649342 EUFORIE
European Futures for Energy Efficiency

Chinese residential sector analysis

WP8 Deliverable D8.3

Revised version, April 15, 2019

This project is supported by the European Commission
Horizon2020 Research and Innovation Programme

www.euforie-h2020.eu

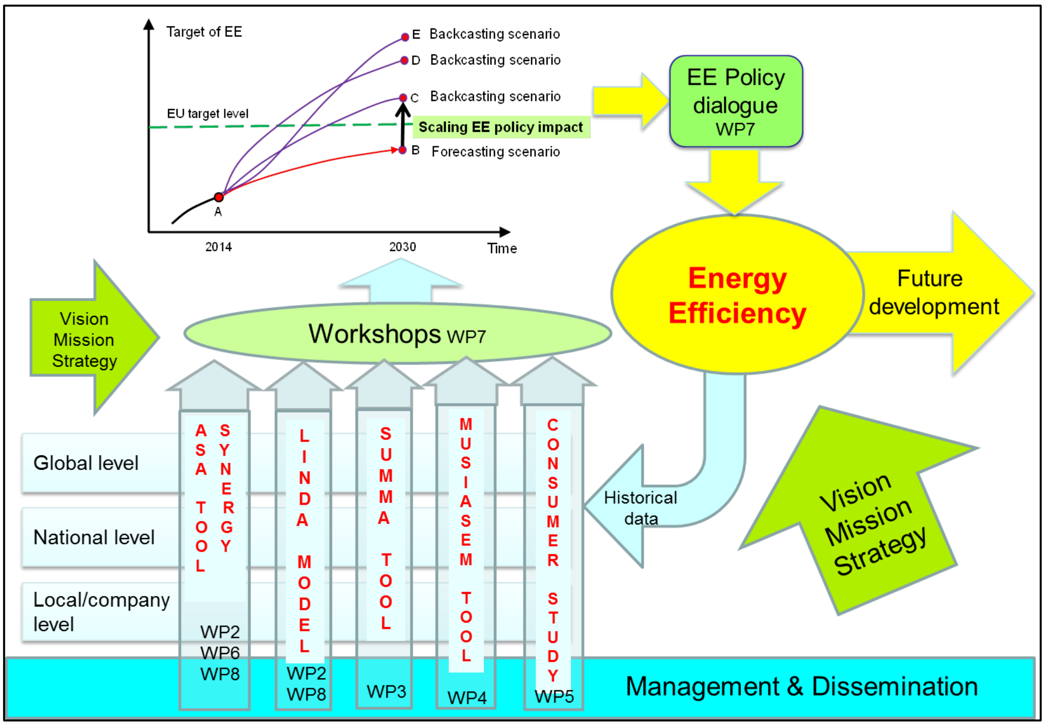
Please cite as: Ying Chen, Jinxing Jiang, Juha Panula-Ontto & Jarmo Vehmas (2019). Chinese residential sector analysis. European Futures for Energy Efficiency (649342 EUFORIE), deliverable D8.3.

The EUFORIE project

The strategic goal of the EUFORIE project is to provide useful and accurate information and knowledge in the field of energy efficiency for the EU Commission and stakeholders in the Member States. The tangible objectives are the following:

1. To provide energy and energy efficiency trends and their drivers, synergies and trade-offs between energy efficiency related policies, as well as energy efficiency scenarios (WP2).
2. To provide data about implementation of energy efficiency in specific processes, sectors and entire systems, in order to understand bottlenecks/efficiency drops and suggest improvements (WP3).
3. To carry out analyses of efficiency of provision, from making useful energy carriers from primary energy sources, and from conversion of energy carriers to end uses across macro-economic sectors (WP4).
4. To identify policy instruments and other measures leading to significant reduction in the energy consumption of households (WP5).
5. To analyse the relationship between investments and change in energy efficiency, and to develop indicators to describe changing energy efficiency at the company level (WP6).
6. To carry out participatory foresight for European stakeholders of energy efficiency with a target of providing ideas for the energy efficiency vision and strategy in the European Union (WP7).
7. To compare energy efficiency policy instruments and measures and their impacts in China and the European Union (WP8).

The EUFORIE Work Packages relate to each other. The project applies different quantitative and qualitative analysis methods to energy efficiency in the EU and its Member States at different levels and from different perspectives. These analyses provide input for foresight activities, which serve European energy efficiency vision and strategy process by generating useful information. Management (WP1) and dissemination (WP9) run in parallel with the research and innovation activities.



Tasks of this deliverable related to WP8

This deliverable D8.3 covers the following WP8 task:

- Task 8.3 “Residential sector analysis”

One interesting sector for energy efficiency policy is the residential sector and related household energy use. This will be related in the analysis to the population growth scenarios and scenarios related to the urbanisation. Changes in population growth, urbanisation and urban/rural household size will be taken into account in the analysis of energy use and energy efficiency in the building sector. ChinaLinda model will be utilized in this analysis.

Executive summary

The EUFORIE WP8 analyses energy efficiency in China at different levels: the macro level, the sectoral level, the provincial level, and the company level. The purpose of this deliverable is to deepen the sectoral level analysis presented in deliverable D8.2 to get an analysis of a selected sector; how changes in energy efficiency and change in different trends affect energy consumption and carbon dioxide emissions of the selected sector. The selected sector is the residential sector, which includes energy consumption in households. The residential sector is one of the fastest growing sectors in terms of energy consumption in China in the future.

From the starting point described above, this deliverable looks at energy efficiency development in the residential sector in China. The focus is in how changes in urbanization and the amount of population have an effect to energy consumption and related carbon dioxide (CO_2) emissions in the residential sector in China.

This task will be done by using the ChinaLINDA model, which is constructed in the EUFORIE project for constructing scenarios for the macro and sectoral levels. ChinaLINDA is based on data accounting, and it relies on an extended Kaya identity which identifies the drivers of CO_2 emissions from fuel combustion:

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP$$

where TPES is total primary energy supply, FEC is final energy consumption, GDP is gross domestic product or vale added in constant process, and POP is the amount of population. The drivers include changes in carbon intensity of the primary energy mix (CO2/TPES), the TPES/FEC ratio (which is a proxy for efficiency of the entire energy transformation system), energy intensity of the economy (FEC/GDP), economic growth per capita (GDP/POP) and the amount of population (POP). Each of these drivers may increase or decrease CO_2 emissions in the selected time period.

The ChinaLINDA model represents the Chinese energy system incorporating different economic sectors, including the residential sector and the construction sector, into the model. Furthermore, the model includes the mix of primary energy sources for the production of energy carriers, and the mix of energy carriers in the final energy consumption of different sectors. The model uses changes in economic activity as well as fuel and electricity intensities as the major input given by the model user. Therefore, the ChinaLINDA model can be used for providing projections on the impact of different assumptions, including assumptions on population growth and urbanization rate, on energy use and CO2 emissions in China, and on the impact of different levels of assumed energy efficiency improvements, presented in terms of fuel and electricity intensities.

The temporal horizon selected for the analysis is until the year 2030. The use of ChinaLINDA model in examining energy efficiency developments in the residential and construction sectors in China revolves around varying the assumptions on population growth, urbanization speed and rate of energy efficiency improvements in the urban and rural areas. From different combinations of these scenario pivot points, different scenario configurations can be formed. The baseline development follows the targets set in the 13^{th} five-year plan for China.

This report presents a ChinaLINDA model driven scenario study of the effects of different sub-scenarios regarding the Chinese urbanization process as well as residential and construction sector energy efficiency development on final energy consumption, electricity consumption and CO_2 emission levels. Fast urbanization, more ambitious energy efficiency policy in the use of buildings, and being able to make at least some energy efficiency gains in the construction sector would result, according to the ChinaLINDA projection, significant reductions by the year 2030:

- 172 Mtoe in final energy consumption
- 40 Mtoe reduction in electricity consumption-
- 300 Mton reduction in CO_2 emissions in 2030

The reductions are in comparison to the baseline scenario where a slower urbanization process, slower residential sector energy efficiency development and slow energy efficiency development in construction sector is assumed.

The results are useful for all stakeholder groups (policy makers, researchers, NGOS and citizens, and energy industry/companies interested in the residential sector development in China, especially for those researchers who consider focus on the impact of population, urbanization and energy efficiency on the fuel and electricity consumption and CO_2 emissions in China as important issues.

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Abbreviations

Abbreviation	Explanation
BEC	Building energy consumption
CO2	Carbon dioxide (emissions)
FEC	Final energy consumption
FYP	Five-year plan
GDP	Gross domestic product
LINDA	Long/range integrated development analysis
Mtoe	Million tonnes of oil equivalent
Mton	Million tonnes
POP	(Number of) population
TPES	Total primary energy supply
UNPD	United Nations Population Division

Introduction

One interesting sector of energy efficiency and related policies in China is the residential sector and related energy use in households, especially in the light of population growth and urbanization. Other things affecting energy use in households include change in the average flat size, change in the heating/cooling technologies, change in the number and electricity consumption of different electric appliances. Last but not least, also change in user behavior affects energy consumption in households.

This report presents a summary of the analysis of the construction and residential sectors of China utilizing results from the ChinaLINDA model. ChinaLINDA is an accounting framework model representing the Chinese energy system but also incorporating the residential and construction sectors into the model. It can be used for providing projections on the impact of different population growth and urbanization scenarios on energy use in China and the impact of different levels of energy efficiency improvements. The temporal horizon of the analysis is up to year 2030.

Population trends in China

The demographic giant China can be said to have completed its demographic transition, the significant mortality declines having taken place between 1950–1975 and the fertility level declined well below the replacement level, being about 1.6 in 2010 [1]. The United Nations population division estimates that the Chinese population will never reach 1.5 billion inhabitants but will rather reach 1.45 billion in 2030, starting to decline thereafter.[2].

The growth of the urban population comes therefore predominantly from rural-urban migration. The rural areas of China still hold a vast reserve of workers employed in low-productivity agricultural work. This reserve workforce can still fuel the expansion of urban economy and population for years to come. Assuming a continuation to the present rate of growth (2.73 % annually) in the share of urban population (57.9 %), the urbanization level could be nearly 88 % in 2030. In can be expected, at the very least, that urbanization level reaches a level of about 70 % by that time.

Urbanization trends in China

China is undergoing a very fast urbanization process. In 2000, the share of the urban population was about 35 %, and the rate of urbanization has since remained exceptionally fast: the share of urban population in 2016 is about 57 % [1]. Despite the rapid change, the share of urban population is still low compared to e.g. United States (82 % in 2016) and the general EU level. This means that there is still a very large reserve of rural population that are expected to migrate to urban centers in the next 20 years. The size of this rural migrant population was estimated in 2009 [3] to be as much as 250 million people by 2025. By 2030, the urban population of China is expected to reach one billion [3]. The urbanization process is expected to produce six more cities with a population of over 10 million by 2030, meaning that China would have eight such megacities altogether by 2030 [3]. Rural migration is the main driver in the growth of the urban centers.

The construction of the urban infrastructure and real estate presents a significant energy efficiency challenge. The estimates of the energy consumption of the Chinese building sector varies, but estimates of the BEC (Building energy consumption, the energy consumption associated with building construction and application) range from 27 % of the total energy consumption of the country in 2007 [4] to 31 % in 2007 [5]. This could be as much as 6 % of the global energy consumption [4]. The 2007 figure for energy use share is likely to have risen as the result of the fast urbanization process and expanded housing stock, as well as fast general rise in the standard of living. The Chinese construction and household sectors present a significant opportunity for energy savings through energy efficiency.

McKinsey Global Institute presented four alternative scenarios in 2009 for the shape or nature of the urbanization process in China, different in terms of the dispersion of growth. The urban growth could, in theory, have a very concentrated nature, where the focus of growth would be in a handful of megacities like Beijing, Shanghai or Chongqing. Alternatively, clusters of medium-sized and small cities could develop around larger ones, and the urbanization in general might have a more local, dispersed nature. The McKinsey Global Institute recommendation in regards to steering the urbanization was that a concentrated pattern of urbanization will offer the greatest opportunities for highest GDP per unit of energy, most efficient use of energy in general, lowest rate of loss of arable land, most efficient mass transit, most effective control of pollution and greatest synergies stemming from concentration and good availability of talent [3]. The development in China has been state-led and government-engineered, and leaning towards a concentrated model of urbanization, steered with the government's fiscal incentives [6].

The Chinese government has issued several building energy efficiency standards. which stipulate an energy saving target of 50 % in building designs [4]. Estimations of building energy consumption and building energy efficiency hint that the energy saving potential in China's building sector is great and building energy efficiency through energy pricing reform is one of the most important areas of government energy policy [4].

ChinaLINDA model

ChinaLINDA [7] is a case or application of a more general LINDA model[1] used in the analysis of economy from an energy and emission perspective. The LINDA (Long-range Integrated Development Analysis) model is based on intensity approach, building on the Extended Kaya Identity, which is used for the calculation of CO_2 emissions [8]. The following equation presents the main Kaya identity components used in LINDA model.

$$CO2 = \frac{CO2}{TPES}\frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP \tag{1}$$

where CO2 is carbon dioxide emissions from fuel combustion, TPES is total primary energy supply (including all forms of primary energy before the processes of producing energy carriers), FEC is final energy consumption (district heat, electricity and fuels used in residential heating and transport), GDP is gross domestic product in constant prices, and POP is the amount of population.

Equation (1) forms the basic conceptual framework behind the LINDA model and the choice of modelled factors is somewhat based on the Extended Kaya Identity. ChinaLINDA is an accounting framework type of model. The model includes different fuels and electricity, electricity production as well as different sectors of economy in the calculation procedures. In addition, the population, accounted as households, is divided into rural and urban groups.

A multitude of factors can be varied by the user in the ChinaLINDA model, including but not limited to population growth, economic development in different sectors, energy production system details including construction of new power plants and plant efficiencies, and fuel use mix in different economic sectors. This analysis focuses on varying the development of rural-urban migration flow and the level of energy intensity improvements in the construction sector and the residential sector. For most technical parameters of the model, such as fuel mix, power plant efficiencies, and construction of new power plants, a reasonable continuation of existing trends is assumed. For the economic development, which is central to the energy efficiency related observations made, the trend forecast relies upon the targets of the 13^{th} five-year plan and a slowing-down trend of economic growth after the 2016—2020 period. The overall GDP growth target for China set in the 13^{th} FYP is 6.5 % annually. The GDP growth is assumed to slow down further in the period after the year 2020.

[1] A detailed presentation of the LINDA modeling approach and the characteristic of the LINDA model is available in the EUFORIE deliverable D2.3&D2.4 [13].

Scenario pivot points

The use of ChinaLINDA model in examining the energy efficiency developments in the residential and construction sectors in China revolves around varying the factors of population growth, urbanization speed and the rate of energy efficiency improvements in urban and rural areas. From the different options of these scenario pivot points, several scenario configurations can be formed.

Population

The UN Population Division (UNPD) baseline population forecast [2] projects the Chinese population to be 1.408 billion in the year 2030 and to start declining in the 2030's. The projected population for 2050 is 1.34 billion. This population estimate assumes that the fertility ratio in the Chinese population remains below 1.7 until 2030 and rises up to 1.75 by 2050. Comparatively, this fertility ratio is low and assuming a much lower ratio might be considered unrealistic. A faster rise in the fertility ratio, however, could be assumed for scenario purposes. Assuming several different but feasible population growth scenarios resulting in notably higher population for 2030—2050, the population could reach a much higher level by 2050. The overall difference in total population in these two population scenarios is, however, not very significant until from 2030 onwards. The difference in population between the sub-scenarios in the time perspective reaching 2030 is only about 0.7 %. For this reason, the alternative population sub-scenario is left out of the scenario set, and the UNPD projection is used as the basis for the alternative scenarios.

Urbanization speed

United Nations Population Division provides a baseline projection [9] for urbanization speed for China. In addition to the baseline projection, an alternative sub-scenario assuming a clearly faster process of urbanization can be envisaged. In Table 1 and Table 2, the urbanization rates and urban, rural and total populations for years 2015, 2020, 2025 and 2030 under the UNPD baseline scenario and the alternative sub-scenario are presented, respectively.

Table 1. Urbanization compliant to UNPD projection.

Variable	2015	2020	2025	2030
Urban population	7.68E+08	8.69E+08	9.36E+08	1.01E+09
Rural population	6.09E+08	5.65E+08	5.24E+08	4.69E+08
Total population	1.38E+09	1.43E+09	1.46E+09	1.48E+09
Urbanization rate	55.8 %	60.6 %	64.1 %	68.3 %

Table 2. Urbanization development under assumption of fast urbanization.

Variable	2015	2020	2025	2030
Urban population	7.74E+08	9.10E+08	1.01E+09	1.08E+09
Rural population	6.03E+08	5.31E+08	4.68E+08	4.02E+08
Total population	1.38E+09	1.44E+09	1.47E+09	1.48E+09
Urbanization rate	56.2 %	63.1 %	68.2 %	72.9 %

Energy and electricity use in the residential sector

Figure 1 displays the converging trend of final energy use per capita in rural and urban populations. The converging trend suggests that in high level modeling of the residential and construction sector energy use, the split of rural and urban population might be rather insignificant for the results, when projecting beyond 2020.

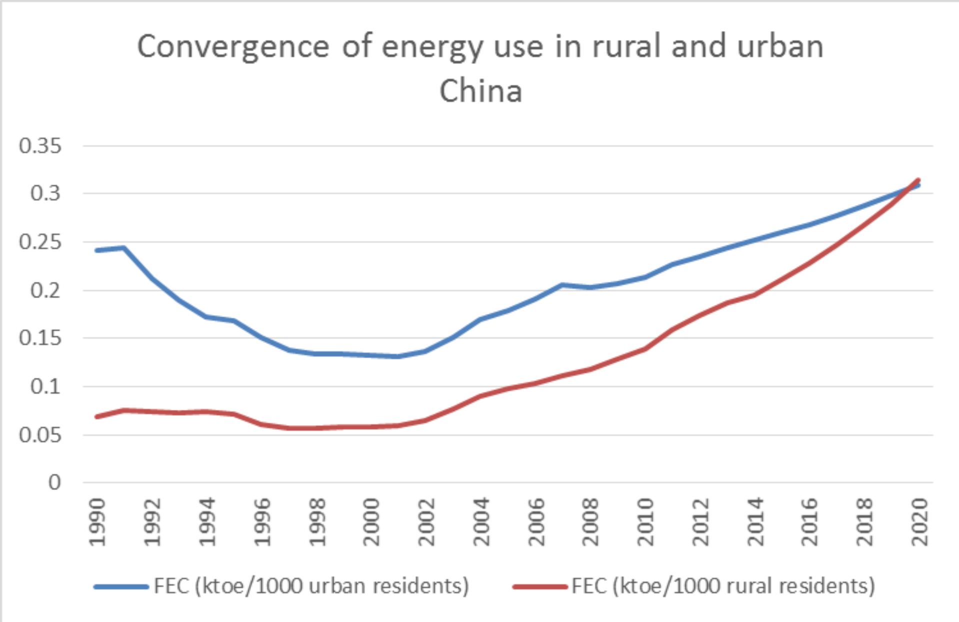

Figure 1. Converging energy use per capita in rural and urban population.

The default final energy consumption and electricity consumption for residential sector for both urban and rural population pools in ChinaLINDA is modeled by means of linear regression to be dependent on the urban or rural population size and GDP per capita. The annual growth rates for urban and rural final energy consumption (FEC) and urban and rural electricity consumption for periods 2014—2020, 2021—2025 and 2026—2030 are presented in Table 3, and Table 4 shows alternative growth rates assuming improvement in energy efficiency.

Table 3. Annual growth rates for urban and rural final energy consumption (FEC) and urban and rural electricity consumption for periods 2014—2020, 2021—2025 and 2026—2030.

Variable	**Annual rate of change**		
	2014-2020	**2021-2025**	**2026-2030**
Final energy consumption, urban	6.0 %	5.7 %	6.0 %
Final energy consumption, rural	6.1 %	5.9 %	6.2 %
Electricity consumption, urban	7.6 %	6.8 %	6.9 %
Electricity consumption, rural	7.3 %	6.9 %	6.9 %

Table 4. Alternative growth rates under default assumptions for urban and rural final energy consumption (FEC) and urban and rural electricity consumption for periods 2014—2020, 2021—2025 and 2026—2030.

Variable	Alternative annual rate of change		
	2014-2020	**2021-2025**	**2026-2030**
Final energy consumption, urban	5.7 %	5.2 %	5.1 %
Final energy consumption, rural	5.8 %	5.3 %	5.3 %
Electricity consumption, urban	7.2 %	6.1 %	5.8 %
Electricity consumption, rural	6.9 %	6.2 %	5.8 %

Energy efficiency improvement in the construction sector

EUFORIE Deliverable D8.2 [10] presents a decomposition analysis revealing the energy efficiency improvements in various sectors of the Chinese economy, including the construction sector. In the construction activity, there is a small (-0.95 %) decrease in energy consumption attributed to the construction sector energy efficiency improvements over the period 2000-2013. Looking only at the more recent period 2009–2013, the change in the final energy consumption attributed to energy efficiency improvements is positive, meaning that the energy efficiency in the construction sector has worsened. Against this background, assuming a 1.5 % annual energy efficiency improvement appears ambitious, and can be compared to the results produced by a sub/scenario assuming no energy efficiency improvements over the scenario period.

Scenarios

Table 5 presents the possible scenarios that form the Cartesian product of the different sub/scenarios presented earlier. The ChinaLINDA model is used to examine the energy use, electricity use and CO_2 emission levels under different scenarios.

Table 5. Alternative scenarios for ChinaLINDA derived from the scenario pivot points.

Scenario	Urbanization	Energy efficiency in the residential sector	Energy efficiency in the onstruction sector
1	UNPD	ChinaLINDA default	Slow efficiency improvement
2	UNPD	ChinaLINDA default	Fast efficiency improvement
3	UNPD	Alternative (fast efficiency improvement)	Slow efficiency improvement
4	UNPD	Alternative (fast efficiency improvement)	Fast efficiency improvement
5	Fast	ChinaLINDA default	Slow efficiency improvement
6	Fast	ChinaLINDA default	Fast efficiency improvement
7	Fast	Alternative (fast efficiency improvement)	Slow efficiency improvement
8	Fast	Alternative (fast efficiency improvement)	Fast efficiency improvement

Table 6 presents the annual GDP growth rates for different sectors of the Chinese economy, a development shared by all residential and construction sector scenarios presented in this report.

Table 6. Annual GDP growth rates in all scenarios.

Economic sector	**Annual rate of GDP change**		
	2014-2020	**2021-2025**	**2026-2030**
Agriculture	4.0 %	3.0 %	3.0 %
Industry	7.0 %	6.0 %	6.0 %
Transportation, communication	6.0 %	5.0 %	5.0 %
Commercial	9.0 %	8.0 %	8.0 %
Construction	14.0 %	13.0 %	13.0 %
Others	6.0 %	5.0 %	5.0 %
Total	7.3 %	6.5 %	6.8 %

Table 7 presents the annual electricity intensity change in all scenarios. The development for these items is shared in all presented scenarios.

Table 7. Annual electricity intensity changes in all scenarios.

Economic sector	**Annual change in electricity intensity**		
	2014-2020	**2021-2025**	**2026-2030**
Agriculture	-3.0 %	-4.0 %	-4.0 %
Industry	-6.0 %	-7.0 %	-7.0 %
Commercial	-5.0 %	-6.0 %	-6.0 %
Transportation	-3.0 %	-4.0 %	-4.0 %
Construction	-2.0 %	-2.0 %	-2.0 %
Others	6.0 %	5.0 %	5.0 %
Import (not intensity)	10.0 %	10.0 %	10.0 %
Export (not intensity)	10.0 %	10.0 %	10.0 %

Table 8 presents the annual fuel use intensity changes in all scenarios in the three scenario periods. As with the electricity intensity development, the development for these items is similar in all the presented scenarios.

Table 8. Annual fuel use intensity changes in all scenarios.

Economic sector	**Annual change in fuel use intensity**		
	2014-2020	**2021-2025**	**2026-2030**
Agriculture	-3.0 %	-4.0 %	-4.0 %
Industry	-6.0 %	-7.0 %	-7.0 %
Commercial	-5.0 %	-6.0 %	-6.0 %
Construction	-2.0 %	-2.0 %	-2.0 %
Transportation	-3.0 %	-4.0 %	-4.0 %
Others	6.0 %	5.0 %	5.0 %

Table **9** presents the main output of the ChinaLINDA model under different scenarios. The construction sector does not contribute greatly to energy use in the building sector. More important savings potential is in the energy used in buildings. According to the ChinaLINDA projection of fast urbanization, a more ambitious energy efficiency policy in the use of buildings and the ability to make (at least some) energy efficiency improvements in the construction sector would result a reduction of more than 172 Mtoe in final energy consumption, 40 Mtoe in electricity consumption, and a nearly 300 Mtons of CO_2 emissions by the year 2030 when compared to a baseline scenario, which assumes a slower urbanization process, a slower energy efficiency development in the residential sector, and a minuscule energy efficiency development in the construction sector.

Table 9. Final energy consumption (FEC), electricity consumption and CO_2 emissions in 2030 under eight different scenarios.

	Urbanization speed	Residential sector energy and electricity use	Construction sector efficiency improvement	FEC 2030 (ktoe)	Electricity consumption 2030 (ktoe)	CO2 2030 (Mtons)
1	UNDP	Default	Slow	3913150	907522	13585
2			Fast	3815711	893327	13413
3		Alternative	Slow	3841510	882791	13475
4			Fast	3744071	868596	13303
5	Fast	Default	Slow	3909436	905759	13580
6			Fast	3811997	891564	13408
7		Alternative	Slow	3838207	881228	13470
8			Fast	3740767	867033	13298

Conclusions

The results presented in Table 9 highlight the possibilities of an urbanization policy with quite realistic targets in reducing energy use and greenhouse gas emissions from fuel combustion. It must be noted that the high-level, intensity approach nature of the ChinaLINDA model does not provide many possibilities to examine specific initiatives concerning energy efficiency in the building sector in a detailed manner. Additionally, the data which the model is reliant upon is sourced from the Chinese statistical office, and the summed residential sector and construction sector energy use figures appear to be significantly lower than the estimates of the building sector energy use found in other sources [4,11,12]. Studies applying a life cycle approach [5,11] to the building sector's energy use and its share of the total energy use allocate a 30-35 % share of total energy use to the building sector, whereas the summed final energy consumption for the residential sector and the construction sector in the ChinaLINDA model only accounts for 15 % in 2015. However, the share rises to 30 % or 32 %, depending on the scenario, by 2030. Keeping this in mind, the energy savings potential in China's building sector could be significantly higher than what the results of the ChinaLINDA scenarios presented in this report indicate.

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