The CO2-Neutral City of the Future

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Summary

Increasing urbanization and climate change are among the greatest challenges of the twenty-first century. Many cities are already facing the negative effects of these issues, such as steadily increasing air pollution from traffic and industry. Solid and liquid wastes are polluting the soil and water bodies, and the advancing noise in our cities is also causing significant burdens for everyone.

A key area here is the growing consumption of fossil fuels in cities. This leads to rising CO_2 emissions, which accelerate climate change. As a result, cities around the world, especially in China, are trying to reduce their carbon footprint. In this context, the concept of so-called “low carbon cities” is being promoted. Currently, nearly one hundred cities in China are being planned based on these considerations. But there is actually no underlying basis for this. Even the very term "Low Carbon City" says nothing about a planning target or the potential savings in terms of percentages!

The first foundations for the assessment were laid with the research project LOW CARBON ECONOMY IN CITIES OF CHINA - POSSIBILITIES TO ESTIMATE THE POTENTIAL OF CO_2-EMISSIONS. On behalf of the German Federal Ministry of Education and Research, an assessment (see Chapter 1602 Title 896 05, 2009) of CO_2 emissions for cities/buildings in China was carried out.

These results were incorporated into our own research. An attempt was made to evaluate the CO_2 emissions of an entire city in a holistic manner. For this purpose, the CO_2 emissions for the city of the future with two million inhabitants were determined as an example. In order to be able to classify the values obtained, a comparison was made with a fictitious city whose CO_2 emissions are based on actual values. The areas of traffic, energy, buildings, and urban development were taken into consideration, and the possibilities of a reduction in CO_2 emissions through the planting of trees were also investigated.

The release of CO_2 from biogenic decay was also considered. Plant residues release the CO_2 bound in them during combustion or decomposition. However, if plant residues are converted into pyrochar in a pyrolysis process, a large proportion of the CO_2 is bound in the charcoal, and pyrochar itself represents an important (raw) material with a wide variety of properties that can be used in different applications.

This process therefore does not merely reduce CO_2 emissions, as is the case with targets for reducing the consumption of energy—e.g. for transport, heating and/or cooling, etc.—but instead removes the CO_2 from the atmospheric cycle and allows it to be stored in the long term.

Through the guided, holistic considerations in this research project, it has now become possible to provide the first generally valid information on planning the *city of the future*.

The basis for this research was formed by the investigations of the influences on the energy demand of so-called low carbon cities in the 2010s [1].

Calculating the CO_2-Emissions of Buildings with Xiamen (China) as an Example

In order to know the energy demand—and thus the CO_2 emissions—of cities, it is first necessary to classify the cities and their buildings. The classification is based on seven building types according to the typology of the MoHURD - Ministry of Housing and Urban-Rural Development, and is subdivided in

- residential buildings
- non-residential buildings.

For residential buildings, a classification of the buildings was made based on the building geometry. The ratio of the exterior wall and roof to the volume (SA:V or surface-area-to-volume ratio) is taken.

Residential buildings were categorized as

a) single-family houses with up to three floors;
b) multi-storey houses for several families.

Non-residential buildings were further classified as

c) office buildings;
d) shopping centers;
e) hotels;
f) congress/ trade fair buildings;
g) schools and other buildings.

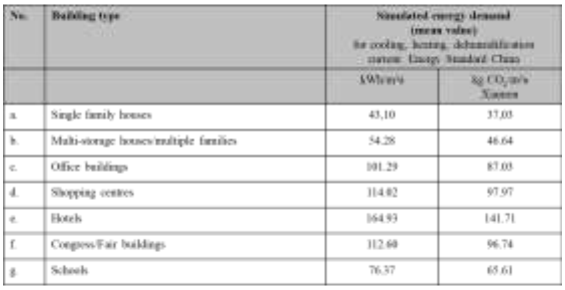
The simulation of the energy demand was calculated using the TRNSYS program system. It is based on a single-zone model of a standard room with different building components, different window-to-wall ratios and different types of use. In addition, the orientation and location of the room was varied.

The properties of the building components meet the minimum requirements of the Chinese standards GB 50189 and JGJ 75 (Baseline). Energy optimization was carried out on the basis of the rating system LEC [1] - Low Energy Certificate (3*–5*, corresponding to an increased European insulation standard).

In this context, the window-to-wall ratio corresponds to the classification of the current Chinese requirements. Different user profiles are provided for use in accordance with the applicable standard in China. Furthermore, additional deductions for user behavior, planning and construction quality were taken into account.

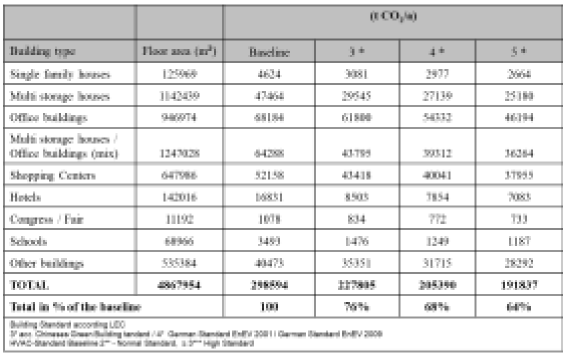
The calculated energy demand of different building types is shown in the following table:

Table 1: Energy demand of different building types.



No.	Building type	Simulated energy demand (mean value) for cooling, heating, dehumidification current Energy Standard China	
		kWh/m²a	kg CO_2/m²a Xiamen
a.	Single family houses	43,10	37,03
b.	Multi-storage houses/multiple families	54.28	46.64
c.	Office buildings	101.29	87.03
d.	Shopping centres	114.02	97.97
e.	Hotels	164.93	141.71
f.	Congress/Fair buildings	112.60	96.74
g.	Schools	76.37	65.61

Table 2: CO_2 emissions of Xiamen at different energy standards.



		(t CO_2/a)			
Building type	Floor area (m²)	Baseline	3 *	4 *	5 *
Single family houses	125969	4624	3081	2977	2664
Multi storage houses	1142439	47464	29545	27139	25180
Office buildings	940974	68184	61800	54332	46194
Multi storage houses / Office buildings (mix)	1247028	64288	43795	39512	36264
Shopping Centers	647986	52158	43418	40041	37955
Hotels	142016	16831	8505	7854	7083
Congress / Fair	11192	1078	834	772	733
Schools	68966	3493	1476	1249	1187
Other buildings	535384	40473	35351	31715	28292
TOTAL	**4867954**	**298594**	**227805**	**205390**	**191837**
Total in % of the baseline		**100**	**76%**	**68%**	**64%**

Building Standard according LEO
3* acc. Chinesse Green Building tandard / 4* German Standard EnEV 2001 / German Standard EnEV 2009
HVAC-Standard Baseline 2** - Normal Standard, 1.3*** High Standard

Based on the determination of the final energy demand, the CO_2 emissions of the primary energy demand were calculated, taking into account the primary energy structure, the energy efficiency of energy conversion, and the losses in electricity transmission (see Table 2).

It became apparent that such a procedure is one way in which the economic savings potential and the amount of energy saved can be compared with the investment costs.

Also taking into account regional specifics, it becomes evident that there is a way to determine the CO_2 potential for China's new "low carbon cities." The results provide a basis for decisions on the implementation of new building standards to limit the energy demand in a special "Low Carbon Standard"—a standard that is far above China's current energy standard.

The CO_2-Neutral City

As part of a separate research project [3] from 2017, the possibility of planning a *CO_2-neutral city* was investigated. It was calculated in which areas CO_2 emissions occur in a city and what options are available to reduce and cut them. The CO_2 emissions for a city with two million inhabitants were used as a basis.

The basic question in this project was: *"Is it possible to optimize the CO_2 emissions of a new city in such a way that with the help of parks and green spaces a CO_2-neutral city can be created?"*

The CO_2 emissions were therefore calculated for a "fictitious" city. These are composed of

- traffic/transport
- energy
- energy distribution
- buildings
- urban layout
- green areas

If we look at the CO_2 emissions of a present-day "fictitious" city (Figure 1), it is clear that transport has a significant influence on CO_2 emissions. The total CO_2 emissions amount to about 2,323 Mt. The storage of CO_2 emissions by the plants with about 238 Mt roughly covers the CO2 emissions caused by the buildings according to the EnEV(2016) standard.

This contrasts with the CO_2 emissions determined for a "city of the future" (Figure 2). Here it is clear that the emissions can be significantly reduced compared to the CO_2 emissions of the fictitious city. The reasons for this are the savings in CO_2 emissions through the avoidance of fossil fuels and the changes in traffic concepts.

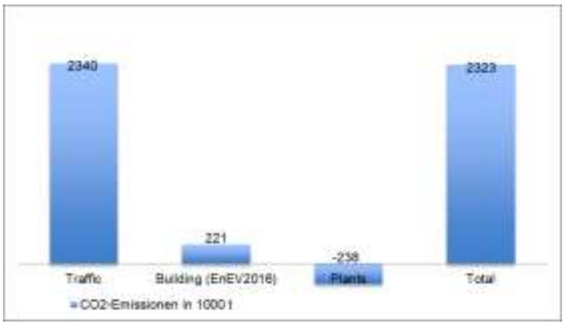


Figure 1: CO_2-emissions of a "fictitious" city

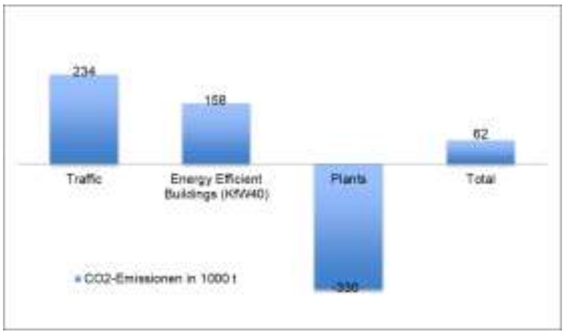


Figure 2: CO_2-emissions of a "city of the future"

Particularly noteworthy, however, is the effect of plants on the sequestration of CO_2 emissions. The research project clearly shows that it is possible to optimize the planning/energy efficiency in such a way that the city's plants can almost completely absorb the CO_2.

Of course, this is not quite correct, since plants release this CO_2 back into the atmosphere when burned or converted to compost. Thus, a process of permanent storage of CO_2 from the plants is needed. For this purpose, however, pyrolysis plants are available to us.

Practical Use of Pyrolysis Plants

Pyrolysis plants can permanently convert the CO_2 contained in biomass from plant growth into plant carbon. The ratio of biomass to charcoal is about 1:3, which means that the pyrolysis plant can permanently remove about one ton of CO_2 from the atmosphere for every two tons of green waste. Furthermore, this process releases approximately 1000 MWh of heat from every 1000 t of biomass. All energy expenditures, such as the transport of the green waste, its shredding, the operation of the plant, and the incorporation of the vegetable carbon into the soil, are taken into account in the overall balance.

The pyrolysis plant is energy self-sufficient and is operated in a continuous process. The energy needed to heat the biomass must first be supplied. The energy for the further process comes from the biomass itself and is generated by burning the gas produced during pyrolysis.

Based on a city with two million inhabitants, this results in approximately 300,000 t/a of green waste, resulting in an annual potential of approximately

- 100,000 t of vegetable carbon as a valuable material, e.g. as additives in materials;
- 300,000 MWh of heat from the pyrolysis process;

and

- the permanent binding of approx. 300,000 t of CO_2—which amounts to the entire CO_2 binding of the urban plant growth!

Vegetable Carbon as a Substitute for Aggregates in Mineral Materials

The use of pyrochar is becoming more and more important in the construction industry. The areas of application are based on the specific properties of the charcoal. The extremely large surface of the vegetable carbon causes a strong cation exchange capacity as well as a strong tendency to absorb and release a lot of moisture. As part of a separate research project in 2018 "Use of Plant Carbon in Construction," the successful addition/incorporation of plant carbon in mineral materials was investigated.

List of References

[1] PROPOSED NEW BASELINE AND MONITORING METHODOLOGIES - (CDM-NM) CDM project activity categories – III.AE. Energy efficiency and renewable energy measures in new residential buildings

[2] LEC - Low Energy Certificate - http://www.lowenergycertificate.com

[3] Research field "Energy and Environment" at the HAWK Hildesheim; Deryck, Henrike; Die CO_2 neutrale Stadt, 2017

Curriculum Vitae

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Vita:

since 1990	Self-employed work / General Manager of the BBS INGENIEURBUERO - Wolfenbüttel
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since 2007	Professor of Building Physics at Hefei University – China
since 2009	CEO of BBS INTERNATIONAL Ltd. – Shanghai, China
since 2017	CTO of and partner in BERLIND (Shanghai) Engineering Ltd. as well as BERLIND (Kunshan) Factory Ltd.
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2000–2022	Professorship for Building Construction and Building Physics at the HAWK Hildesheim - University of Applied Sciences and Arts
2001–2013	President of the WTA - (Scientific-Technical Working Group for Building Conservation and Monument Preservation)
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