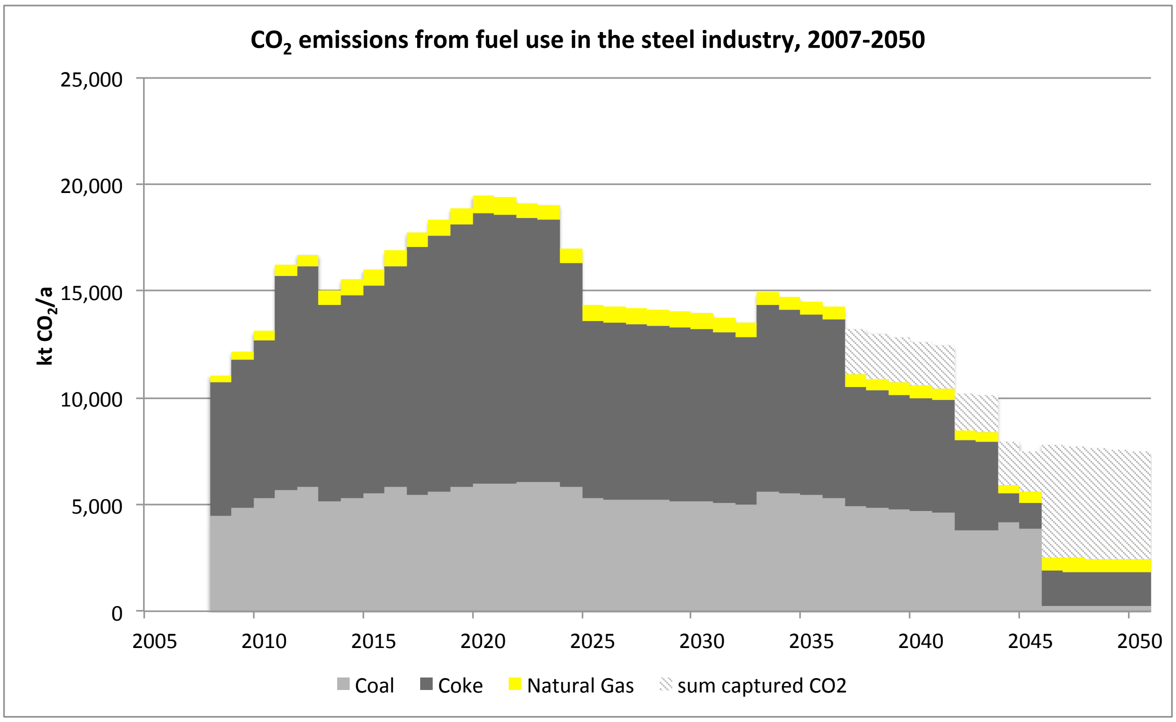


Figure 17: CO_2 emissions from fuel use in the steel industry, 2007-2050



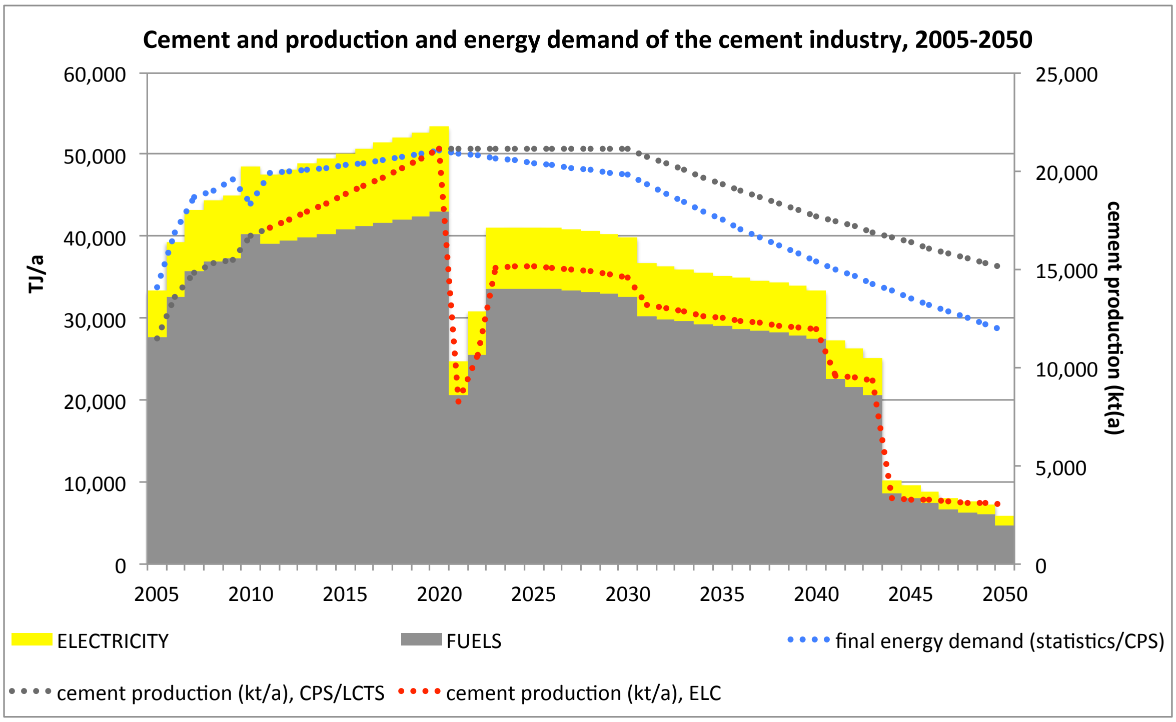
By using CCS in the steel industry 2,000 kt of CO_2 would be captured per annum between 2037 and 2046, increasing to 5,000 kt per annum in the remaining scenario period.[3] In this project, it is not possible to survey if there are adequate storage capacities near the sites of steel plants in Wuxi. The availability of storage sites strongly determines the economic viability of CCS and related logistic challenges. Such an assessment would require a further in-depth study.

Wuxi's cement industry will be affected by declining cement demand due to a fall in construction activity in the building sector in the coming decades. It is assumed that this development is valid not only for Wuxi but also for the regional cement market. Therefore, cement production is adjusted to regional demand.[4]

[3] It is assumed that CCS will be available in China from 2030 onwards. According to the modelled investment cycle the first investment in new capacities after 2030 will be in 2037.

[4] In 2020, the model outlines a sharp decline in cement demand due to a change in assumptions about the growth of floor space from 2020 and thereafter. Cement production in the ELCS corresponds to local cement demand. So the very sharp decline in 2020 with a rapid increase afterwards can be considered as a model artefact.

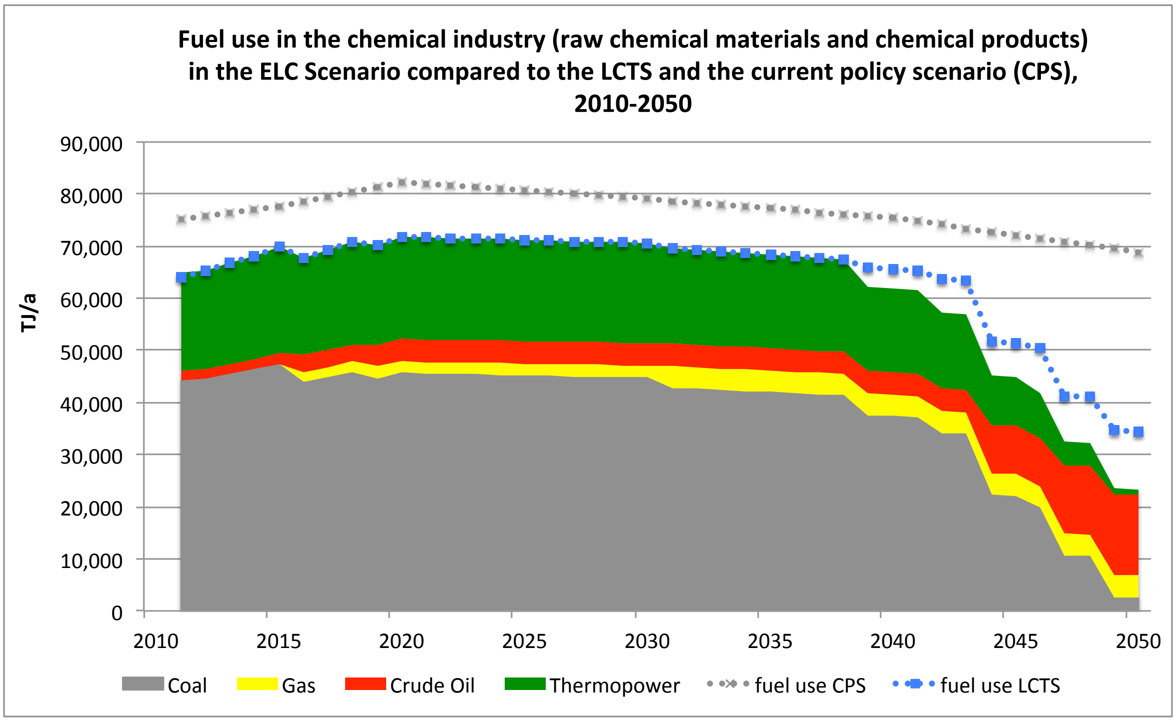
Figure 18: Cement production and energy demand of the cement industry, 2005-2050



Declining cement production leads to lower fuel demand and energy-related CO_2 emissions. Process-related CO_2 emissions, which are relevant in the cement industry, are not considered in the modelling.

Wuxi's chemical industry in the ELCS is quite similar to the LCTS – except for the phasing out of ammonia production in the city. It is assumed that new capacities will be established with a better access to hydrogen produced via electrolysis from renewable electricity. Nevertheless, hydrogen could also be produced in Wuxi if electrical grids are augmented accordingly.

Figure 19: Fuel use in the chemical industry (raw chemical materials and chemical products) in the ELCS compared to the LCTS and the CPS, 2010-2050

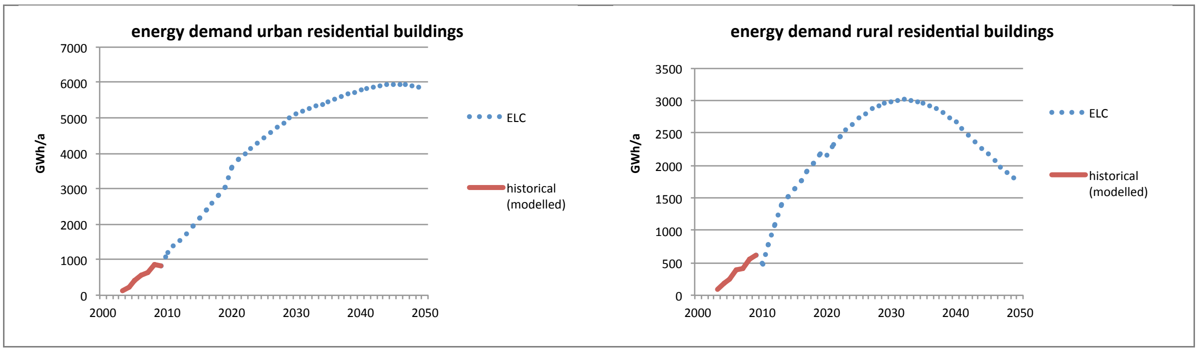


3.7.2 Housing

As the floor space increases (decelerated compared to CPS/LCTS), so does the move towards more energy-intensive lifestyles such as those in industrialised countries (e.g. by accelerated deployment of air-conditioning systems) causing an increase in both specific and absolute electricity demand (see graphs in Figure 20 below). It must be stressed, however, that due to the growing market penetration of low energy and ultra-low energy buildings[5] the increase in energy demand is considerably lower compared to a scenario that would provide the same comfort for inhabitants but with lower energy standards for residential buildings.

[5] Specific energy consumption of ultra-low energy buildings is 74% (multi-family houses) or even 90% (single family houses) lower compared to a reference building.

Figure 20: Electricity demand for housing (ELCS), 2000-2050



3.7.3 Electricity and thermopower[6] production

A key driver for the further reduction of energy-related CO_2 emissions in the ELCS compared to the LCTS is the increased production of electricity from renewable sources. The LCTS shows that the local potential is very limited. One of the basic assumptions of the scenario pathways is, therefore, that electricity imports to Wuxi from renewable sources meet, to some extent, the demand of the energy-intensive industries. Therefore after 2035 no new conventional power plants (without CHP) will be installed. The following figure illustrates the effects that occur after 2030. As a consequence, about 73 TWh or 61% of Wuxi's electricity supply would be provided by renewable electricity imports, requiring sufficient installed capacities for electricity from renewable sources in adjacent municipalities and regions. Such a scenario calls for the profound assessment and mapping of renewable energy sources as well as intensified collaboration between Wuxi city government, neighbouring municipalities and provincial decision-makers in promoting renewable power generation.

[6] Thermopower is steam produced by industrial CHP and distributed by small grids that are not interconnected.

Figure 21: Wuxi's supply of electricity (ELCS), 1995-2050

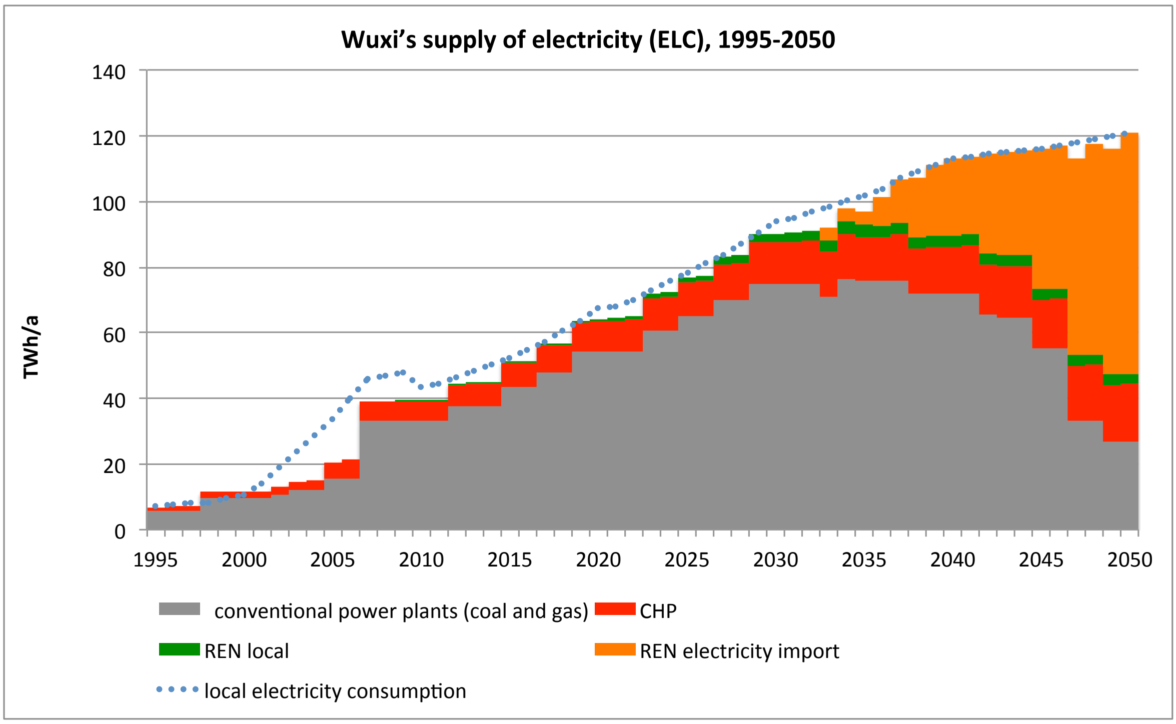
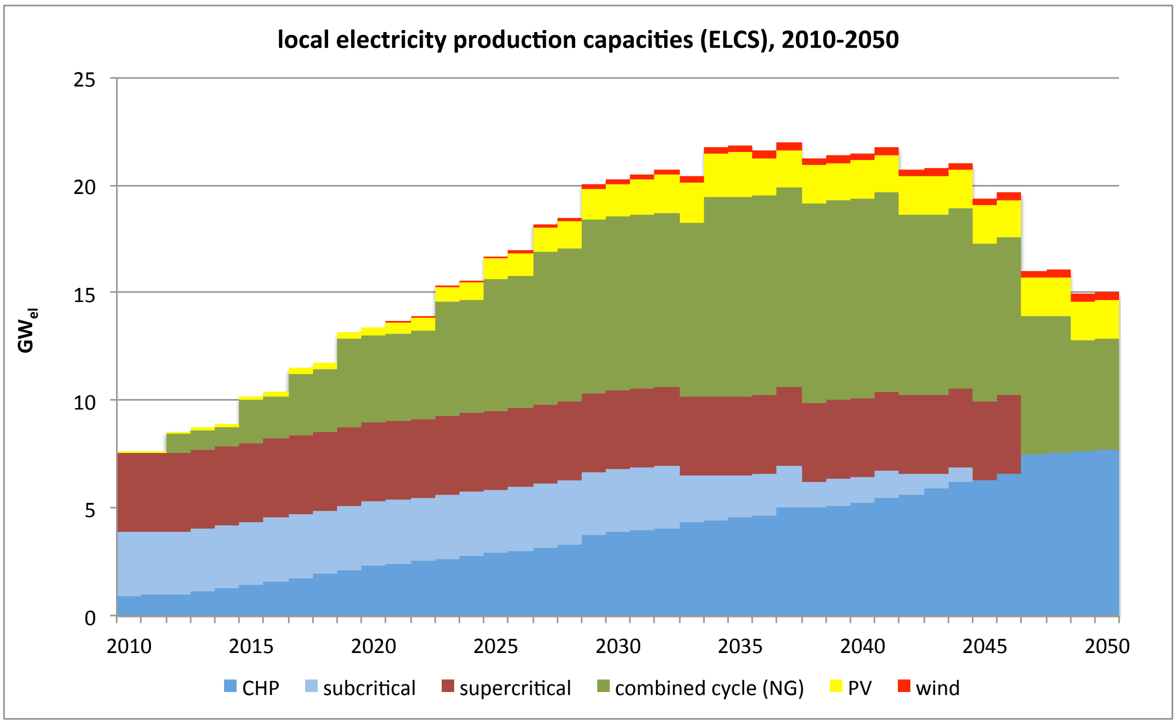


Figure 21: shows the development of local electricity production capacities in the ELCS. Until 2040, installed capacities of natural gas-fired power generating units will increase substantially up to 9 GW_{el}. CHP power plants will provide additional electrical capacity of 5.3 GW by 2040 and of 7.7 GW by 2050. Today's existing plants will be replaced step-by-step by gas-fired plants. Additional CHP capacities are also assumed to be gas-fired. However, in contrast to the LCTS, the share of natural gas-fired combined cycle plants without CHP is assumed to decline to some degree after 2040 as 30 year-old capacities are withdrawn from the grid without replacement. The shortfall of local electricity production is offset by imported renewable electricity from 2035 onwards.

Figure 22: Local electricity production capacities (ELCS), 2010-2050

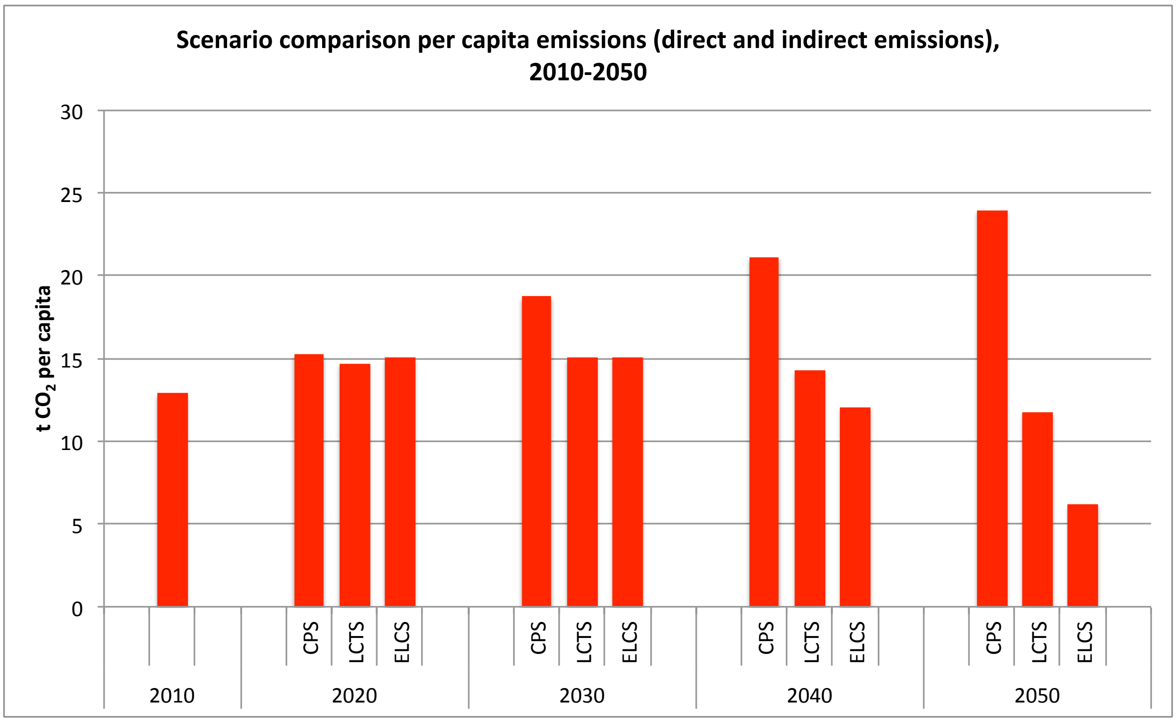


It should be pointed out that the composition of Wuxi's local electricity production capacities relies heavily on the development of base load hours of the different power plant types assumed in the ELCS. If other base-load hour assumptions are applied, the level and distribution of capacities could be very different. For example, in an energy system that is mainly based on renewable energies, the annual operating hours of conventional power plants would be significantly lower than in an energy system centred on fossil fuel. In the ELCS, CHP as well as gas-fired combined cycle power plants serve as base load power plants.

3.8 Comparison of scenario results

As mentioned in the section on the basic assumptions of the LCTS, the need for a more differentiated and detailed analysis in some sectoral sub-models became apparent. Therefore, some of the sub-models were varied significantly when calculating the Extra Low Carbon Scenario (ELCS). This applies particularly to the residential building sector. In contrast to its assumptions in the LCTS, the further elaborated residential buildings model for the ELCS explicitly took into account the trend for local residents in Wuxi to adopt lifestyles closer to those in industrialised countries. This results in higher energy consumption than in the LCTS in the short and mid-term. As a consequence, comparability of both sectoral sub-models is limited.

Figure 23: Scenario comparison of per capita CO_2 emissions (direct and indirect emissions), 2010-2050

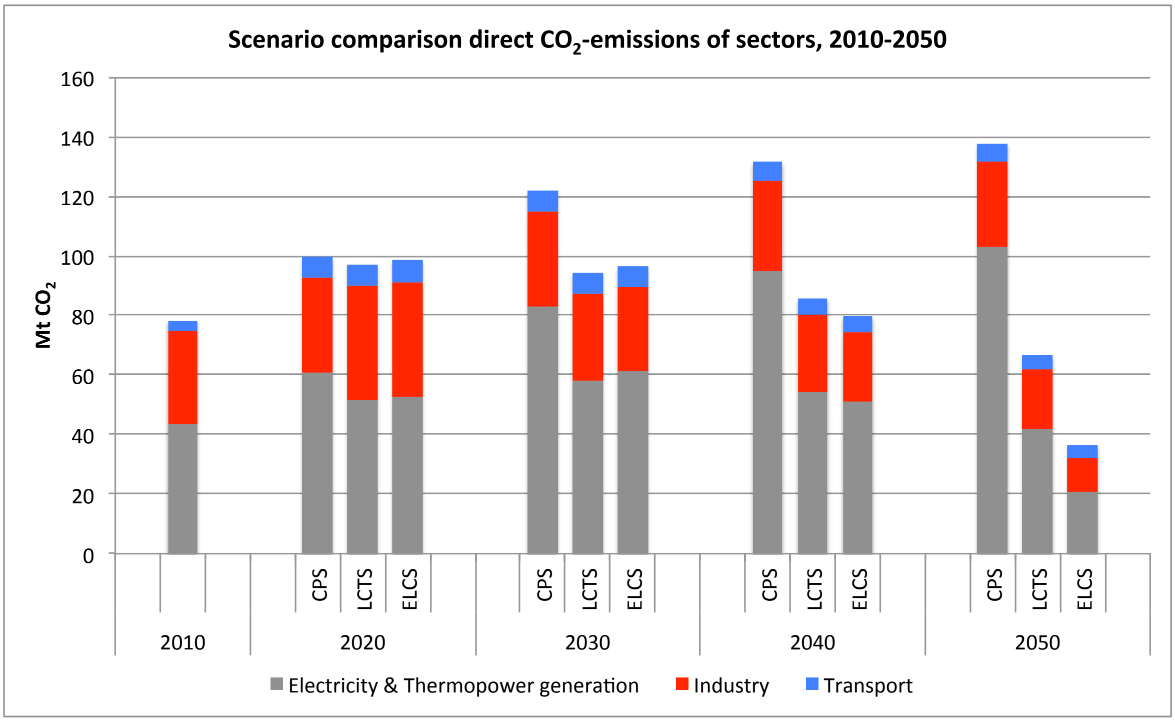


Until 2020 the trend of per capita emissions in all three scenario paths is equal due to the general assumption that the existing policy framework adopted by Wuxi's city government, such as the 12th Five-Year Plan and the municipal low carbon plan, define the city's low carbon strategy until 2020.

Differences between the CPS and the two low carbon pathways become more apparent after 2020. While per capita emissions continue to rise in the CPS pathway, both the low carbon scenarios show stagnating development. Before 2030, the two pathways do not differ from each other. After 2030, additional highly effective mitigation technologies and other non-technical measures, such as a reduced growth in per capita floor space, were assumed in the ELCS, reaching beyond the mitigation efforts taken in the LCTS.

Overall, Figure 23 indicates that CO_2 emissions per capita in the CPS almost double by 2050; in the same year, per capita emissions in the ELCS are only half as high as in the CPS. Additionally, it is clear that an emission level of 2 tonnes per capita, which is the level required in German cities to comply with the IPCC target for low carbon development, is not achieved despite the high level of technological ambition in the ELCS. However, by excluding the industry sector the emission level drops to 1.1 tonnes per capita by 2050. Taking into account that flight transport, process-related emissions in industry and land use are not accounted for in the city model and supposing an emission level of 2 tonnes per capita as "low carbon", there would be a 'balance' of 0.9 tonnes per capita for industry, flight transport and land use. As Wuxi's industrial sector produces goods for the whole economy of China, emission 'allowances' from other cities or rural regions could be transferred to Wuxi.

Figure 24: Scenario comparison of direct CO_2 emissions of sectors, 2010-2050



The general trends outlined in the presented scenario pathways are also reflected in the direct CO_2 emissions of each sector as shown in Figure 24:. In the case of the transport sector it should be pointed out that the set of basic assumptions, such as the saturation rate of private vehicles or the desired modal split, were not varied between the LCTS and ELCS. As a consequence, the LCTS and ELCS indicate an equal development of CO_2 emissions. Industrial CO_2 reduction in the LCTS (compared to the CPS in the respective year) can be mainly attributed to the use of best available technologies (BAT) and a shift to natural gas. In the ELCS the use of hydrogen and the implementation of industrial CCS, as well as a decrease in construction activity in the building sector, are the drivers of the emission reductions that come into play after 2030. Regarding electricity and thermo-power generation, the fact that gas power plants and local renewable energies replace coal in the LCTS and ELCS, together with lower overall electricity production, leads to divergent emission paths between CPS and LCTS/ELCS after 2030. After 2030, additional renewable electricity imports increasingly squeeze electricity from gas power plants out of the market; an additional reduction in local electricity demand helps to halve the CO_2 emission level in the ELCS compared to the LCTS.

Figure 25: Scenario comparison of direct and indirect CO_2 emissions of sectors (including CO_2 emissions allocated to thermopower, heat and electricity), 2010-2050

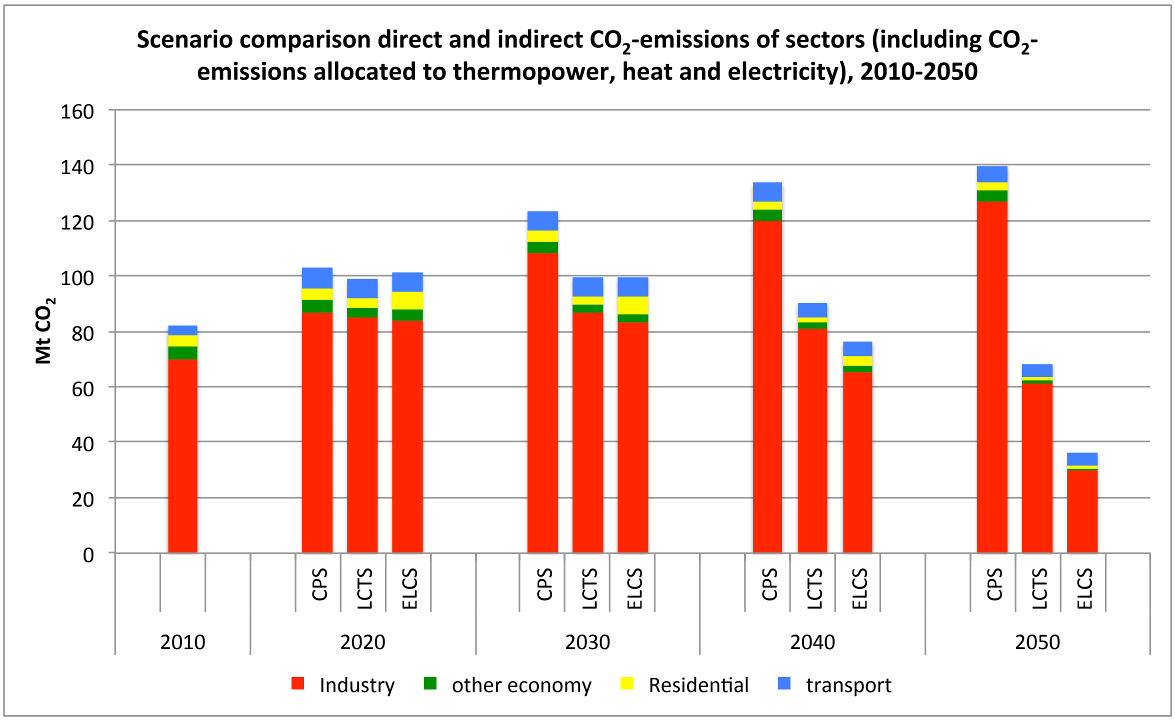
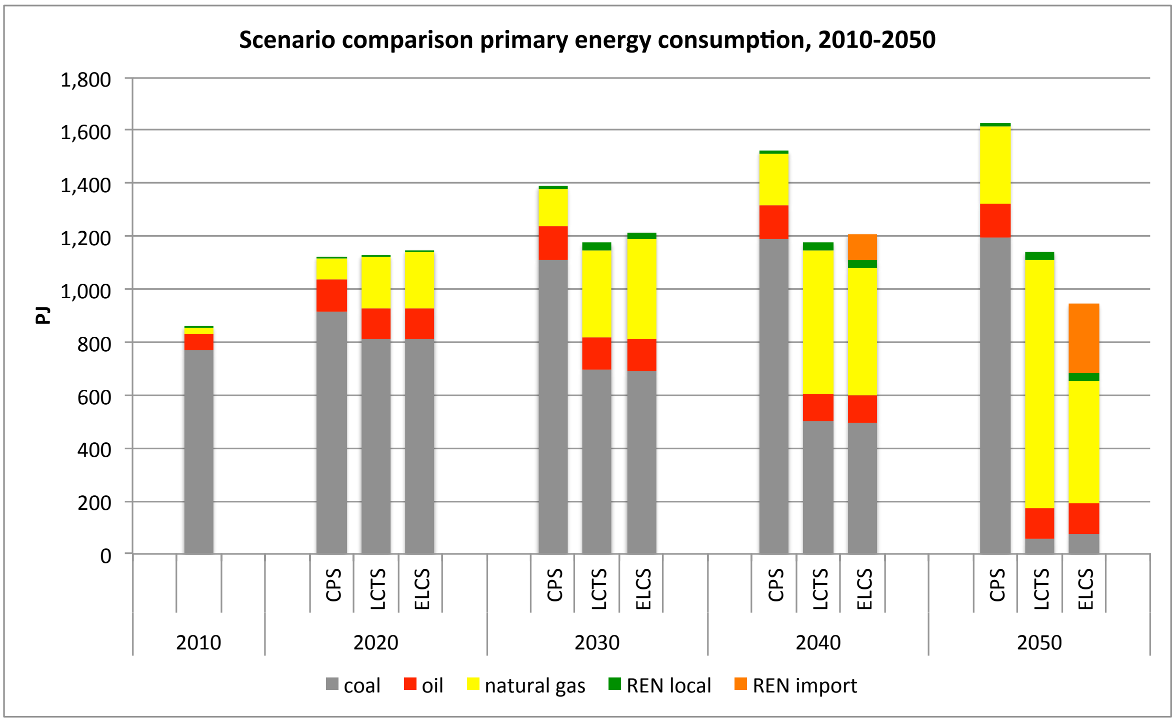


Figure 25: shows emissions from electricity and thermo-power that are allocated to the final energy use in the four given sectors. Once again industry is the main emitter of CO_2 and the sector's emissions in the ELCS are half the level of those in the LCTS, due to a reduction in direct emissions. The latter mainly results from the usage of the additional mitigation technologies mentioned above as well as from reduced emissions from electricity generation (see above).

For the residential sector, the comparability of results between the CPS/LCTS and the ELCS is limited due to the different assumptions underlying the final energy use (electricity) as described above. From 2020 onwards, the more differentiated modelling approach for the building sector in the ELCS (see section 3.1) is reflected in the scenario results. Due to the assumed increase in living standards, e.g. leading to higher electricity demand, the residential building sector is more significant for Wuxi's overall carbon footprint in the ELCS than in the LCTS. This results in slightly higher overall emission levels between 2020 and 2030. However, in the longer term the lower emission factors for power generation in the ELCS more than compensate for the increase in emissions in the residential building sector.

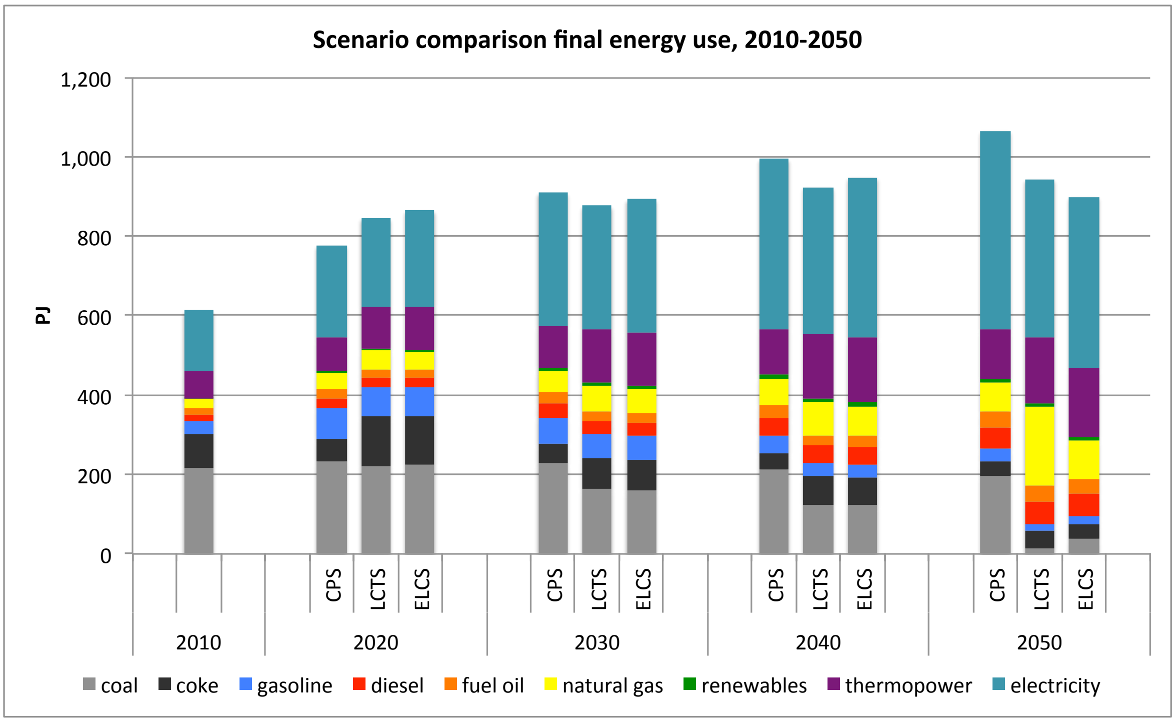
Figure 26: Scenario comparison of primary energy consumption, 2010-2050



0 illustrates the development of primary energy consumption by energy source. The most striking feature of both low carbon scenarios compared to the CPS is the drastic reduction in coal usage, especially after 2040, which is necessary to significantly reduce CO_2 emissions. The most prominent reason is that after 2040 the existing coal power plants gradually cease production and are not replaced in the LCTS or ELCS. The slight increase in coal use in the ELCS in 2050, compared to the LCTS, is due to the production of steel via coal in combination with CCS, whereas in the LCTS direct reduction with natural gas has a higher share in steel production.

Furthermore, it is apparent that the LCTS in 2050 relies heavily on the use of gas as it represents the only option to meet the industry sector's persistently high energy demand with rather clean electricity. Local energy production from renewable sources is an exception to this, but the potential is limited. Due to China's limited natural gas reserves, it seems doubtful whether increasing the use of gas, as assumed in the LCTS, would be possible. In the ELCS, the dominance of natural gas as a mitigation option is alleviated due to higher levels of imported electricity from renewable sources in addition to the local potential realised in the LCTS after 2035.

Figure 27: Scenario comparison of final energy use, 2010-2050



Final energy demand is projected to increase consistently in both scenarios (CPS and ELCS[7]). Only in the final decade does the ELCS show a decrease. The ever-growing share of electricity is mainly caused by lifestyle changes (as previously described) and the rapid growth of new industries for Wuxi such as machinery construction and the service sector, which consume less heat but are heavily reliant on electricity. Heat demand in industry is - to a very high degree - provided by combined heat and power plants that are currently fired by coal, but will be replaced in the scenarios by gas-fired units. Coal and coke usage remains stable in the CPS and will decline significantly in the ELCS.

3.9 Classification of the scenario results

At first glance the ELCS results, showing an emission level of 6.4 tonnes of CO_2 per capita by 2050, appear very unsatisfactory. However, it should be stressed that Wuxi has an important role in China's economy, producing a number of energy-intensive goods for the regional, national and international markets. Wuxi's share in the production of CO_2 intensive goods is higher than its population share. To classify the emission level indicated in the ELCS we assumed the CO_2 intensity calculated for Wuxi as a benchmark for China (see Table 5:).

This means that all Chinese production facilities (for steel cement, etc.) are assumed to be

[7] Due to the different assumptions between the LCTS and the ELCS, comparisons between these two scenarios with regards to final energy use are not possible.

equally as efficient as those in the city of Wuxi under the ELCS.

Table 5: Allocation of CO_2 emissions between Wuxi and the rest of China

	activity 2050				CO_2 Benchmark 2050	Benchmark electricity	allocated emissions 2050 (kt CO_2/a)	
	activity unit	Wuxi	China	Wuxi share	kt CO_2/unit of activity*)	TJ/unit of activity**)	Wuxi	China
Steel	kt Steel p.a.	11,338	360,000	3.15%	0.23	0.7	3,038	96,451
Cement	kt Cement p.a.	3,019	900,000	0.34%	0.56	0.4	1,733	516,526
Glass	kt Glass p.a.	0	580,000	0.00%	0.40	1.5	0	273,158
Ammonia	kt Ammonia p.a.	120	12,000	1.00%	3.02	0.0	362	36,227
Ethylene	kt Ethylene p.a.	865	5,500	15.73%	1.15	0.0	997	6,336
Soda Ash	kt Soda Ash p.a.	0	22,000	0.00%	0.06	0.3	0	1,552
Caustic Soda	kt Caustic Soda p.a.	145	24,000	0.61%	0.09	8.6	73	12,132
Paper	kt Paper p.a.	0	120,000	0.00%	2.52	1.6	0	311,714
Aluminum	kt Aluminum p.a.	0	33,000	0.00%	0.21	11.0	0	24,631
other industry production	value added (Mill. $Yuan_{2005}$)	2,116,632	118,024,265	1.79%	0.003	0.2	24,140	1,346,034
subtotal: industry		-	-	-	-	-	30,343	2,624,761
service sector	value added (Mill. $Yuan_{2005}$)	3,219,784	202,381,910	1.59%	-	0.006	930	58,450
residential sector	1,000 inhabitants	5,826	1,460,000	0.40%	-	5.5	1,568	392,870
transport sector	1,000 inhabitants	5,826	1,460,000	0.40%	0.79	0.09	4,622	1,158,182
total		-	-	-	-		37,462	4,234,264
total per capita		-	-	-	-		6.4	2.9

*) process related emissions included**) emission factor for electricity is assumed to be 0.175 kg CO2/kWh

Source: China activity values according to JIANG, K. HU X., ZHUANG X. et al. (2008); own calculations.

By combining China's activity values with Wuxi's specific values for 2050, an emission level of 2.9 tonnes per capita is reached as an average level for China.

However, it should also be noted that 2.9 tonnes of CO_2 per capita is still above the level necessary to comply with the IPCC's 2 tonnes CO_2 per capita target and that expert analyses assert that the level should be even lower.

For example, the analyses of the WBGU (German Advisory Council on Global Change; WBGU, Factsheet No. 03/2009) conclude that industrial and emerging countries should achieve about one tonne of CO_2 per capita by 2050. The important global role of the Chinese economy must be taken into account; however, it is obvious that carbon neutral development will be difficult to achieve even with the very ambitious assumptions under the ELCS.

Further possible ways for additional CO_2 reductions to be made must be identified. From today's perspective the technological potential seems to be almost exhausted taking into account the assumptions of the ELCS. Another starting point could be the development of mitigation strategies for freight transport (modal shift), as this was not considered in the previous modelling. However, this is unlikely to have a great effect. Furthermore, resource savings should be taken into account, with an overall reduction in steel and cement production as a possible target.

Overall, the modelling clearly shows that it will be difficult to initialise and implement a carbon neutral strategy. However it should be noted that this problem is not unique to Wuxi, or to China as a whole. A complete rethink on the global stage is required in order to achieve greater efficiency and sustainability. China and its cities such as Wuxi play an important role within this process and can be greatly influential. However, established industrial countries in Europe and North America will have to take the lead in this process.

4 Resource utilisation in selected sectors under the Extra Low Carbon Scenario (ELCS)

4.1 Objectives and methodology

Bringezu (2011) characterises three big (and increasingly significant) environmental pressures of worldwide concern (referred to as the "Big Three"), notably interrelated and linking to other environmental pressures with a higher regional anchorage such as water consumption:

- Emissions of greenhouse gases (precursors of climate change)
- Extraction of abiotic resources (eventually and inevitably ending up as waste)
- Change of land use (replacing natural ecosystems with built-up or agricultural land)

The focus of the present project is on the first of the Big Three. This part of the study is designed to enhance the resulting GHG emission inventories and climate mitigation and adaptation strategies with insights into the second of the Big Three: abiotic resource use (and associated water consumption, where relevant). The objective is to provide answers to the underlying research question that can be phrased as follows: "Do climate mitigation and adaptation strategies shift environmental pressures from GHG emissions to resource use?"[8]. In this phase of the project, we apply this question to the ELCS.

Having defined this objective, a choice must be made about which system to investigate and which methods to apply. In terms of the focus of the investigation, the object under scrutiny is obviously Wuxi's socio-economic system, divided into sectors of production and consumption (whose typology is described in WP2 report for the emission inventory). In terms of methods to apply, two main methods taken from the wider material flow analysis (MFA) toolbox are useful here (Bringezu and Bleischwitz 2009):

- *Material Input per unit of Service (MIPS):* also referred to as *material footprint*, it belongs to the larger family of life cycle studies and operates at the micro-level (as in *micro*economics). It focuses on the input side of the life cycle inventory[9] of the studied product, service, or process and demarks itself by accounting for economically non-valued resource extraction (Ritthoff et al. 2002, Schmitt-Bleek et al. 1993).

[8] A second and complementary research question could be phrased as follows: "Can resource efficiency strategies contribute to climate mitigation and adaptation?" This question is not addressed here. There is enough substance in this question alone for another project entirely.

[9] The life cycle inventory of a product is the list of material inputs and outputs (such as emissions) necessary along the entire lifetime of the product (from raw material extraction, manufacturing, through distribution, use, to end-of-life of the product.

- *Economy-wide material flow analysis (EW-MFA):* it covers in principle all material flows of the studied region (all materials entering the economy as extraction or imports, and all materials exiting the economy in the form of emissions, waste, or exports). For feasibility reasons, the scope of the analysis is circumscribed here to well-defined sectors of the economy and relevant input and output material flows.

A variety of material flows and stocks associated with Wuxi's production and consumption activities can be derived from the methods outlined above. The headline indicator we are pursuing in order to accurately represent Wuxi's resource use is called *total material requirement* (TMR). It aggregates in one variable the domestic and foreign resource extraction (here vis-à-vis Wuxi's boundaries) that can be directly or indirectly linked to Wuxi's production and consumption activities.

This characteristic of TMR is important since it differs from the scope of the emission inventory. GHG emissions from a given sector in the emission inventory cover only the direct emissions of this sector, whereas the TMR of this sector accounts for resources used indirectly by the suppliers of this sector.

The absolute value of TMR measures the environmental pressure associated with the second member of the Big Three. The total material requirement can also be expressed relative to a physical or economic unit of output from the same system, thus building an intensity indicator easier to manipulate for cross-comparisons.

4.2 Rationale of sector selection

Bringezu and Bleischwitz (2009) demonstrate that no more than ten product groups were responsible for about 75% of the total material requirement of the German economy in the early 2000s. These product groups were (in descending order of sectoral TMR): 'construction', 'food and beverages', 'basic metals', 'energy (electricity and gas)', 'manufacture of motor vehicles', 'manufacture of machinery and equipment', 'coal', 'agriculture', and 'coke, refined petroleum'. Why are these sectors such high contributors to TMR and how can we use this insight for the present study?

The sectors listed above (except coal mining) actually have rather low direct resource extraction but they use energy, which is a resource intensive product in a country whose fuel mix is dominated by coal. They also require considerable amounts of minerals and metals from domestic and foreign mining and quarrying industries. All these upstream resource uses amount to large sectoral TMRs.[10]

[10] The waste management sector is not among the biggest contributors to German

As the focus of this project is on the first of the Big Three worldwide environmental pressures (GHG emissions and related climate mitigation and adaptation strategies), it is understandably beyond its scope to consider the resource use of Wuxi's entire socio-economic system. The analysis therefore needs to limit itself to key sectors deemed relevant for both Wuxi's low carbon development strategy and Wuxi's resource use. Accordingly, two sectors were selected in an earlier phase of the project.

The criteria devised to select these two key sectors for the assessment of resource use in Wuxi were threefold:

1. The probability should be high that the resource intensity and absolute resource use of the selected sector are significant today.[11]
2. The sector should be identified as a potential key sector in the GHG emission inventory.
3. The probability should be high that mitigation and/or adaptation measures applying to the sector will be defined in the project.

Against this backdrop we decided to assess in priority the resource use of the following economic sectors:

- Electricity and heat production
- Construction

In support of this choice, here is how the electricity and heat production sector scores based on the three selection criteria:

1. Wuxi's (and China's) energy mix is dominated by coal which is a notoriously highly resource intensive energy carrier: in the 1990s in Germany, for example, the production of 1 MWh electricity from hard coal, lignite, oil, and natural gas was responsible for the extraction of 722 kg, 11,348 kg, 306 kg, and 283 kg of primary materials respectively (Manstein 1995).
2. The emission inventory shows that due to its high emissions, growth and economic relevance this sector can be regarded as a key sector.
3. The energy sector is addressed by the mitigation and/or adaptation measures to be

TMR. It is, nevertheless, obviously a relevant sector in terms of resource management and resource efficiency, e.g. considering waste treatment options such as recycling and waste-to-energy. This aspect, however, pertains to the second research question mentioned earlier ("Can resource efficiency strategies contribute to climate mitigation and adaptation?"), which is not addressed in this work.

[11] As a reminder, resource use refers here to both direct and indirect resource inputs (e.g. including inputs occurring upstream in the supply chain of a given industry).

defined in the project and the proposed technologies (e.g. renewable energy technologies) may be assessed for their resource requirements.

In turn, the construction sector fulfils the three selection criteria as follows:

1. The construction sector generally accounts for a large share of the total resource requirement in industrialised countries: "the construction sector is the largest consumer of raw materials in the EU" (EIO 2011). It is potentially even more so in countries like China with booming infrastructures.
2. Due to lack of data, the emission inventory could not address this particular sector. The construction sector was nevertheless selected as a key sector for Wuxi (current high volume and expected increase of construction work in China; potentially relevant for climate adaptation due to increased land sealing).
3. The construction sector is addressed by the mitigation and/or adaptation measures to be defined in the project and the proposed technologies (e.g. building efficiency technologies) may be assessed for their resource requirements.

The following sections present detailed stock-flow diagrams illustrating the resource use of the selected sectors in Wuxi under the conditions set in the ELCS. Where relevant, we draw comparisons with the results from the analysis of the CPS in an earlier project phase.

4.3 Modelling

This section briefly introduces how the methods described above were applied to model Wuxi's resource use in the selected sectors.

4.3.1 Resource use of Wuxi's electricity and heat production sector

A detailed energy balance has been established for Wuxi (See WP2 report) in order to produce current and future GHG emission inventories under several scenarios, including the ELCS. Material and water intensity factors (including both direct fuel use and indirect material flows, also referred to as ecological rucksacks) are coupled with the established current and future (under the ELCS) energy balance to deliver a resource flow analysis model for electricity and heat generation in Wuxi (Xia 2011). The modelling parameters and results are consistent with the energy balance assumptions and modelling of CO_2 emissions in Wuxi's energy sector in the ELCS.

4.3.2 Resource use of Wuxi's construction sector

It was not possible to model the whole construction sector due to a lack of data on commercial and industrial buildings and on infrastructures. The model is therefore limited to residential buildings, with a distinction between urban and rural buildings. This modelling decision is backed up by scientific literature which states that "construction of housing space constitutes approximately 80% of all new space added to China's building stock" and that "to enclose the same floor area, commercial buildings require approximately 62% and industrial 13% of the bulk volume of the material required by residential buildings" (Fernandez 2007).

A stock dynamics model, coupled with a material flow analysis model for construction materials and their associated environmental rucksacks, was developed to provide the basis for the analysis of resource use in the residential building sector in Wuxi. In short, this means that:

1. The stock of residential buildings is exogenously calculated for each year of the modelled time series (1949-2050) as the product of population statistics and estimated per capita floor area.
2. Buildings have an expected lifetime (modelled as a probability distribution) before they are demolished; the lifetime of a building depends on the year when it was built.
3. Each year new buildings make up for the sum of demolitions and the change in stock compared with the previous year.

The key driving parameters of the model are population, per capita floor area, buildings' lifetime, and material intensities (Fernandez 2007, Yang and Kohler 2008, Hu et al. 2010, Hu 2010, Xia 2011). The model is calibrated so as to be fully consistent with the assumptions made for the modelling of CO_2 emissions in Wuxi's building sector in the ELCS, which covers the period 2010-2050.

4.4 Resource use from the electricity and heat production sector under the Extra Low Carbon Scenario (ELCS)

4.4.1 How to read the stock-flow diagram

The middle section of the diagram in Figure 28: shows the development of the metabolism of the electricity and heat production sector in Wuxi between 2010 and 2050 under the conditions set by the ELCS. It shows the chronological pattern of the energy and material flows produced in Wuxi and in China by electricity and heat consumption in Wuxi, while water flows and material stocks are only represented at two points in time (in 2010 and 2050). It also shows an estimate of the amount of materials trapped in Wuxi's power and heat plants. The diagram differentiates between direct material inputs (e.g. materials actually used in the electricity production process) and the associated ecological rucksacks. The latter comprise all materials used to supply the direct material flows in the first place. For example, in the case of a direct input of coal into the electricity production process, the associated ecological rucksack would consist of the activity at the coal mine (economically non-valued resource extraction) and the fossil fuels (including coal) required to produce the energy necessary to mine the coal that is later used to produce electricity in Wuxi.

The arrows representing the material and energy flows are graphs showing the continuous development of these flows from 2010 to 2050 (from left to right, or top to bottom for electricity imports). All stocks and flows represented in the diagram are to scale: the thickness of the graph arrows representing the direct material flows and their rucksacks at each time point; the height of the square representing the material stock in the energy production infrastructure (i.e. in the plants); and the height of the drops representing the water flows. The water flows are, in order of magnitude, larger than the material flows. To keep the diagram legible the water drops are scaled as to represent one tenth of the actual water flows. The simple arrows showing flows coming in and out of the energy production infrastructures in Wuxi represent *cumulative* material inputs (for new power and heat plants) and outputs (from decommissioned plants) over the period 2010-2050.

The direct material flows and their ecological rucksacks are colour coded: the yellow part of the flow represents the materials linked to heat generation, the blue part corresponds to electricity generation. This distinction is the result of a calculation procedure called "allocation" that is used in multi-output processes (here combined heat and power plants) to attribute to each output from the process (here heat and electricity) its corresponding share of the input flows into the process.

The top section of Figure 28: reproduces the stock-flow diagram showing the material and water use required by the electricity and heat production sector in Wuxi between 2010 and 2050 under the conditions set by the CPS. This diagram stems from an earlier phase of the project and was designed following the same methodology as described above.

4.4.2 Stock-flow analysis of the energy sector

A good place to start is to qualitatively compare the metabolism of Wuxi's electricity and heat production sector in two different scenarios: the CPS (top section of Figure 28:) and the ELCS (main diagram in the middle section of Figure 28:). It is clear from the two diagrams how the two scenarios differ: the ELCS relies much less on domestic electricity production than its counterpart. In the ELCS imported electricity shows steady growth and this electricity comes increasingly from renewable energy sources, while Wuxi's domestic electricity and heat production shifts from a coal to gas-dominated fuel mix.

In quantitative terms, electricity consumption in the ELCS increases almost threefold between 2010 and 2050 while heat consumption more than doubles. Coal is phased out before 2050 for both electricity imports (60% of electricity use in 2050, up from 9% in 2010) and domestic energy generation. The development of increasingly efficient natural gas-fired combined heat and power plants in Wuxi allows the city to generate 23% more electricity and twice as much heat in 2050 than in 2010 while leaving behind a material footprint almost four times smaller (16 Mt in 2050, down from 61 Mt in 2010, almost two thirds of which could be traced back to the environmental rucksack of coal). Natural gas has indeed both a higher energy density (almost twice as high) and a lower ecological rucksack (almost three times lower) than coal, which denotes lower fuel imports for the same end-energy need, together with less associated hidden flows.

In the same period of time, electricity imports escalate significantly (they increase 18-fold between 2010 and 2050, from 4 TWh to 73 TWh) but the related total material requirement does not follow suit (only 2.5 times higher in 2050 than in 2010, from 6 Mt to 15 Mt). This is because renewable energy technologies[12], which represent 100% of the electricity imports from around 2040, have a lower material footprint. While wind turbines and photovoltaic installations exhibit direct material requirements per installed capacity (per "Watt-peak") comparable to incumbent coal-fired power plants, the picture looks quite different when

[12] A detailed model of Chinese grid electricity is beyond the scope of this project. The material requirements of electricity imports to Wuxi were therefore calculated with the assumption that imported electricity is generated using the same technologies (coal, wind, solar) as those deployed in Wuxi (although the ratio between renewable and non-renewable energy sources is different), which is a reasonable assumption when looking at a single country, as is the case here.

environmental rucksacks are taken into account: coal power requires more resources for extraction than wind or solar power.

All material flows mentioned above are either hidden flows (ecological rucksack) that never reach Wuxi (but still result in environmental pressures in other regions of China) or direct fossil fuel inputs to Wuxi's energy sector that eventually end up in the atmosphere after combustion. There is, however, also a quantifiable amount of energy generation-related material that stays in Wuxi: the materials making up the power and heat plants. The stock of materials that coal-fired, gas-fired, wind, and photovoltaic power plants amount to will roughly double between 2010 and 2050 (from 4 Mt to 7 Mt). Interestingly, this stock increase will cumulatively require around 5 Mt of materials (concrete, steel, etc.) while the decommissioned power and heat plants will cumulatively represent around 6 Mt of materials. This does not, however, mean that if that the materials from the decommissioned plants were recycled, the new plants would scarcely require any primary materials. The shape of the energy production curve in Wuxi indicates that the sector will, in fact, first go through a phase of stock expansion, while the bulk of the decommissioning will kick in later on. Consequently, forward planning should be undertaken to identify in which other sectors this flow of potential secondary materials could be used; otherwise decommissioned materials may constitute more of a waste burden than a recycling opportunity. It should be noted, however, that although this represents a large amount of waste/recycling materials, this issue is still dwarfed by the amount of fossil fuels pumped into Wuxi's energy system in any single year.

In addition to material stocks and flows, the issue of water consumption directly and indirectly associated with energy generation is not one to be taken lightly. Here again, the shift to natural gas for domestic production and to renewables for imports, away from coal in both cases, implies that Wuxi will decrease its energy-related water footprint both within and outside the city (by 67%, from 339,000,000m^3 overall in 2010 down to 113,000,000m^3 in 2050). Wuxi's new efficient gas-fired CHPs will require less water than coal-fired plants, as extracting gas is less water intensive than coal mining, and renewable energy technologies, although their lifecycle water requirements should not be ignored, are much less water-intensive than combustion technologies (significantly less water-intensive when compared to coal-fired electricity).

Overall, if Wuxi's energy sector were to develop as indicated in the ELCS, its GHG emissions would be considerably reduced and so would its direct and indirect material and water requirements.

Figure 28: Resource use in Wuxi's energy sector under the ELCS conditions

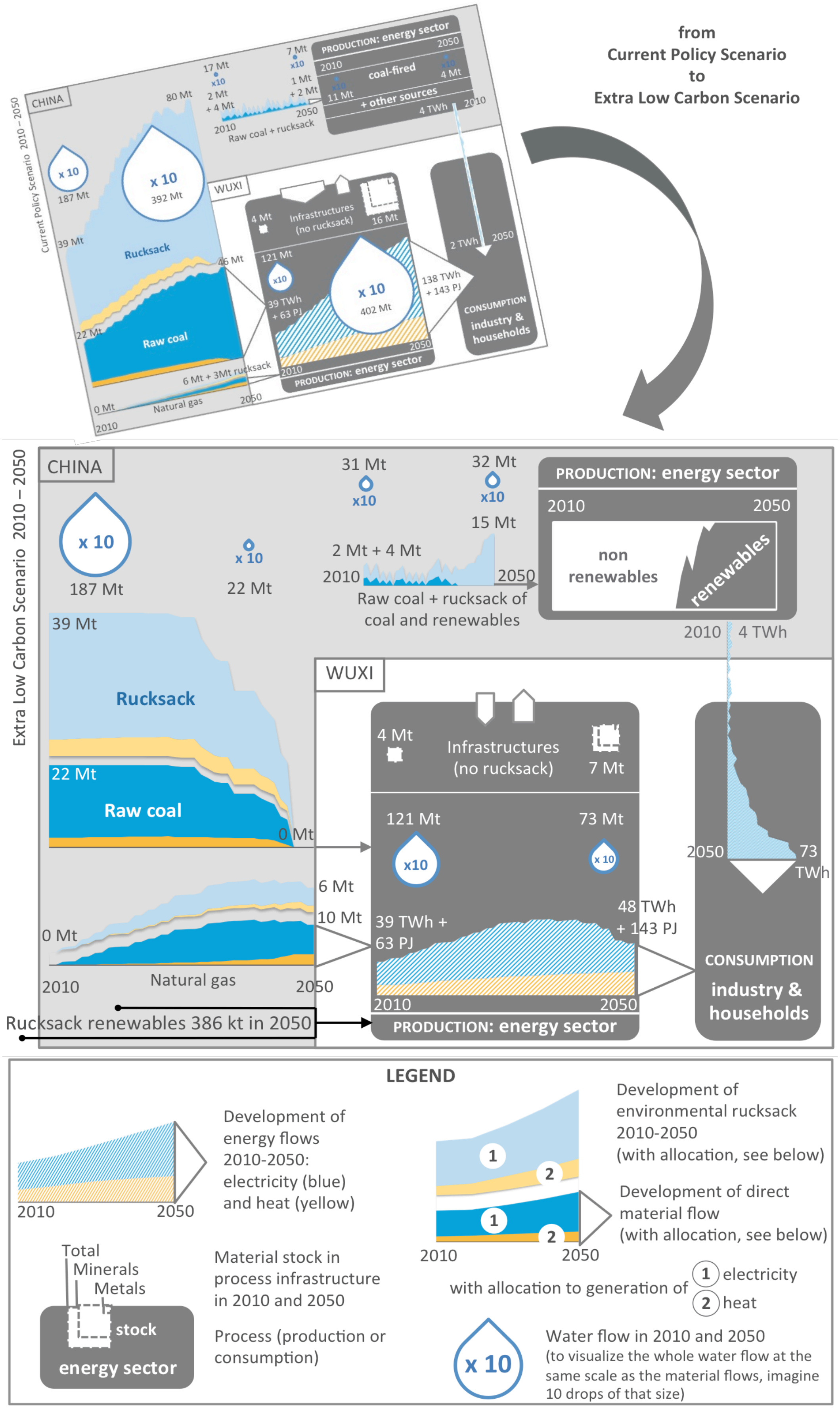


Table 6: Indicators of resource use in Wuxi's energy sector under the ELCS conditions

KEY AGGREGATE INDICATORS: ENERGY SECTOR 2010-2050								
Indicators	Absolute flows [million tonnes or m³]			Intensities [t or m³ / MWh]			Change [%]	
	2010	2030	2050	2010	2030	2050	2010-2030	2010-2050
DMI	22	30	10	0.4	0.2	0.1	+37%	-56%
TMR	66	78	31	1.1	0.6	0.2	+18%	-53%
TWU	339	430	113	5.6	3.4	0.7	+27%	-67%

DMI = Direct Material Input; TMR = Total Material Requirement; TWU = Total Water Use

4.5 Resource use in the residential building sector under the Extra Low Carbon Scenario (ELCS)

4.5.1 How to read the stock-flow diagram

The diagram at the top of Figure 28 shows the development of the metabolism of the residential building sector in Wuxi between 2010 and 2050. It shows the chronological pattern of the material flows caused in Wuxi and in China by demand for housing in Wuxi, while material stocks are only represented at two points in time (in 2010 and 2050). The colours simply distinguish stocks and flows linked to urban (blue) and rural (yellow) residential buildings.

The diagram differentiates between direct material inputs (e.g. construction materials actually used in the buildings) and the associated ecological rucksacks (includes e.g. the activity at the quarry and the fossil fuels required to produce the energy necessary to quarry the construction material).

All stocks and flows represented in the diagram are to scale. The arrows representing the material flows are graphs showing the continuous development of these flows from 2010 to 2050 (from left to right). Each colourful tile represents 5 million tonnes of materials trapped in the building stock. The variations of the graph arrows over time represent the development of direct material flows and their rucksacks: at each time point the thickness of each graph is scaled accordingly. For example, the blue demolition material flow in 2050 (10 = 2x5 Mt) is as thick as two of the blue tiles piled up.

The middle section of Figure 28, also using the convention that one tile represents 5 million tonnes of materials, shows the net additional requirements for construction materials in the ELCS (above the arrow) and the net saving of materials associated with energy generation (below the arrow) with respect to an imaginary case where the energy efficiency of buildings would have stagnated after 2010 (i.e. where buildings would have required less construction materials to build but more energy to live in than in the ELCS).

4.5.2 Stock-flow analysis of the building sector

Underlying the stock-flow diagram in Figure 29: is a dynamic building model[13] adapted to the analysis of long-term trends, which suits the present purpose. Our model is designed to simulate urban and rural residential building stocks, the construction of new buildings, the demolition of old ones, and the associated direct construction material requirements and related environmental rucksacks for the period 1949-2050. Figure 29: is, therefore, extracted from this longer time series. These modelling results are in no way rigid predictions. They are consistent with the ELCS and logically emerged from a series of informed assumptions about the driving parameters.[14]

The building stocks (actually the floor area in square metres) are calculated for each year of the time series as the product of the population numbers by the average per capita floor area (i.e. the dwelling surface divided by the number of people in the household). The model considers three sizes of buildings, further differentiated into four levels of energy requirements.[15] Urban and rural areas are modelled each with their own arrangements combining the twelve building types. In the ELCS, the trend both in urban and rural areas is towards taller, more energy efficient buildings.

The amount of materials needed for construction depends on the building type. The model limits itself to structural and finishing materials, excluding equipment materials.[16] Lower buildings require bricks as well as concrete as structural materials, while medium and high-rise buildings rely on concrete and reinforced steel. Improved building energy efficiency is

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[13] Which belongs to the family of stock dynamics models (Müller 2006).

[14] Main driving parameters and assumptions concerning them:

- population: growing in urban areas until 2030, then stabilising or slowly decreasing; stable in rural areas, then decreasing from 2015.
- per capita floor area: increasing until 2050 in both urban and rural areas; growth rate slowing down past 2030; remains higher in rural than in urban areas.
- lifespan of residential buildings: increasing until 2050 in both urban and rural areas; remains higher in urban than in rural areas.

[15] The model uses a simplified building typology that distinguishes between brick-concrete (3 storeys or less), concrete frame (4-8 storeys), and shearing-force structures (higher dwellings) (Yang and Kohler 2008, Hu et al. 2010), further differentiated into reference buildings, low energy buildings, ultra-low energy buildings, and plus energy buildings.

[16] The structural and finishing materials considered here (and aggregated in the diagrams) are: concrete, steel, bricks, tiles, glass, PVC, and insulation materials.

assumed not to affect the amount of structural materials required per square metre. However, with the growth of energy efficiency in the construction sector, it is expected that the levels of inputs of finishing materials such as glass (improved glazing) and insulation materials (negligible in reference buildings, increasing from 2% to 5% by mass for the other types) will rise. The amount of materials required per square metre, therefore, varies between about 1.7 tonnes (medium-size reference building) and 2.5 tonnes (high-rise plus energy building).

Under the ELCS assumptions, a general downward trend can be observed for construction activity in the coming decade in both urban and rural housing systems before an upward oscillation kicks in for a short period. After 2025, construction activity takes on a declining (rural) or somewhat stabilising (urban) path again. These variations logically emerge from past trends: buildings from the construction booms in the 1980s and 1990s had a life expectancy of less than 20 years (rural) to about 35 years (urban). The intermediary peak that can be observed in the input flows of material construction occurs when the demand for replacement kicks in. After this, the stabilising population levels (urban), or decreasing population levels (rural), slow down building stock expansion (urban) or initiate its reduction (rural).

The development of demolition activity presented on the right hand side of the diagram depends mainly on "life expectancy"[17] assumptions of existing and future buildings. Demolition levels will rise in urban areas until 2050, while in rural areas they are already at their highest and will start steadily decreasing at the end of the coming decade. It should, however, be recognised that although the absolute volume of demolition waste in rural areas is decreasing, it will remain at a significant level. For the next decade it will be around 12 Mt yearly, higher than the demolition waste level in urban areas at its highest in 2050 (10 Mt). After three decades of decrease, demolition waste in rural areas in 2050 will still be higher (5 Mt) than in urban areas today (2 Mt). This projection can help raise awareness of the need for waste management and illustrates that further research into the potential for recycling part of that waste flow is necessary.[18]

It is apparent that in 2050 (under the ELCS assumptions) the urban building stock will reach

[17] Represented with a normal probability distribution characterised by its mean and standard deviation. A 30 year mean life expectancy (or lifetime) means that the building has a 50% chance of being demolished before that age. The probability of being demolished is low for "young" buildings and is highest around the average life expectancy.

[18] In particular, a more detailed breakdown of the types of construction materials would be required to evaluate the recycling potential and re-use in urban buildings, which may use different materials.

a quasi steady state with regards to material flows: 11 million tonnes input against 10 million tonnes of demolition waste. By that time, the material stock in urban residential buildings will have increased by about 70% compared to 2010 (from 288 Mt to 488 Mt). This is the result of an increasing urban population with growing living space requirements. Simultaneously, the amount of materials trapped in rural residential buildings will decrease by almost half (from 309 Mt to 152 Mt): the diminishing rural population more than makes up for the increase in per-capital floor area (PCFA) and material intensity.

These future developments in both rural and urban building stocks until 2050 in Wuxi will create, cumulatively, over 680 million tonnes of demolition waste and the input of over 750 million tonnes of construction materials which, in turn, will be indirectly responsible for the extraction of about 515 million tonnes of additional abiotic materials (ecological rucksack).

This illustrates that the environmental pressures from the demand for construction materials and disposal of building waste are deeply significant in the ELCS. China has the largest building stock in the world, and it is still growing (Yang and Kohler 2008). And Wuxi is a part of it.

Finally, an important link between the two key sectors (residential buildings and energy) deserves to be analysed. The middle section of Figure 29: shows that the steadily improving building energy efficiency in the ELCS would cumulatively create about 90 Mt more direct and indirect material requirements (for better glazing, more insulation etc.) than would have been needed if the building energy efficiency had not been improved. Simultaneously, the energy saved by the more energy efficient buildings would cumulatively represent about 43 Mt less direct and indirect material requirements. Overall the building energy efficiency strategy of the ELCS would, therefore, increase Wuxi's total material requirements by 47 Mt cumulatively over the period 2010-2050. To put this result into context, it should be remembered that the resource intensity of Wuxi's energy consumption (unit of resource use per unit of energy used) steadily decreases in the ELCS (see previous section), meaning that potential synergies between energy and resource savings are eroded. With an energy mix as in the CPS (heavily coal-based throughout the period 2010-2050), the additional material use from the construction of more energy efficient buildings and the material savings from energy savings would more or less offset each other.

Furthermore, resource efficiency strategies (beyond energy and emission oriented strategies) could push the result even further towards net material savings. Recycling demolition waste in order to reduce primary material inputs would be one such strategy (also called urban mining). Design and engineering strategies targeted at making the structure of buildings lighter (essentially using concrete, brick and steel inputs) would be another such strategy. It is, therefore, of utmost importance to analyse the breakdown of Wuxi's building sector in a detailed and comprehensive way. The model presented here provides the framework to do so.[19]

[19] Precise knowledge about what materials are actually in use in the construction sector in Wuxi, and in what quantities, could be greatly improved by surveying "Bill of Quantities" (Deng et al. 2010). Although submitting Bill of Quantities is required by the Code of Valuation with Bill of Quantity of Construction Works (GB50500-2008) issued by the Chinese Ministry of Construction, this kind of data is not yet collected in Wuxi.

Figure 28: Resource use in Wuxi's residential building sector under the ELCS conditions

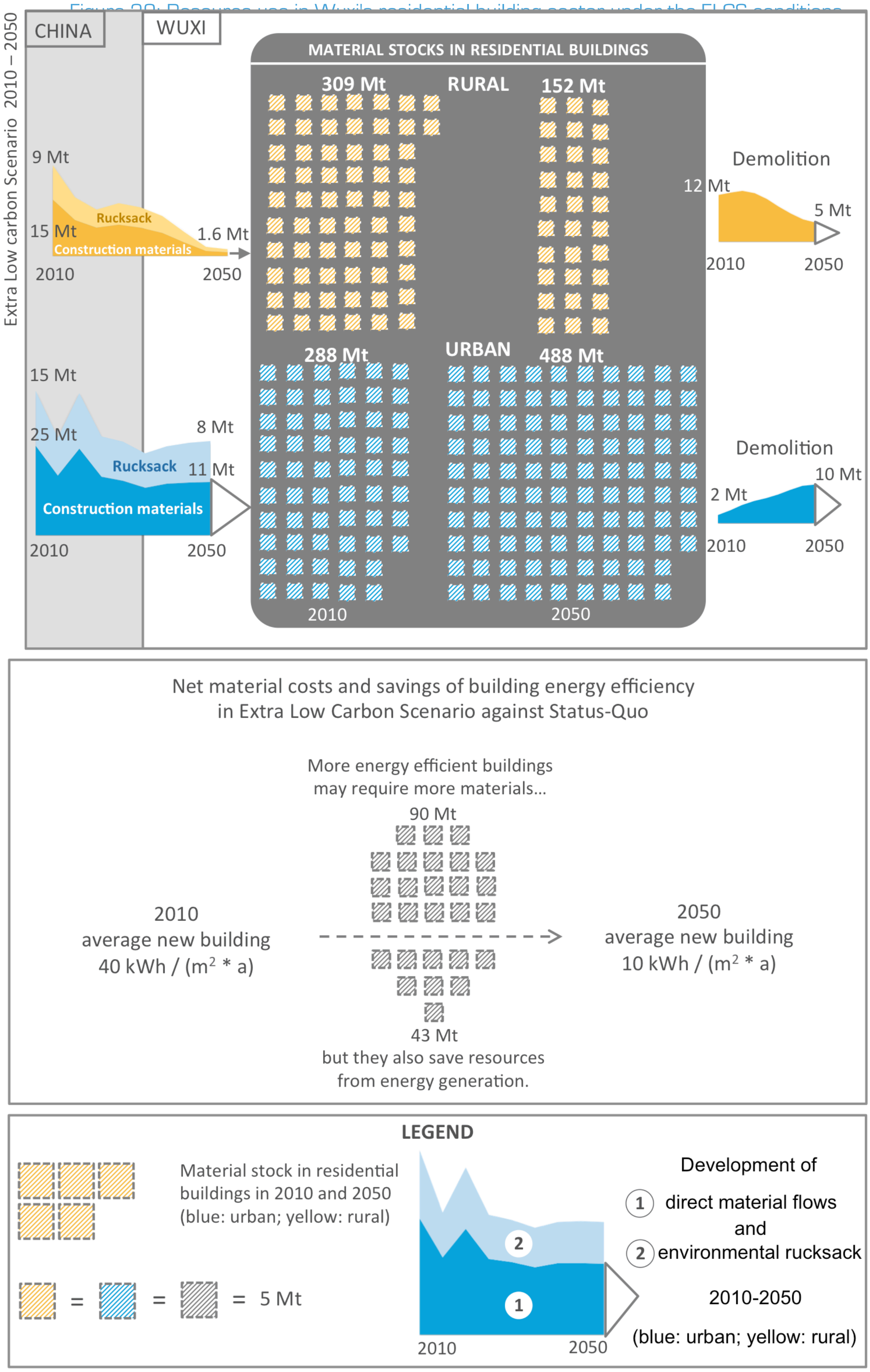


Table 6: Indicators of resource use in Wuxi's residential building sector under the ELCS conditions

KEY AGGREGATE INDICATORS: RESIDENTIAL BUILDINGS 2010-2050								
Indicators	**Absolute flows [million tonnes]**			**Intensities [t / cap]**			**Change [%]**	
	2010	**2030**	**2050**	**2010**	**2030**	**2050**	**2010-2030**	**2010-2050**
DMI new	32	18	12	5.1	2.8	2.0	-44%	-63%
TMR new	52	31	21	8.2	4.7	3.6	-40%	-60%
Demolition	14	18	15	2.2	2.7	2.6	+24%	+7%
Stock	588	686	643	91.8	104.1	109.5	+17%	+9%

DMI new = Direct Material Input for new buildings; TMR new = Total Material Requirement of new buildings; Demolition = Materials from demolition; Stock = Materials trapped in building stock

5 Implications of the low carbon scenarios for adaptation to climate change

The goal of the LCFC research project is to design an integrated low carbon strategy. Integrated means that in addition to the mitigation perspective and the resource check of the mitigation technologies employed in both the low carbon scenario pathways (as presented above), the interdependencies of both problem dimensions with adaptation to climate change should be demonstrated. A particularly pertinent focus for this analysis is the installation of air conditioning systems in the buildings sector. Introducing new and highly efficient technologies to the market will be indispensable for the construction industry. At the same time, the demand for air conditioning technologies is increasing due to rising average temperatures, a trend expected to continue in the coming years.

5.1 Discussion: Changes in climate and vulnerability aspects in Wuxi

As part of Work Package 2 (WP2) of the LCFC project, historic climate data was assessed to understand changes in Wuxi's local climate to the present day and to build long-term models of future climate change and its implications for the city's vulnerability to natural hazards (Gemmer, M., Fischer, T.; Tong, Jiang (2012). Changes in Climate Parameters and Vulnerability Aspects. Low Carbon Future Cities Report 4/2012. Wuppertal.). The decreasing number of observed and projected frosty and cold days, as well as the increased number of observed and projected warm spells and summer days, are relevant both with regard to mitigation and adaptation efforts in Wuxi. Whether or not adaptation options in the building sector counteract or support mitigation strategies depends greatly on the design of the measures. For example, the increased average temperature during summer leads to more air conditioning systems being installed and used, creating greater demand for electricity. In turn, heating demand in winter will decrease. Therefore, the observed and projected changes in heating and cooling degree days were calculated[20].

The annual number of heating degree days (HDD[21]) in Wuxi has decreased by approximately

[20] This is an addition to the climatological standards that are used in WP2 and the thresholds focus on the relation of electrical loads to climate. Heating degree days refer to the accumulated number of average daily degrees lower than the benchmark temperature (5°C for China) over a certain period (month, quarter or year). Cooling degree days refer to the accumulated number of average daily degrees higher than the benchmark temperature (26°C or 28°C for China) over a certain period (month, quarter or year).

[21] For a definition on heating and cooling days see: Gemmer, M., Fischer, T.; Tong, Jiang (2012). Changes in Climate Parameters and Vulnerability Aspects. Low Carbon Future Cities Report 4/2012. Wuppertal

20 between 1961 and 2009. This trend is projected to further continue in the future. By 2050, HDDs are expected to decline by a further 11 days and in 90 years' time the prediction is that there will be less than 15 HDDs.

The number of annual cooling degree days (CDD) has increased by about 10 during the observed period for the 26°C standard (e.g. for particular types of buildings such as hospitals, children's nurseries etc.). The number of CDDs per year is projected to increase by about 20 by 2050.

5.2 Climate change and urban environment

Although a decrease in heating requirements during the winter season has been observed and forecast, the increase in summer heat waves is greater and this augments the cooling energy demand. The overall consumption of primary energy in China is higher in summer than in winter. The peak energy demand will further increase due to continuing urbanisation (causing more air conditioning units to be installed) and higher standards of living (increasing the density of air conditioning units). This rising standard of living leads to a greater demand for cooling energy. In the case of Wuxi, cooling is mainly provided by mechanical air conditioning devices.

An adapted and sustainable urban environment should make use of well-designed green and blue spaces for cooling, water storage capacity and infiltration of rainfall. Poorly adapted cities that are not designed to cope with hotter, drier summers will witness a further increase in the use of mechanical air conditioning. This not only reinforces climate change (through increasing GHG emissions due to electricity consumption), but also has social implications. Planners, developers, urban designers and architects must consider the potential conflict between adaptation and mitigation responses in order to ensure the sustainability of future communities (Shaw et al., 2007). While mechanical air conditioning is an obvious way to guarantee thermal comfort during hotter summers, this solution contributes excess heat to the surrounding air, significantly increases energy demand and compromises GHG reduction targets. Emerging best practices are to reduce the cooling load as far as possible by using passive solutions and applying the best mechanical solutions available. This is done by using the option that best fits the other design objectives to meet any remaining cooling requirement.

5.3 Current and future use of air conditioning in Wuxi - impacts and potential pathways

In this section, the current use of air conditioning for heating and cooling (baseline 2010) and projected energy demand and costs for electrical energy use of air conditioning systems

(2010-2050) are analysed. The increase in energy demand for air conditioning use is mostly due to an increase in urban households (urbanisation) and higher standards of living. Higher costs occur for summer cooling as a result of hotter summers. Costs can potentially be decreased via the implementation of various low carbon measures, such as the introduction of energy efficient air conditioning devices, adaptation to heat waves, and investment in research and development (R&D) of new technologies.

In 2004, a mandatory energy efficiency standard in air conditioning was introduced in China. Since then, regular revision and upgrading of the energy efficiency limit values, energy efficiency ratings and energy saving evaluation values has been encouraged. A number of technologies offer opportunities to significantly reduce the power and energy use of air conditioning devices. The performance of heat pump systems (i.e. air conditioning units) has improved over time to achieve better overall system integration and performance. The efficiency of a heat pump depends on the technical specifications of the heat pump and whether the heat pump is operating at full load or not.

Adaptation to heat waves is possible (e.g. green roofs, insulation, urban planning for near-surface air exchange). A number of structural solutions offer effective means of managing heat risks and reducing thermal discomfort such as planting, shading and advanced glazing systems to reduce solar heat gain and air conditioning demand (EEA, 2012; Kazmierczak and Carter, 2010). These can include:

- Materials to prevent penetration of heat, including use of cool building materials and green roofs and walls.
- Innovative use of water for cooling, including ground water cooling using aquifers or surface water.
- Urban planning and zoning regulations to exploit the role of natural wind patterns and dense vegetation in reducing problems of overheating and air pollution.
- Mechanical cooling, including chilled beams and conventional air conditioning systems.
- Increasing ventilation and heat removal using fresh air (only effective when outside air is cool).
- Use of thermal storage or mass to absorb heat during hot periods so that it can dissipate in cooler periods, usually using ventilation. Ground coupled systems make use of thermal storage in the ground.
- Development and implementation of adaptation strategy such as investment in parks and urban forests.

For example, the installation of green roofs results in the reduction of CO_2 emissions, and also lowers energy costs associated with the cooling and heating of buildings. A simulation by the

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), conducted for the green roof on the city hall of Chicago, showed that every one degree Fahrenheit decrease in ambient air temperature within the building results in a 1.2% drop in cooling energy use. The study suggests that if, over a period of ten years or more, all of the buildings in Chicago were retrofitted with green roofs, (30% of the total land area), this would yield savings of $100 million annually from reduced cooling load requirements in all of the buildings in Chicago (Kazmierczak and Carter, 2010).

The main options for R&D to respond to the increased demand for air conditioning in a highly energy-efficient way are given here (based on Ecologic Institute, 2010; and IEA, 2010):

- Optimising component integration as well as improving heat pump design and installations for specific applications, including the reduction of costs and increase in reliability and performance.
- Developing intelligent control strategies to adapt operation to variable loads and optimise annual performance, as well as automatic fault detection and diagnostic tools.
- Developing integrated heat pump systems that combine multiple functions (e.g. space conditioning and water heating), offering significant potential and resulting in very high efficiency/low carbon systems.
- Prioritising absorption cooling (which allows the use of excess heat from other processes) over compression cooling (which mainly uses electric energy).
- Using district cooling instead of local cooling. The absorption chilling systems are powered by excess heat from combined heat and power (CHP) plants, or use heat from waste incineration.

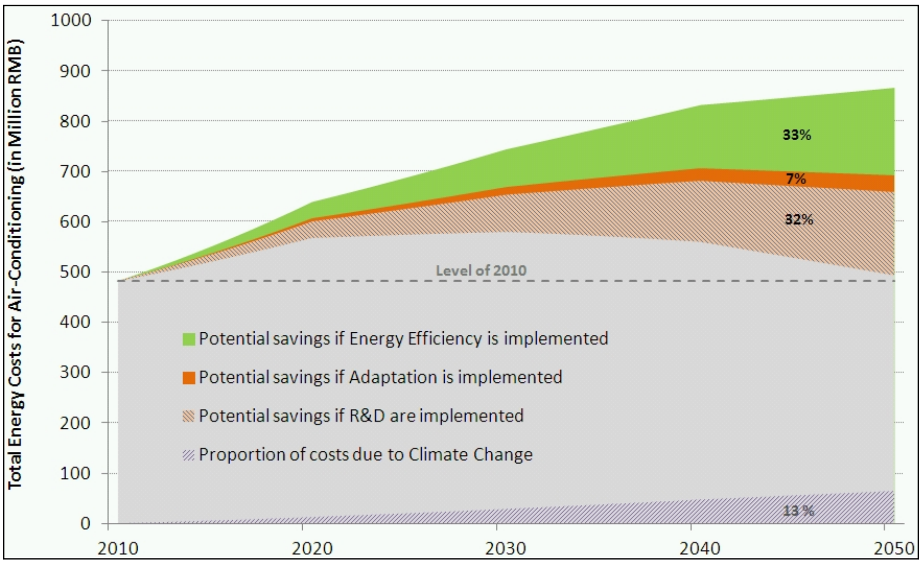
It should be emphasised that the technologies listed above are only applicable and efficient under certain conditions. A basic requirement is that a district heating system based on CHP is in place. Application of absorption cooling is only warranted where there is a regular need for air conditioning (high base load), which is the case in Wuxi. The application of district cooling requires a certain density of buildings/connections and sufficient proximity to the supply station. This is a huge opportunity for Wuxi. Many of the new residential areas are built from scratch. In order to provide a climate change adaptation option that reduces GHG emissions, all of these requirements could be taken into consideration. In brief, efficient adaptation requires a structural change in the provision of cooling devices and installations.

5.4 Current and future use of air conditioning in Wuxi - cost analysis

A major issue in the instigation of climate change adaptation strategies is an analysis of the costs the city government would face when applying pathways of 'business as usual' versus ‘taking action now’ (Ecologic Institute, 2010). Figure 30 shows the results of the analysis for the projected costs of energy for air conditioning in Wuxi until 2050, including winter heating and summer cooling in both pathways. Based on the assumptions in Table 7, the total energy costs for air conditioning will increase from nearly 500 million RMB/year in 2010 to nearly 900 million RMB/year in 2050 if no measures are taken with regard to energy efficiency improvements, increasing urbanisation, climate change and adaptation[22].

About 13% of the increase in total energy costs for air conditioning can be attributed to climate change (mainly due to an increase in CDDs, see WP2). About 33% of the increase can be reduced by energy efficiency measures in mechanical air conditioning. The potential reduction of the average power demand of an air conditioning unit from 1,000W to 800W is based on an assumed improvement in China’s energy technologies with about 20% less electricity demand for appliances in 2050 (Grantham Institute, 2012). Around 7% of the increase in total energy costs of air conditioning can be covered by adaptation measures such as green roofs and green aeration corridors (see above). A further 32% can be potentially reduced by significant investment in R&D for processes enhancing heat pump design and new technologies in mechanical room air conditioning.

Figure 30: Projected annual costs of energy for air conditioning in Wuxi (2010 to 2050)



[22] It is assumed for the purposes of the calculation that the increase in electricity prices will be lower than inflation.

Table 7: Assumptions of the baseline (2010) and projected (2050) annual costs of energy consumption for air conditioning in Wuxi

Assumptions	Baseline (2010)	Projection (2050)
Increase in cooling degree days (CDD), based on linear regression > ***Climate Change***	76 days per year	96 days per year
Decrease in heating degree days (HDD), based on linear regression > ***Climate Change***	38 days per year	27 days per year
Population growth (i.e. households): first increase (2010-2030 to approx. 2.2 million) and later decrease (2030-2050)	1,950,000 total households	2,000,000 total households
Urbanisation: increase in urban households	1,150,000 households	1,650,000 households
Standard of Living: increase in number of air conditioning units per urban household	2 units per household	3 units per household
Standard of Living: increase in number of air conditioning units per rural household	1.4 units per household	2 units per household
Stable electricity price* for kilowatts/hour	0.5 RMB per hour	0.5 RMB per hour
Stable hourly use of air conditioning systems	2.5 hours per HDD/CDD	2.5 hours per HDD/CDD
Energy Efficiency: improvement in power demand of air conditioning units	1000 Watts per unit	800 Watts per unit
Adaptation: linear decrease in annual energy consumption	0 % of annual energy consumption	5 % of annual energy consumption
R&D: Future improvement/optimisation of technologies for energy efficiency and adaptation	1000 Watts per unit	600 Watts per unit

*considering inflation rate and CPI

5.5 Current and future use of air conditioning in Wuxi - conclusions

Overall, if all measures including energy efficiency, adaptation and R&D are stringently implemented until 2050, the annual costs for energy for air conditioning can be maintained at 2010 levels although urbanisation, increasing standards of living, and climate change will put additional stress on this sector. It must be highlighted that energy efficiency measures will contribute more to energy savings than adaptation measures will; however, the adaptation path must also be targeted in the LCFC approach and adaptation can be regarded as "highhanging fruits”. Additionally, climate change will contribute to only 13% of the theoretical increase in energy demand (including summer cooling and winter heating) in the period up to 2050, with a successive steady increase. However, it should also be emphasised that the calculation that leads to this conclusion is only a rough estimate. Nonetheless, it can be concluded that structural changes such as urbanisation and increasing standards of living are the main factors for energy demand in the use of air conditioning in Wuxi. Both factors can be tackled by enforcing energy efficiency, adaptation technologies and increasing R&D investments.

6 Drivers for the LCFC roadmap

The modelling of the LCTS and the ELCS illustrates how climate-friendly development could be pursued in the city of Wuxi. These quantitative modelling results can be used as drivers for the development of an integrated roadmap and strategy for facilitating low carbon development in Wuxi.

The starting point for such considerations should be the availability of suitable mitigation technologies. The scenarios have demonstrated at what time and to what extent the different technologies should be implemented in order to achieve CO_2 mitigation in the different sectors. As a second step, it is necessary to identify policy instruments, which are necessary to ensure the successful implementation of the technology.

The following three tables again represent the key technologies of the two low carbon scenarios (LCTS and ELCS). The tables are differentiated according to the availability of the technologies and/or the time they have to be implemented. This makes it possible to select suitable policy instruments for certain periods of time.

The selected time intervals are “instantly available”, “implementation from 2020” and “implementation from 2030”.

6.1 Technological options for the short-term

Table 8: Technologies instantly available[23]

Sector	Technology	Development in modelled period of time	Relevance of technology in the specific sector	Key technology?
Households	Efficient air conditioning systems	Refurbishment of stock, new acquisition only at highest efficiency standards	Medium	
Generation	Photovoltaic	350 MW, until 2030 1500 MW, until 2040 1800 MW	Medium	Yes
	Natural gas plants	Installation of additional capacity and substitution of coal plants (17 GW in 2050)	High	Yes
	Combined cycle power plants (natural gas)	Additional capacities and replacement of coal (peak: 9 GW 2034-2041; 2050: 5 GW)	High	Yes
Industry	Usage of granulated cinder ("Hüttensand") as a substitute for Portland cement	Existing potentials are used, potentials declining due to shrinking oxygen steel production	High	Yes
	Heat-recovery	Conversion of existing manufacturing plants; if economically viable consideration of new construction	High	Yes
	Efficient pumps		High	Yes
	Industry-CHCP	Until 2050 increase capacity (8 times) up to 7.7 GW	Medium	Yes
	Micro-CHCP in tertiary industry		Low	

[23] Selection of technologies is described in chapter 2

	Retro-fitting of membrane processes at existing production plants; at a later stage, replacement of old production units with new plants operating with oxygen consumption cathode technology	Conversion instantly, new construction from 2030	High	Yes
	Direct iron reduction for steel production based on natural gas	Stabilising share (today about 50%)	High	Yes
Tertiary industry	Efficient air conditioning systems	Refurbishment of stock, new acquisition only at highest efficiency standards	Medium	

Derived hypotheses as short-term starting points for a LCFC roadmap:

- A lot of technological measures can be implemented instantly and should be supported by adjoining policy strategies in the short-term.
- In the short-term, air conditioning systems in buildings currently offer the only possibility to implement effective technological measures in the household sector.
- In the short-term, the focus of the roadmap should be on the development of efficiency potential and the use of renewable energy sources in power generation.
- Another short-term approach is the process improvements in selected key industrial sectors.

6.2 Technological options for the mid-term

Table 9: Technologies to be implemented from 2020[24]

Sector	Technology	Development in modelled period of time	Relevance of technology in the specific sector	Key technology?
Households	Highly efficient household appliances	Consequent new acquisition of best available technologies	High	Yes
	Ultra-low and plus energy buildings	Increasing market shares (only new buildings!): 44% in 2030; 100% in 2050	High	Yes
Generation	Wind power (6MW)	Until 2035 increase up to 330 MW in agricultural areas	Low	
	Biomass-gasification of waste	Until 2030 installation of infrastructure	Low	
Industry	Designing new blast furnaces as "CCS ready"; later: retrofit of blast furnace with top gas recycling/CCS	2000 kt production capacity	High	Yes
	BAT for new or replacement investments in manufacturing plants		High	Yes
	Increased use of scrap steel (recycling) in electric arc furnaces	Increase of share to 65% in 2050	High	Yes
	Lower cement production in Wuxi compared to CPS and LCTS (lower local demand and lower exports)	2043: -45%; 2050: -80% compared to CPS and LCTS	High	
Transport	Electric vehicles	From 2030 PHEV and BEV, 60% market share in 2050; 30% of stock	High	Yes

Derived hypotheses as mid-term starting points for a LCFC roadmap:

- From 2020, mitigation through energy efficient optimisation of buildings becomes more important.
- To boost the development of renewable energies, it will be necessary to develop

[24] Selection of technologies is described in chapter 2

additional potential in the field of wind energy. The general importance of wind energy in overall power generation remains relatively small.

- Process optimisation in the selected industrial key sectors remains highly significant.
- From 2020, electric mobility provides a technological possibility for the transport sector to contribute to reducing CO_2 emissions. The strategic support of technology diffusion in the context of the roadmap must ensure that electric mobility meets sustainability criteria.

6.3 Technological options for the long-term

Table 10: Technologies to be implemented from 2030[25]

Sector	Technology	Year	Development in modelled period of time	Relevance of technology in the specific sector	Key technology
Generation	Import of renewable electricity	2033	Increase to 73 TWh in 2050, share of 60% in electricity supply	Very High	Yes
Industry	Phasing out of ammonia production in Wuxi (moving to areas with "cheap" renewable H2)	2039	2048: production capacity 0 kt compared to 520 kt (LCTS)	Medium	
	Iron ore production via smelt reduction and CCS	2047	17% share in steel production	High	Yes

Derived hypotheses as long-term starting points for a LCFC roadmap:

- The local potential for renewable energy in the long-term will not be sufficient to achieve the desired low carbon development in Wuxi. Importing renewable energy will be highly important in the long term.
- The industry sector will remain a hotspot for CO_2 mitigation in Wuxi. The industry sector will remain the main driver of CO_2 emissions and therefore there is a need for long-term approaches to increase efficiency in the industrial processes of the identified key sectors.

[25] Selection of technologies is described in chapter 2

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