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On track to become a low carbon future city? - First findings from the pilot city of Wuxi

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Abstract: The Low Carbon Future Cities (LCFC) project aims at tapping three-dimensional challenge and to develop an integrated city roadmap, balancing low carbon development, gains in resource efficiency and adaptation to climate change. The paper gives an overview of first outcomes of the analysis of the status quo and assessment of the most likely developments regarding GHG emissions, climate impacts and resource use in Wuxi, the Chinese pilot city of the LCFC project. An emission inventory for Wuxi was developed, which helped to identify key sectors. Next to that the future development of energy demand and related CO_2 emissions in 2030 were simulated in a current policy scenario (CPS). Selected aspects of material and water flows were analysed and modelled for energy and the building sector. In addition, recent and future climate impacts and vulnerability were investigated. Although Wuxi's government started a path to implement a low carbon plan, the first results show that more ambitious efforts are needed to overcome the challenges faced.

Keywords: Low Carbon Future Cities; low carbon city strategies; China; Wuxi; low carbon scenario; circular economy; adaptation; mitigation

1. Introduction

Cities have always been hot spots of innovations, but since the beginning of the industrialization they also face severe environmental impacts due to the high concentration of industries, population and infrastructures. Today and in the coming decades, cities can also be seen as hot spots of greenhouse gas emissions, being most severely exposed to the impacts of climate change [1]. This is particular true for cities in developing regions, where the urbanisation rate and number of industries is increasing at a high pace. According to UN Habitat [1] about 40 % to 78 % of global greenhouse gas emissions are estimated to originate in urban areas.

Therefore, low carbon city strategies and concepts implicate large greenhouse gas (GHG) mitigation potentials. At the same time, with high population and infrastructure densities as well as concentrated economic activities, cities are particularly vulnerable to the impacts of climate change and need to adapt. Scarce natural resources further constrain the leeway for long-term, sustainable urban development.

This paper presents outcomes of the Sino-German Low Carbon Future Cities (LCFC) project. Aim of the project is to develop an integrated urban low carbon, adaptation and circular economy strategy to address the large mitigation potential in urban areas by and through engaging cities and stakeholders in both China and Germany in an integrative approach. The study focuses on two pilot regions - one in China (Wuxi) and one in Germany (Düsseldorf+) - and is conducted by a German-Chinese research team supported by the German Stiftung Mercator.

The pilot city Wuxi is located in the east of China on the lower Yangtze River. It has a population of about six million. Wuxi's economy has witnessed a considerable increase in recent years. The overall GDP was CNY 575.8 billion (EUR 64.3 billion) in 2010, double that of 2005 and with an average annual growth rate of 14% (2006-2010). All these achievements make Wuxi's comprehensive strength and competitiveness rank high among large and medium cities in China.

In this study, results of a core work phase are summarized. Purpose of the presented study within the LCFC project was the analysis of the status quo and the assessment of the most likely future development for the city of Wuxi taking into account three project dimensions:

- Greenhouse gas emissions and related mitigation potentials;
- Vulnerability to climate change and adaptation options as well as
- Material and resource uses

The outcomes of this study form the scientific basis for the Low Carbon Future City strategy to be developed in later working steps.

The study was divided into five main working areas. The emission inventory gives an overview on the present relevant GHG emissions. It follows the IPCC-guidelines and uses data of the Wuxi statistical yearbook (WMBS) [2]. The results are basis for the key sector identification. The vulnerability to climate change in Wuxi was assessed by analysing recent climatic changes and projecting expected changes in temperature and precipitation in the coming four decades. The future development of energy demand and related CO_2 emissions in 2030 were simulated in the current policy scenario. This modelling approach uses five different sub-models and implies Wuxi's low carbon targets. Selected aspects of Wuxi's current material and water flows in the energy transformation sector and the buildings sector were investigated and modelled. After shortly describing the applied methodologies, the paper summarizes the results and provides first conclusions for decision-makers as well as for further research needs.

2. Methods

For each project area – vulnerability to climate change; status quo and projection of greenhouse gas emissions as well as analysis of resource use & material flow in selected sectors – different groups of experts have been involved, applying the most suitable models and methodologies for the analysis of their research questions within the study. A short description of the used methodology is given in the sub-sections below. Basis for this paper are detailed calculations and background reports, which have so far not been published [3].

2.1 GHG emissions – Inventory and future model

2.1.1 GHG Inventory

Present CO_2 emissions and possibly other GHG emissions have been quantified in an emission inventory for the Wuxi territory. Based on these figures and other criteria, the most important sectors for low carbon city development in Wuxi have been identified to focus the in-depth study and measures on.

A greenhouse gas inventory accounts for the amount of greenhouse gases emitted to or removed from the atmosphere due to human activities over a specific period of time.

Quantification of greenhouse gas emissions for inclusion in an inventory is a multi-step process, which includes: (a) The identification of all anthropogenic greenhouse gas sources and sinks; (b) The selection of measurement, calculation or estimation approaches; (c) The selection and collection of activity data; (d) The selection or development of greenhouse gas emissions or removal factors; (e) The application of calculation methodologies to quantify greenhouse gas emissions and / or removals [4].

In this study, the inventory methodology outlined in the 2006 IPCC guidelines on GHG inventories [5] was followed in a simplified and adapted manner. The study focused on CO_2 emissions; only to a lesser extent other GHGs have been considered, depending on available data.

The inventory is largely based on Wuxi's statistical yearbook [2] and information and data provided by Chinese project partners, especially the Wuxi Low Carbon Development and Research Centre (WLCC) and Wuxi city government.

2.1.2 Current policy scenario

The Current Policy Scenario (CPS) shows the development of energy demand and energy related CO_2 emissions in Wuxi until 2050. The scenario has considered today's (2011) political framework (based on "Wuxi Low Carbon City Development Plan") and a set of assumptions about the development of the city's society, economy and infrastructure. For the future economic development, in parts estimations of the NDRC Energy Research Institute (ERI) on the development of the outputs of major industrial products in China have been considered [6].

The CPS was developed by using a complex simulation modelling approach. This approach can be described as a model framework, consisting of one core model and five sub-models. The core model named Wuxi CESS Model (CESS= City Energy System Simulation) is an energy system simulation model and has been developed by the Wuppertal Institute (WI). The Wuxi CESS Model's database is linked to five sub-models (Industry, Buildings, Household appliances, Service Sector, Transport and Power & Heat sub-model). They provide activity data, market shares and mean efficiencies of technologies. The industry sub-model as one of the five sub-models is part of an independent econometric energy system model developed by China Environment Research (CER), which comprises the whole energy system of Wuxi (except the transport sector). The building sub-model has been developed by experts of the Research Centre for International Environmental Policy (RCIEP) at the Tsinghua University in Beijing.

All sub-models have been designed as disaggregated technology-based simulation models to account for the use of low carbon (LC) technologies, which is intended to be part of forthcoming low carbon scenarios for Wuxi.

2.2 Vulnerability to climate change & adaptation aspects

The vulnerability to climate change in Wuxi was assessed by analysing recent climatic changes and by projecting expected changes in temperature and precipitation for this century. Special attention has been devoted to water-related risks and possible economic losses. Based on these findings, sectors, which are particularly vulnerable to climatic changes, have been identified.

The National Climate Center (NCC) of the China Meteorological Administration (CMA) conducted this assessment. They used the most comprehensive set of climate data available for Wuxi in order to analyse observed and projected changes in climatic parameters that are relevant to the identified weather and climate hazards. Daily climate parameters for seven meteorological stations in Wuxi were used in order to identify and describe changes for the period from 1961 to 2009 [7]. Suitable climate change indices, which primarily focus on extreme events, have been developed. The same parameters were used for climate projections until 2100. These have been based on an ensemble of three General Circulation Models (GCMs): ECHAM5/MPI-OM (General Circulation Model European Center Hamburg/Max Planck Institute-Ocean Model, 5th generation of the model version) [8], CSIRO-MK3.5 (3rd generation of the Commonwealth Scientific and Industrial Research Organisation Climate Model Mark 3.5) [9], and NCAR CCSM3 (National Center for Atmospheric Research Community Climate System Model version 3).

2.3 Resource utilization

Selected aspects of resource use and flows in Wuxi, which are relevant for its low carbon development strategy, have been investigated and modelled. The system boundaries for a complete assessment of Wuxi's resource efficiency ought to be those between Wuxi's technosphere (the socioeconomic system within the geographical boundaries) and the ecosphere (the natural environment worldwide). In terms of flows, it means that all natural resource inputs (direct or indirect, economically used or unused, domestic or foreign) that are activated by human activities in Wuxi - including through trade - have to be accounted for.

Mainly two methods taken from a wider material flow analysis (MFA) toolbox were applied: Material Input per unit of Service (MIPS) and Economy-wide material flow analysis (EW-MFA). The first one, MIPS, focuses on the input side of the life cycle inventory of a studied product or process and accounts for economically non-valued resource extraction [10, 11]. The latter method EW-MFA covers all material flows of the studied region.

It was beyond the scope of the study to consider resource use of Wuxi's entire socio-economic system. Thus, the analysis concentrated on selected sectors that: a) have high relevance for the resource intensity and absolute resource use today; b) had been identified as potential key sectors based on the GHG inventory; c) shall be targeted by mitigation and adaptation measures drafted in further work of the low carbon future city project.

The two selected key sectors that fulfilled these criteria were the "electricity and heat production sector (energy industry sector 1A1a)" and the "construction sector (focussing on residential buildings)".

Especially the aspects of the material flow linked to the construction sector are of interest and, therefore, described in the results and discussion section.

2.4 Activity Data

Most important data source for this study was the Statistical Yearbook of Wuxi, of the Wuxi Municipal Bureau of Statistics [2]. Although the statistical yearbook provides extensive data, which is exceptional for a city level, the gap between data available and data required for the inventory and the projection models is still high. Especially for the industry sector only statistical data for "above-designed-size" industries were available.

"Above-designed-size enterprises" refer to those with an annual prime operating revenue exceeding CNY 5 million. From 2011, the "above-scale enterprises" will cover those with annual prime operating revenue bigger than CNY 20 million, which will reduce the available data and slightly increase uncertainty of the results. Moreover, in country statistics and in the city statistics (like the one of Wuxi), the processes within the industry and applied technologies are normally not reported. This fact is a global challenge for inventory reporting.

In addition to these aspects, the available statistical data itself always have uncertainties. A study that was recently undertaken by a group of scientists from China, Britain and the United States analysed different sets of Chinese statistical data. One set was based on nationwide data, the other on data from 30 provinces (for the years 1997 – 2010). The comparison showed that there are high differences between the data that could lead to a gap of up to 1.4 billion tons of CO_2 emissions (for 2010) between the datasets for the same area [12, 13].

The results presented in the following sections are based on the activity data available as well as on different models and methodologies, like calculation factors, simulation models. For each of the future models, specific assumptions for the conditions in the future had to be considered to be able to apply the models. This limits in fact the possible options for future development to these conditions, which is a simplification of the future prospects. So projections can always be seen as one theoretical possible future development, which will in fact never become reality in exactly the same way.

3. Results and discussion

3.1. Emission inventory

Main source for Wuxi's emissions is the combustion of raw coal, which is needed to meet the high demand for energy. Electricity and heat production are main sources of emissions, representing more than half of the current carbon dioxide emissions (39 million tons CO_2). The total CO_2 emissions of the energy, manufacturing industry and transport sectors (almost 72 million t CO_2 in 2009, as far as calculated; see Fig. 2) sum up to about a fourth of the corresponding CO_2 emissions of the industrial centre of Germany North Rhine-Westphalia or the total CO_2 emissions of the country Chile. In the manufacturing industries energy-intensive branches, like the iron and steel industry and the chemical industry, are currently most relevant for the total CO_2 emissions, but also other sectors have considerable emissions (see Fig. 1, Tab. 1 and section on key sectors). – Although it was intended to analyze and integrate all "Kyoto" greenhouse gases, the data availability did not allow for a complete calculation. Thus, for non-CO_2 emissions and non-energy related CO_2 emissions, qualitative assumptions or process descriptions have been given. As Wuxi is hosting several industries with potentially high process-related emissions, the current total emissions are higher than the figures calculated in the inventory. For agriculture only some exemplified sub-sectors have been calculated and no figures could be given for waste sector.

Thus, high improvement potentials are given for future inventory work. On the other hand it has to be stated that the data sources for Wuxi have already been very detailed compared to other cities around the world (also in comparison to European cities).

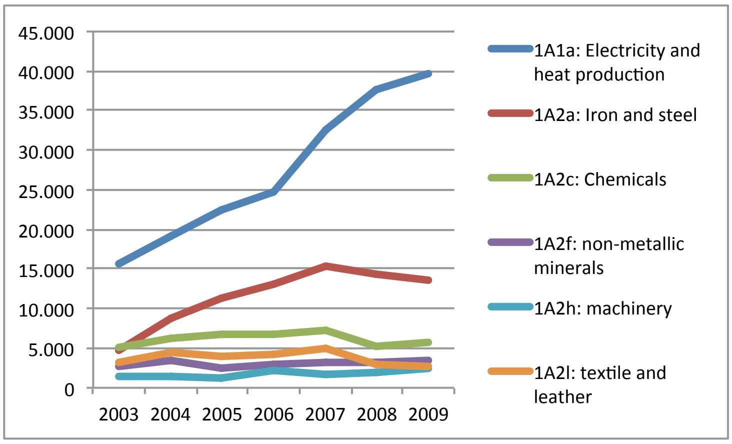

Figure 1. Development of CO_2 emissions (in kt; 2003 - 2009) of some relevant sectors in the Energy and Manufacturing industry (1A1 and 1A2) of Wuxi

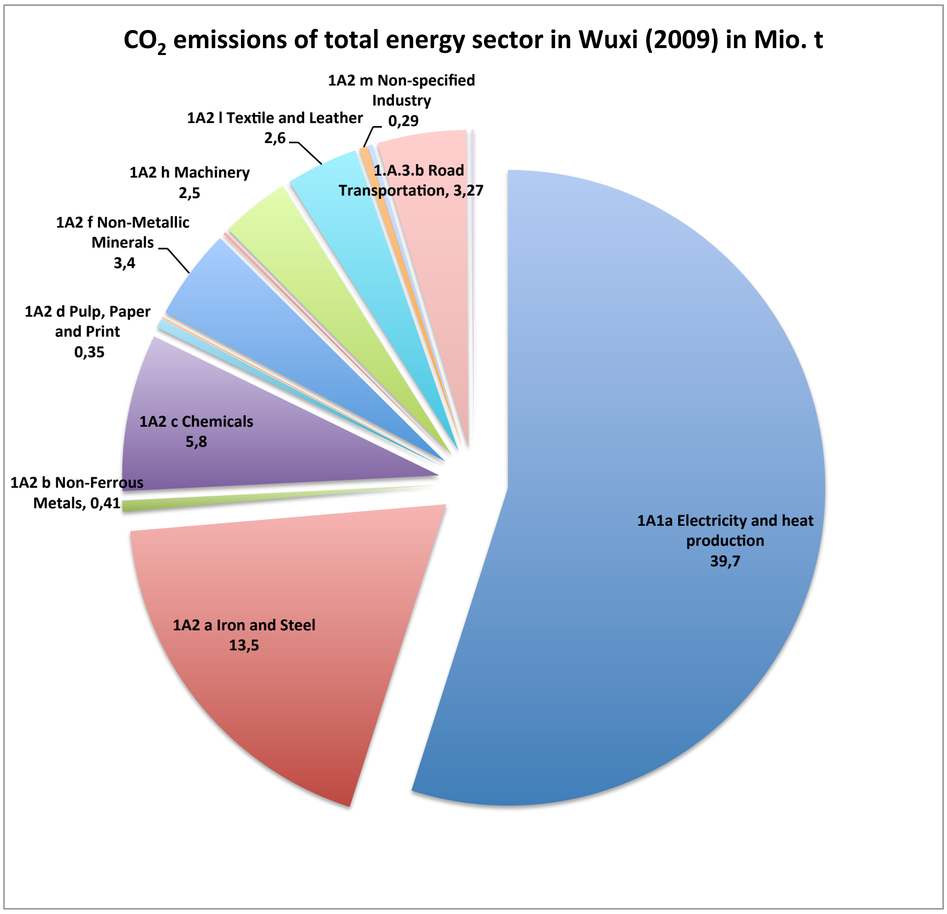

Figure 2. Total CO_2-emissions of Sector 1A, Energy (1A1-1A3), divided in sub-sectors (in Mio t CO_2)

3.2. Key sectors identified

The most relevant key sectors from the perspective of current greenhouse gas emissions have been identified, also taking into account the relevance for regional policies, vulnerability to climate change and future trends. Next to the dominant energy sector, representing the electricity and heat production, most of the key sectors are industry sectors, like iron and steel industry, chemical industry, non-metallic minerals (cement), as well as electric equipment and machinery manufacturing (see Tab. 1). Next to that, the construction sector is relevant due to the high material/resource uses and the increasing electricity needs for room cooling and heating purposes. This aspect also has relevance for adaptation needs due to increasing temperatures and living standards. Linked to them are also the highly increasing electricity needs in the residential sector and in the commercial (service) sector, which are also regarded as two relevant key sectors. The enormous increase of road transport, its related emissions, air pollution and the future infrastructural challenges, makes it as well a key sector to be considered for Wuxi's intended low carbon future development.

Table 1. Total GHG emissions of all IPCC sectors (calculation of CO_2, CH_4 and N_2O) in CO_2eq; Key sectors identified

IPCC Guidelines 2006 – Sectors (Summary of sectors)	CO_2 emissions	% of sector emissions	Other GHG emissions*	*Key sector (++ high; + middle)*
Total Emissions and Removals	**in Mio. t**		**in kt CO_2e**	
1 ENERGY	**72.4**			
1A1 Fuel Combustion Activities	**39.7**		**200.0**	
1A1a Electricity and heat prod.	**39.7**		**200.0**	**++**
1A1b Petroleum Refining	**NE**		**NE**	
1A1c Manufacture of Solid Fuels			**NE**	
1A2 Manufacturing Industries	**29.0**		**200.28**	
1A2 a Iron and Steel	**13.5**	46,7%	**91.5**	**++**
1A2 b Non-Ferrous Metals	**0.41**	1,4%	**2.5**	
1A2 c Chemicals	**5.8**	19,96%	**40.5**	**++**
1A2 d Pulp, Paper and Print	**0.35**	1,2%	**2.5**	
1A2 e Food Processing etc.	**0.07**	0,2%	**0.5**	
1A2 f Non-Metallic Minerals	**3.4**	11,6%	**23.6**	**++**
1A2 g Transport Equipment	**0.10**	0,3%	**0.5**	
1A2 h Machinery	**2.5**	8,7%	**17.2**	**++**
1A2 j Wood and Wood Products	**0.01**	0,03%	**0.05**	
1A2 k Construction	**NE/ND (!)**		**NE/ND (!)**	**++**
1A2 l Textile and Leather	**2.6**	9,1%	**19.4**	**+**
1A2 m Non-specified Industry	**0.29**	1,0%	**2.0**	
1A3 Transport	**3.5**			
1.A.3.a Civil Aviation	***(0.18)***	4,7%	NE	
1.A.3.b Road Transportation	**3.27**	93,2%	NE	**++**
1.A.3.d Water-borne Navigation	**0.08**	1%	NE	
1A4 Other Sectors				
1A4a Commercial/Institutional	**IE****			**++**
1A4b Residential (only NG & LPG)	**IE** (+0.22)**		**0.58**	**++**
2 INDUSTRIAL PROCESSES AND PRODUCT USE (non-energy)				
2A Mineral Industry	**NE/ND (!)**			**(++)**
2B Chemical Industry	**NE/ND (!)**		**NE/ND (!)**	**(+)**
2C Metal Industry	**NE/ND (!)**			**(++)**
2D Non-Energy Products from Fuels and Solvent Use	**NE/ND (!)**		**NE/ND (!)**	
2E Electronics Industry	**NE/ND (!)**		**NE/ND (!)**	**(?)**
2F Product Uses /Substitutes ODS	**NE/ND (!)**		**NE/ND (!)**	**(?)**
3 AFOLU (Agriculture, Forestry...)			**881,2**	**(?)**
3.A.1: Enteric Fermentation	**0,031**		**30,9**	
3.A.2: Manure Management	---		**2,3**	
3.B: Land (Rice cultivation)	---		**848,0**	
4 Waste	---		**NE/ND (!)**	**(?)**

"NE/ND (!)" not estimated due to not available data/factors; "NE" not estimated; "NO" not occurring in the specific; "—" not applicable; "IE" included elsewhere; (++) high relevance & key sector; (+) middle relevance; (?) possible relevance; * so far only CH4 & N2O; ** calculated for total consumption for information only; included in electricity production

3.3. Changes in climate parameters and vulnerability aspects

The vulnerability to climate change in Wuxi has been assessed by analysing recent climatic changes and by projecting expected changes. For the period from 1961 to 2009, data of seven meteorological stations in Wuxi have been used and the projections until 2100 were based on an ensemble of three General Circulation Models (GCMs).

The results show that in the last 50 years all temperatures increased. While the minimum temperature increased in almost all months, the increases in maximum temperature mainly occurred in summer and autumn. For the changes in precipitation, it can be summarized that April and September became drier and January became wetter.

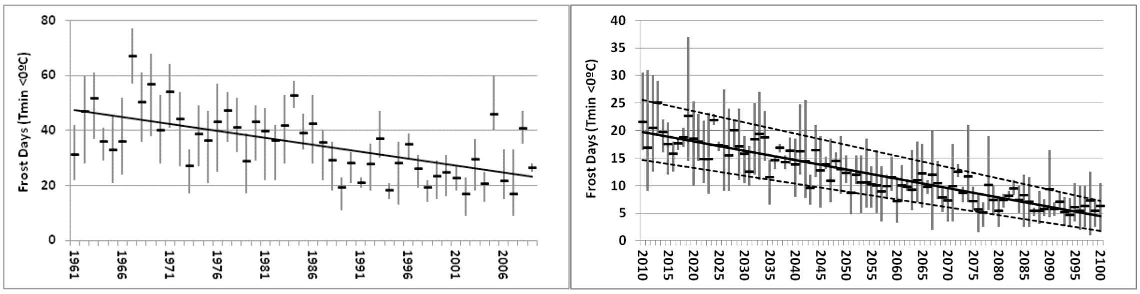

Figure 3: Annual number of frost days observed (left panel) and projected (right panel) for Wuxi.

In the future, the temperatures are projected to further increase in each month at least until 2099, whereas the increase in summer is lower than during winter. Heavy and very heavy rain days are projected to increase non-significantly. Highest changes in climatic parameters (both observed and projected) are detected for frost days (decreasing, see Fig. 3), summer days (increasing), warm spells (increasing, Fig. 4), and cold spells (decreasing). Water levels have not undergone trends and no changes in the water balance are expected for the coming decades.

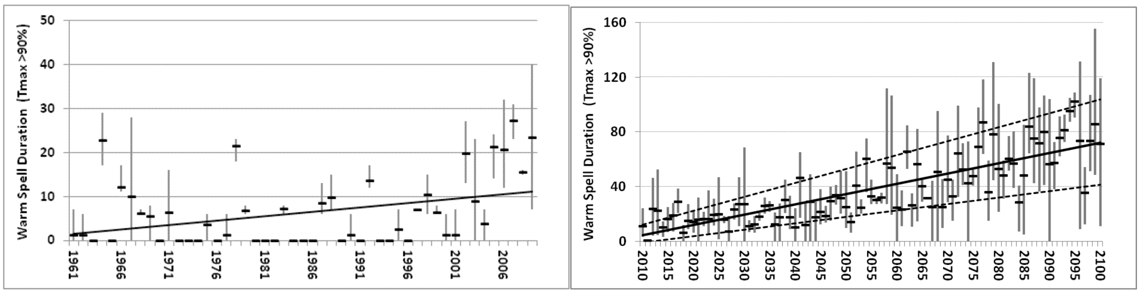

Figure 4: Annual warm spell duration observed (left panel) and projected (right panel) for Wuxi

For Wuxi's vulnerability (coping capacity * damage potential) it is presumed that the risk will increase due to higher damage potentials, especially for floods/rain and temperature. More details on the recent and future developments in Wuxi can be found in the background paper [7].

3.4. Resource Use

For the energy transformation and the residential building sector the current status quo as well as the future material and water flows have been analysed and modeled, combining two methods of material flow analysis.

For electricity and heat production not only the direct use of coal in Wuxi is relevant, but also the material used for the extraction, i.e. the ecological rucksack. A high share of the materials and water used are hidden behind the two sectors Wuxi, like the resources needed for the imported electricity. For 2009 the total material flow sums up to 60 million tons. Even more than 5 times higher is the associated water consumption (332 million tons). – These figures would significantly increase under the assumptions of the current policy scenario.

In 2005, Wuxi's residential buildings represented a stock of 464 million tons of materials. Further increasing population and living standards lead to an increasing building stock. At the same time, older buildings, which have far shorter "life expectancy" than European buildings, are demolished and replaced by bigger housings. – Thus, the related demand for construction materials and disposal of building waste also needs to be considered and will be highly significant in both, near- and long-term. More details on the resource use can be found in the comprehensive background report to the study (Dienst et al. 2012).

3.5. Current Policy Scenario (CPS)

The future development of energy demand and related CO_2 emissions in 2030 were simulated in the current policy scenario (CPS), using five different sub-models described in section 2.1.2. The assumptions have been made in accordance with Wuxi's Low Carbon Plan (set targets until 2020), while for the later decades national scenario values have been translated into a local CO_2 intensity reduction path.

The Wuxi government has committed itself to reduce the carbon intensity of the city's economy by 50% by 2020 compared to 2005. For the time after 2020 we assumed in the CPS that carbon intensity of industry will develop according to the whole economy's development in the baseline scenario of the ERI (Jiang. et al. 2008) study (2030:-65%; 2040:-70%; 2050:-75%).

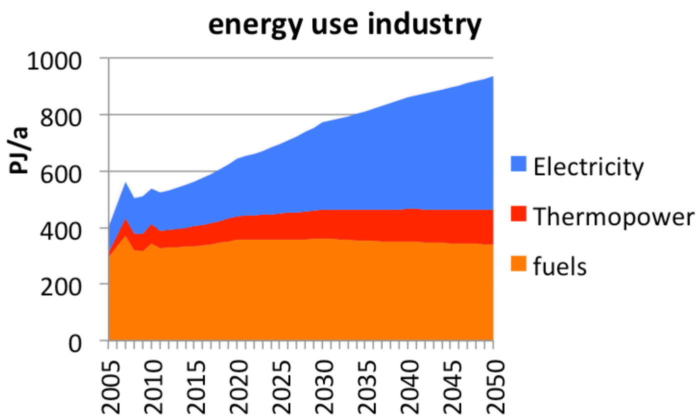

Figure 5: Energy carrier structure in Wuxi's industry 2005-2050
Source: Wuxi Statistical Yearbook, CER/WI (projection).

Mainly due to economic growth, the final energy demand in the CPS is expected to grow by 86% (2050 compared to 2009). In parallel, structural change is supposed to occur, thus non-energy intensive industries and the service sector would growing stronger than others. Nevertheless, energy intensive industry would still exist in Wuxi in 2050 and maintain their production, but with a lower share in GDP. Fig. 5 shows the final energy demand of industry, differentiated per energy carrier.

In our CPS there is only little advancement in industrial energy efficiency after 2020: However, the overall energy intensity of the sector is supposed to decline due to structural changes within industry and not due to an improvement of technical processes.

Due to the economic growth, an energy carrier shift to electricity and due to a phase-out of electricity imports, emissions from electricity generation would be of even more importance than today in the CPS. Total local electricity demand and production in Wuxi is shown in Fig. 6.

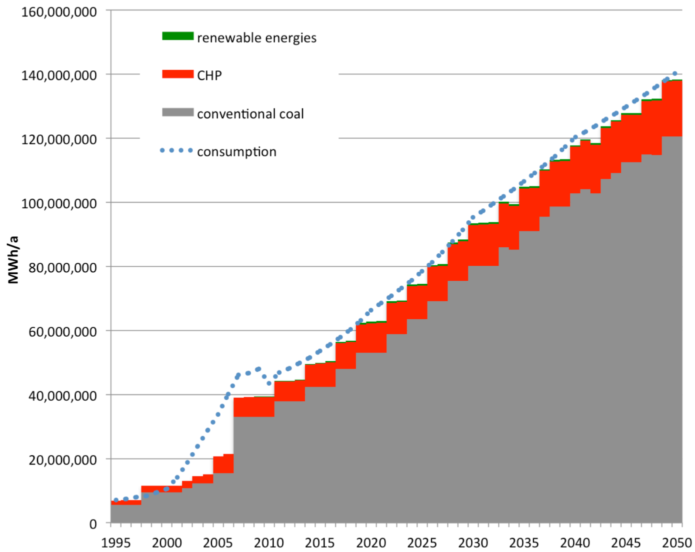

Figure 6: Electricity production and demand

Source: Wuxi Statistical Yearbook (WMBS), WI (projection).

Although in the scenario the intensity targets are supposed to be achieved, this would not lead to absolute emission reductions, as the projected growth would overcompensate the relative reduction. In the CPS the old energy intensive industries could even keep up their high emission levels while the new industries' additional demand for electricity would result in higher emissions of the power plants (Fig. 7).

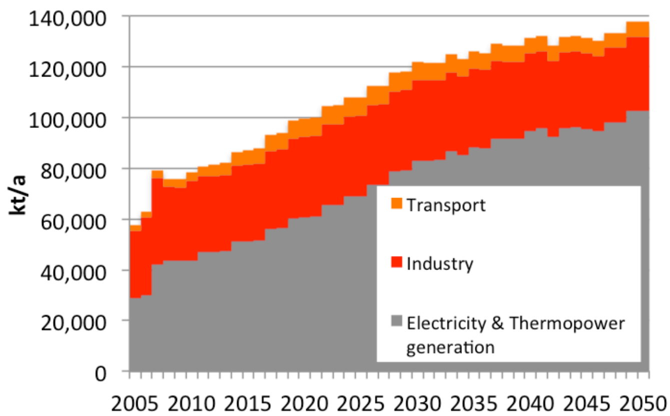

Figure 7: Total CO_2 emissions in the CPS

Source: Wuxi Statistical Yearbook (WMBS), WI (projection).

In the forthcoming work of LCFC project, Low Carbon Scenarios shall set more ambitious paths to reduce the emissions in Wuxi. Hence two further scenarios shall be developed: A "Low Carbon Technology Scenario" which is supposed to show an accelerated use of low carbon technologies especially after 2020 and an "Extra Low Carbon Scenario" which will be designed as a target scenario where ambitious climate protection targets are met by using non-technical measures and behavioural change additionally.

4. Conclusions

The picture we got from the analysis is impressive in a manifold manner. From a European perspective, the geographic boundaries and economic structure of Wuxi reach beyond "normal" city dimensions and so do the emissions. If Wuxi would be counted as a country, it would be among the first 50 countries with highest CO_2 emissions in the world.

Wuxi has several direct emission sources, especially in the industry sectors, which are almost "uncountable". Meaning that due to the high number of complex industry processes and limited data on these processes, mainly the direct carbon dioxide emissions could be quantified in the inventory, while for most of the other process-related emissions and so-called "Kyoto-gases" only some qualitative assessments could be given. – To be able to monitor the future GHG emissions (of direct emissions within the boundaries of Wuxi), not only the establishment of a regular inventory reporting is recommendable, it would be as well important to improve data quality and calculation methodologies according to local conditions. Especially for non-CO_2 sources, like waste disposal and agriculture, but also for process-related emissions, there is high improvement potential for data and methods.

To focus on the most relevant sources in the next project phases, we identified the most relevant key sectors, based on the current greenhouse gas emissions, also taking into account the relevance for regional policies, vulnerability to climate change and future trends. - A number of nine broad key sectors that cover more than 90% of Wuxi's CO_2 emissions have been pre-selected, almost all are in industry sectors. Purpose of the next phases of this project is to do an in-depth analysis of some of the main identified key sectors and propose technological options for GHG mitigation and policy measures. Based on these findings a low carbon roadmap shall be developed.

The huge energy demand is not only linked to the traditionally energy intensive industries, but also to the high need for electricity in other upcoming "modern" industry sectors, in the increasing service sector as well as in the residential sector.

Due to the higher electricity needs and higher production capacities within the city in Wuxi's future outlined by the CPS, direct emissions from electricity generation in Wuxi will be of even more importance than today. Thus, despite the assumed fulfilment of targets and relative reduction of energy intensity (related to local GDP), the projected economic growth will overcompensate the relative reduction and no absolute emission reductions will occur.

Wuxi's goal of reducing CO_2 intensity by 50% until 2020 is therefore a good starting point, but as can be seen in the CPS it is by far insufficient to ensure that Wuxi will be a city with low emission levels and compatible with IPCC scenarios and the 2°C goal. Setting the focus on 2020 targets may lead to structures, which will inhibit stronger reductions in the long term.

So electricity saving measures and electricity generation from renewable energies will be very important in the forthcoming more ambitious Wuxi Low Carbon Scenarios. Furthermore reduction of fuel use in industry and transport need to be considered.

The direct carbon dioxide emissions, assessed in the GHG inventory and scenarios for the territory of Wuxi, are only one side of the coin. Looking at the overall material and resource uses that are linked to the imported coal used in the energy industry and electricity imports, the figures get even more impressive. About double of the material flows that are related to the coal combusted in Wuxi need to be added for the extraction of this fossil fuel. Considering the same assumptions as the CPS for future development, the high increase of electricity needs and imports is supposed to correspond with increasing resource demands.

Further increasing population and living standards lead to an increasing building stock. Thus, the related construction and disposal of building waste also need to be considered and are expected to retain high significance.

Although the current discussions on climate change, mitigation and low carbon strategies mainly focus on greenhouse gas emissions and their impacts, the environmental pressures from the demand for coal and other resources, like construction materials and water flows, must not to be forgotten. On a long-term, they are as relevant (or even more) for the sustainability of the global environment.

In order to understand past and future changes of Wuxi's regional vulnerabilities to climate change, we analysed climatic parameters and the changes that have been observed and that are projected. The temperature risk will increase due to climate change, i.e. the frequency and magnitude of heat waves and maximum temperatures will increase. Although the risk of economic losses due to temperature hazards is relatively low today, it might dramatically rise in the future. Linked to the temperature changes in combination with the need for higher living standards are the above-mentioned increased needs for cooling and heating of residential buildings.

Of higher importance for economic development is the risk of flood and heavy rains, despite the fact that this hazard did not and will most probably not severely change. However, due to an increasingly dense infrastructure, Wuxi's vulnerability towards floods and heavy rainfalls is projected to grow. Therefore, it is recommended to increase Wuxi's coping capacity against such weather events in order to reduce impacts of temperature and flood hazards and thereby reduce the city's vulnerability.

Overall, it is concluded that although Wuxi's city government has set reduction targets and developed a low carbon plan, the projection results show that more ambitious efforts are needed to overcome the challenges faced and reduce the total CO_2 emissions and material uses. To set the path for a low carbon future in the city of Wuxi, it is crucial to understand the current situation and most likely future development. Therefore, the outcomes of this study form the scientific basis for the Low Carbon Future City strategy and roadmaps to be developed in later work /studies.

The results of the analysis above try to give a full picture of the real status quo and future development. – However it needs to be stressed that the data used is not only incomplete, it also bears uncertainties that need to be kept in mind. This is also true for the data used in the scenarios, for the calculation of the material flows as well as for the models used to determine the climate change vulnerability.

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Conflict of Interest

The authors declare no conflict of interest.

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* More literature used in background reports.