EUFORIE
European Futures for Energy Efficiency

European Futures for Energy Efficiency

6493423 EUFORIE

Comparative energy efficiency analysis between the EU and China

WP8 Deliverable D8.5

Revised version, April 16, 2019

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

www.euforie-h2020.eu

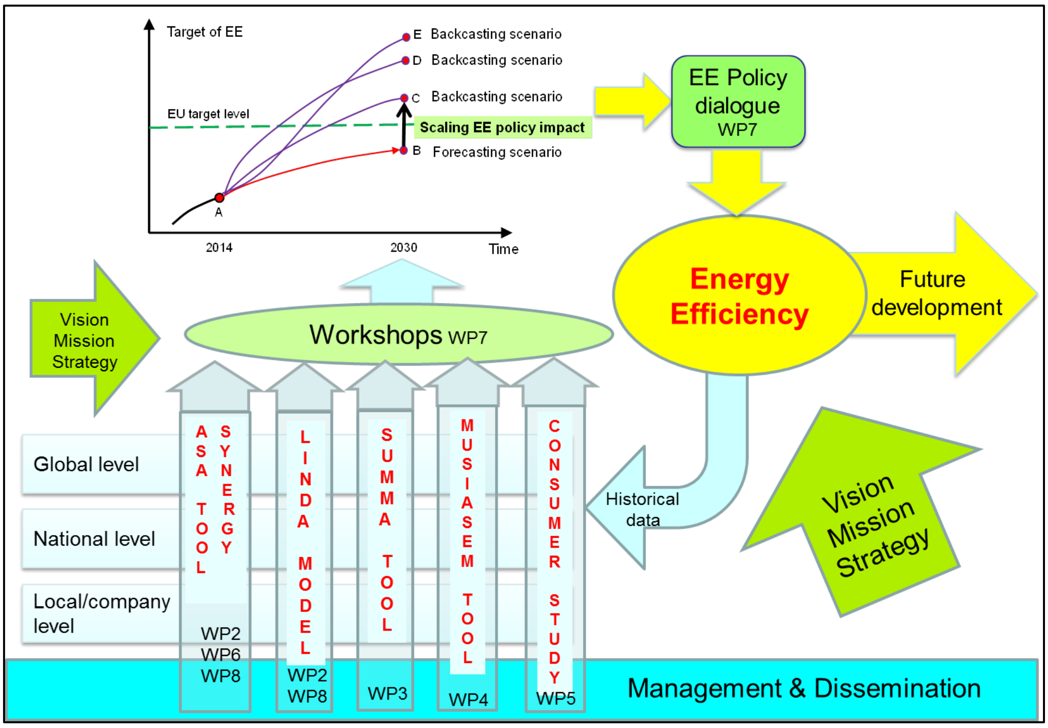
Please cite as: Vehmas, Jarmo (2019). Comparative energy efficiency analysis between the EU and China. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D8.5.

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.



Executive Summary

The purpose of this deliverable is to compare energy performance, energy efficiency, and energy efficiency policies in the European Union and in China, which are major energy consumer and emitters of greenhouse gas emissions at the global level. The comparison is done by using the literature, and by empirical analyses of energy performance carried out for the EU and in China in the EUFORIE project.

The major tools used in the analyses include chained incremental two-factor decomposition analysis and the LINDA modelling approach. Decomposition analysis and LINDA modelling have been used in the EUFORIE project for both the EU and China.

The decomposition approach relies on the following identities based on the Kaya identity

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

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

where CO2 is carbon dioxide emissions from fuel combustion, TPES is total primary energy supply, FEC is final energy consumption, GDP is gross domestic product in real/constant prices, and POP is the amount of population. The LINDA modelling is based on the latter identity where the main drivers of CO_2 emissions are identified. CO2/TPES is change in carbon intensity of the primary energy mix, TPES/FEC ratio is a proxy for change in efficiency of the entire energy transformation system, FEC/GDP is change in energy intensity of the economy, GDP/POP is change in economic activity per capita, and POP is change in the amount of population.

For this comparative analysis, the historical data used in the decomposition analysis has been updated up to the year 2015. The source for all data used in the decomposition analysis is International Energy Agency (IEA). Data for the LINDA models is taken from various sources. In the EuroLINDA model, major data sources include IEA for the CO_2 and energy data, World Bank for the economic data, and United Nations for the population data. In the ChinaLINDA model, the data has been mostly taken from the Chinese National Bureau of Statistics (NBS) databases.

Regarding the results, there is a major difference between the EU and China, both in CO_2 emissions from fuel combustion and the primary energy use. In China, CO_2 emissions from fuel combustion as well as total primary energy supply (TPES) have strongly increased in 1990-2015, but in the EU, both trends have slightly decreased during the same period. Carbon intensity of total primary energy supply has increased in China, but decreased in the EU. This is visible also in their effects to the change of CO2 emissions and TPES during the period 1990-2015.

The TPES/FEC ratio, which is a proxy of efficiency of the entire energy transformation system, has also increased in China and decreased in the EU. Change in the TPES/FEC ratio has thus has an increasing effect to both total primary energy supply and CO_2 emissions in China, and a slightly decreasing effect in the EU.

Energy intensity, in terms of final energy consumption divided by gross domestic product (FEC/GDP), has decreased in both China and the EU. Change in energy intensity has had a larger decreasing effect to total primary energy supply and CO_2 emissions in China than in the EU.

Regarding the other drivers, change in economic activity (GDP/POP) and change in the amount of population (POP), the effect has been an increasing one in the EU and China. The effect of GDP/POP has been a decreasing one during the financial crisis in the EU especially in the years 2008-2009, while in China the increasing effect was a large one. Carbon intensity of the primary energy mix has slightly deceased during the studied period, but its annual effects to total primary energy supply and CO_2 emissions has varied a lot both in the EU and in China.

In the EU baseline scenario, significant decrease in primary energy and final energy use as well as CO_2 emissions takes place. The target of the share of renewable energies in the energy mix seems to be the most challenging one. Major result from the Chinese scenarios is that there is a major gap in 2020 between sectoral energy intensities between the baseline scenario and the energy efficiency scenario. Economic growth is of great importance from this perspective. Perhaps in the next five year plan China will follow the example of EU and set absolute targets for primary and final energy use, and preferable also for CO_2 emissions.

In this deliverable, a hypothesis was set on the better effectiveness of the EU 0nergy efficiency policy in comparison to China. The trends described above give a reason to think that among other things, the development might be a result of a contribution by energy efficiency policies. When looking at the major policy documents, there is a clear difference between China and the EU. Chinese five-year plans focus on relative targets and concrete actions such as investments in power plant capacity in the production side and development projects in the consumption side. EU directives focus on absolute targets, but the policy measures and actions are left at the disposal of Member States and the economic actors. This is a difference in the political system, which makes actual comparison of energy efficiency policies very difficult.

The results from the comparative analysis are useful for policy makers in the EU, and especially from the perspective of the negotiations related to the United Nations >Framework Convention on Climate Change (UNFCCC). The results are useful for all stakeholders (including policy makers, researchers, NGOs and energy industry/companies who are interested in energy and environmental performance of the EU and China, and for those who are interested in the methodology of performance analysis such as decomposition analysis and accounting type of modelling and scenario construction.

Tasks of this deliverable related to WP8 and other EUFORIE WPs

This deliverable covers the following EUFORIE WP8 (Chinese energy efficiency and comparison of European/Chinese energy policies) task:

- Task 8.5: “Comparison EU-China”

Results from WP8 deliverables D8.1, D8.2 and D8.4, and WP2 deliverables D2.1 and D2.3&D2.4 are used in the comparison.

WP8 and this deliverable has also a link to the WP4 deliverable D4.4, where comparisons between the EU and China will be made using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MUSIASEM) approach.

Contents

Abbreviations

Abbreviation	Explanation
ASA	Advanced Sustainability Analysis
CO_2	Carbon dioxide (emissions)
EFF	Energy efficiency scenario
ETS	Emissions Trading Scheme/System
EU	European Union
EUFORIE	European Futures for Energy Efficiency
FEC	Final energy consumption
FYP	Five year plan
GDP	Gross domestic product
GW	Gigawatt(s)
IEA	International Energy Agency
LINDA	Long-range Integrated Development Analysis
Mtoe	Million tonnes of oil equivalent
Mton	Million tonnes
MW	Megawatt(s)
NBS	National Bureau of Statistics, China
NEEAP	National Energy Efficiency Action Plan
POP	Population, number of population
TPES	Total primary energy supply
USD, US$	United States dollars
WEC	World Energy Council

List of Tables

List of Figures

Introduction

This report presents a comparison between the EU aggregate and China, including the 28 EU Member States (Figure 1) and 34 Chinese administrative regions (Figure 2) in terms of energy efficiency policies, historical trends related to energy efficiency and energy efficiency as a driver of changing total primary energy supply (TPES) and carbon dioxide emissions from fuel combustion (CO_2). Energy efficiency related trends include total primary energy supply (TPES), final energy consuTPES/FEC). Analyses provided in previous EUFORIE reports are utilized, and some new analyses are provided as well.

In the next Chapter, basic information of the European Union and China will be given, including the EU-28 Member States and Chinese provinces and other administrative regions. Then energy efficiency policies at the EU Community level and at the national level in China will be described. This description is followed by the presentation of energy efficiency related trends in the EU-28 aggregate and China. The aim is to test a hypothesis that energy efficiency policies in the EU have been more effective than the energy efficiency policies in China. The trends of CO_2 emissions and total primary energy supply are presented also at the level of EU Member States and Chinese regions. Then, total primary energy supply and CO_2 emissions are decomposed to the effects of their major drivers, energy efficiency among them, on annual basis. The results are presented for selected periods between the years 1990 and 2015, i.e. 1990-2000, 2000-2010, 2010-2015 and 1990-2015. The purpose of this analysis is to find out the effect of changing energy intensity (FEC/GDP) and the TPES/FEC ratio to the change in TPES and CO_2 emissions, in order to test further the hypothesis of EU and Chinese energy efficiency policies. The last test of the hypothesis on effectiveness of EU and Chinese energy policies is done with the scenarios constructed for the EU and China in the EUFORIE project. The scenario results and assumptions are presented, and compared when possible. In the final chapter, preliminary conclusions are drawn on the effectiveness of EU and Chinese energy efficiency policies.

European Union and China: Member States and administrative regions

At the moment, the European Union consists of 28 Member States (Figure 1). The size of the Member States varies considerably in terms of geographical area (Figure 1), number of population (Figure 3) and economic activity (Figure 5).

Figure 1. The European Union and its 28 Member States. Source: Council of the European Union 2018.

Regional administrative division of People’s Republic of China includes 23 provinces, five autonomous regions with a particular ethnic minority, four municipalities, two special administrative regions (Hong Kong and Macau) and one claimed province (Taiwan), altogether 35 administrative regions (Figure 2). Like in the case of the EU Member States, the size of Chinese administrative regions also varies considerably in terms of geographical area (Figure 2), number of population (Figure 4) and economic activity (Figure 6).

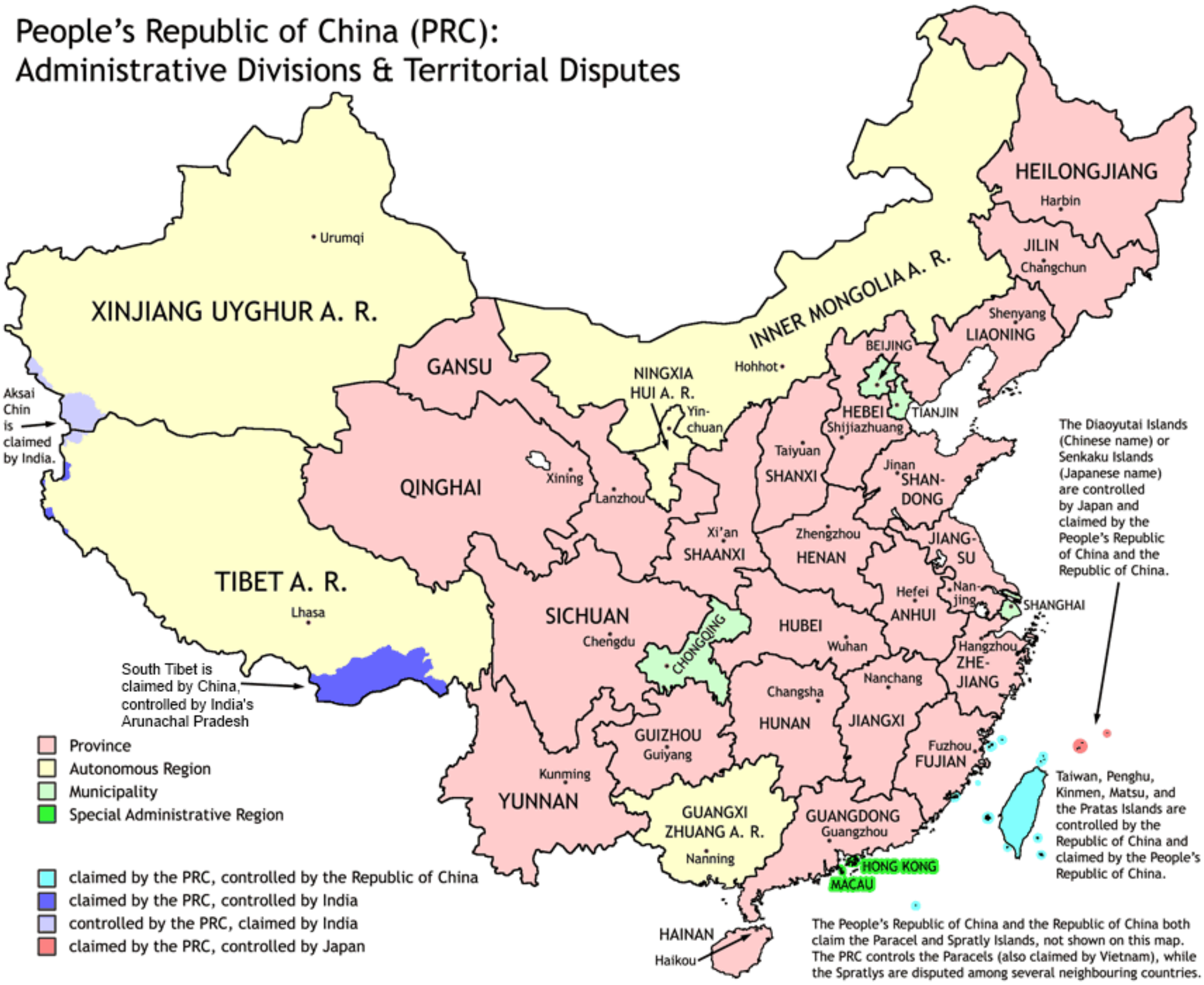


Figure 2. Administrative regions in China. Source: Wikivoyage 2017.

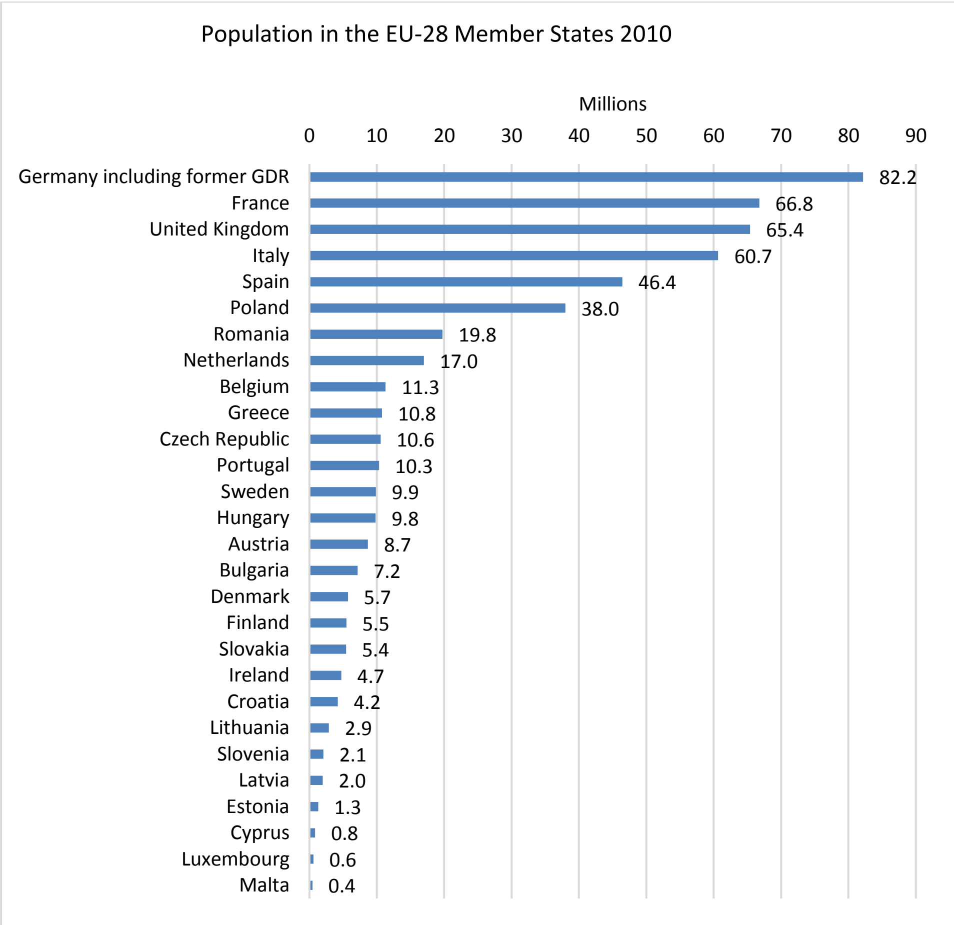


Figure 3. Number of population in the EU-28 Member States on 1st of January 2016. Data source: Eurostat 2017.

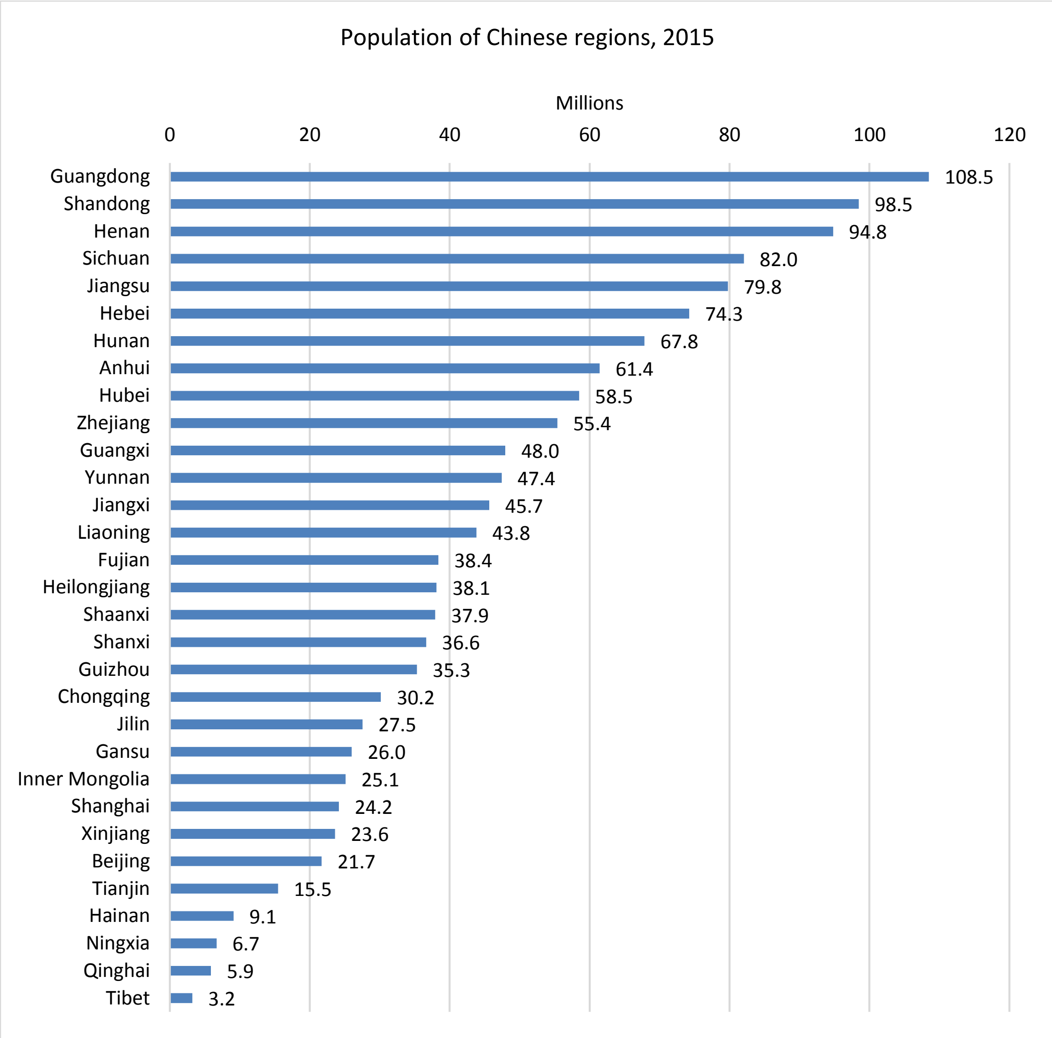


Figure 4. Number of population in the Chinese regions at the end of the year 2015. Data source: NBS 2017.

The total number of population in China (1374.6 Million) is almost three times larger than the number of population in the EU-28 (510.3 Million). Moreover, the distribution of the population into administrative regions in China (Figure 4) is more equal that the distribution of population into Member States in the EU (Figure 3), because there are so many large regions in China and so many small Member States in the EU. In the EU, the largest Member State (Germany, 88.2 million inhabitants) is 220 times larger than the smallest Member State (Malta, 0.4 million inhabitants). In China, the largest administrative region (Guangdong, 108.5 million inhabitants) is 34 times larger than the smallest administrative region (Tibet, 3.2 million inhabitants).

In terms of economic activity (GDP), the differences are even larger (Figure 5 and Figure 6). The largest EU Member State (Germany, 3144 billion euros) is 318 times larger than the smallest Member State (Malta, 9.9 billion euros). The largest Chinese region (Guangdong, 931 billion USD) is 72 times larger than the smallest region (Tibet, 13 billion USD).

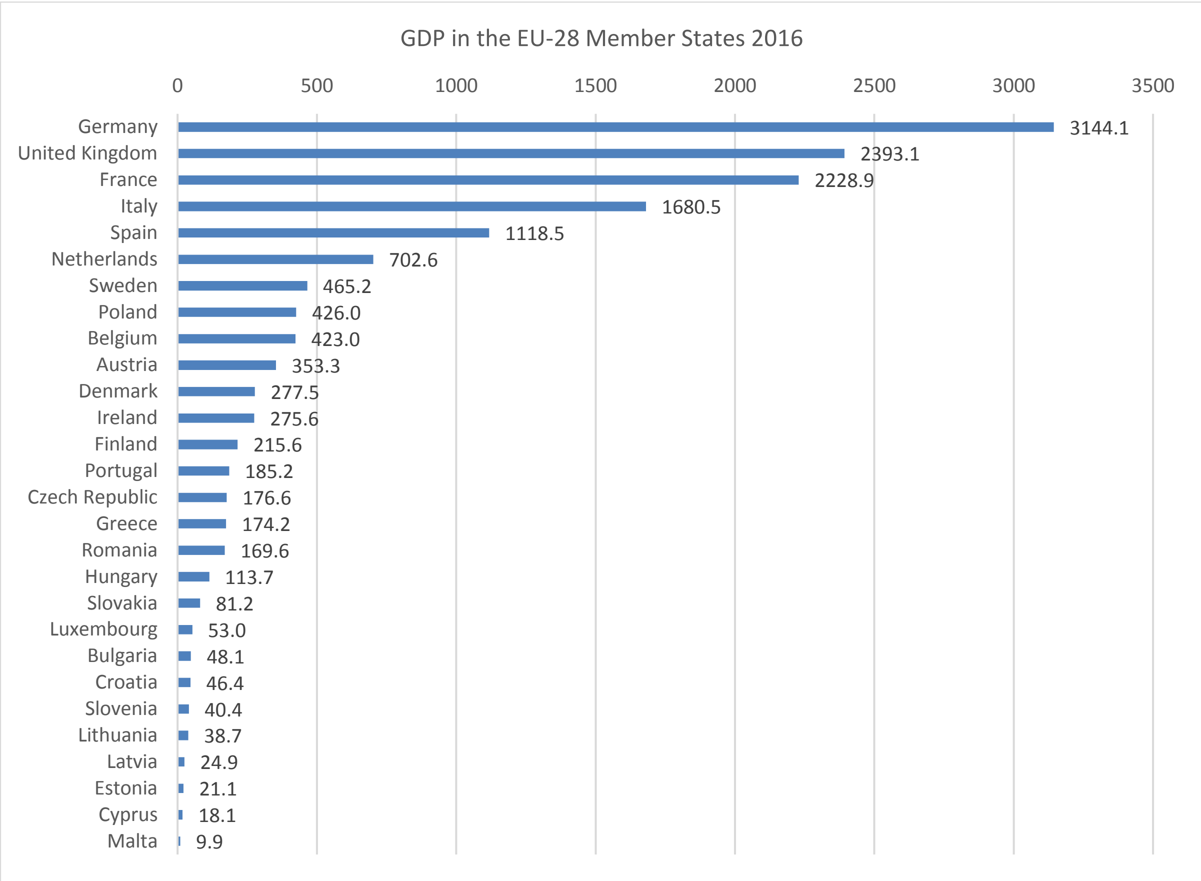


Figure 5. GDP in the EU-28 Member States. Data source: Eurostat 2017.

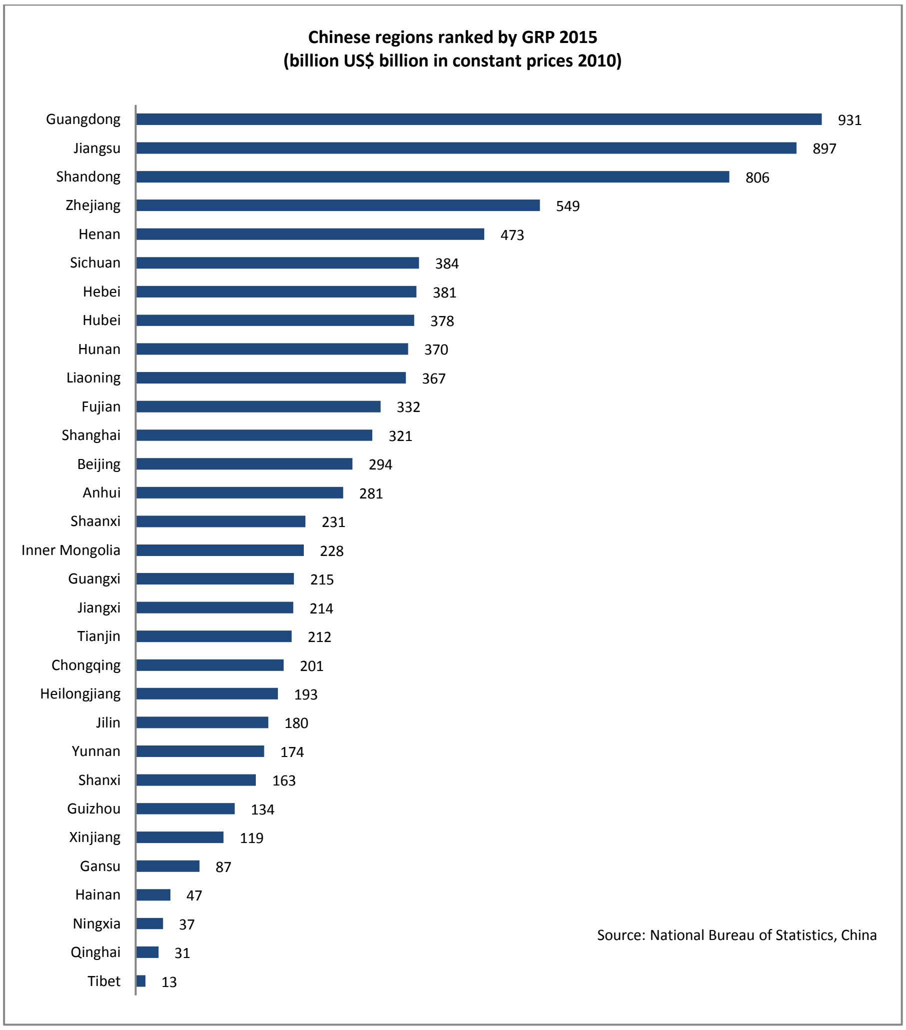


Figure 6. GRP in the Chinese regions. Data source: NBS 2017.

Energy efficiency policies in the EU and China

It is often said that in a market economy, increasing energy price is the best driver of energy efficiency. However, in the conditions of low energy prices, price signal alone cannot guarantee that a more efficient energy use will be achieved. Thus, energy efficiency policies and measures are necessary to reinforce the role of energy prices: to create appropriate market conditions for energy efficient equipment and services in different sectors, and to encourage consumers and other actors to choose cost effective solutions (WEC 2016). However, major reasons for failure in market mechanisms include the following (WEC 2016):

- incomplete information of available possibilities,
- limited availability of efficient appliances and production devices,
- lack of technical, commercial and/or financial capacity,
- investors and final users are often different persons (“split incentives”),
- over-emphasizing the investment costs.

In addition to triggering the price signal, energy efficiency policies should address the reasons for market failure mentioned above.

After the transition period of Brexit the European Union will consist of 27 independent Member States implementing their own national energy efficiency policies in a framework created by the EU legislation (directives) and other related policies accepted at the Community level.

At the moment, the energy efficiency related policies consist of the EU “2020 climate and energy package” and further improvements to it such as the 2030 targets given since then (European Commission 2018a). The original 2020 climate and energy package includes the following targets: reduction of greenhouse gas emissions by 20 % from the 1990 level, especially CO_2 emissions, increasing the share of renewable energies in the EU energy mix up to 20 %, and improving energy efficiency by 20 % by the end of the year 2020. National targets fulfilling these common targets have been specified in Table 1.

The 2030 climate and energy framework for the EU sets three Community level key targets for the year 2030 (European Commission 2018a):

- At least 40 % cut in greenhouse gas emissions from the 1990 levels,
- At least 27 % share for renewable energy, and
- At least 27 % improvement in energy efficiency.

National targets of the individual EU Member States based on these Community level targets are not available yet. In a previous EUFORIE report (Vehmas et al 2017a), Community-level scenarios about the possibilities to reach the 2030 targets have been introduced. The webpage of the EU 2030 climate and energy framework states that the 40 % reduction target requires that the sectors belonging to the emissions trading system (ETS sector) should reduce greenhouse gas emissions by 43 % and the non-ETS sector by 30 % by the year 2030 from the 2005 level (European Commission 2018a).

Table 1. Projected energy consumption in the EU Member States in the year 2020. Source: European Commission 2016a. Primary/final energy consumption ratio added by the authors.

EU Member State	Energy consumption in 2020 as notified from Member States in 2013, in the NEEAP 2014 or in a separate notification to the European Commission in 2015		
	Primary energy consumption, Mtoe	Final energy consumption, Mtoe	Primary/final energy consumption ratio
Austria	31.5	25.1	1.25
Belgium	43.7	32.5	1.34
Bulgaria	16.9	8.6	1.97
Croatia	11.5	7.0	1.64
Cyprus	2.2	1.8	1.22
Czech Republic	39.6	25.3	1.57
Denmark	17.8	14.8	1.20
Estonia	6.5	2.8	2.32
Finland	35.9	26.7	1.34
France	219.9	131.4	1.67
Germany	276.6	194.3	1.42
Greece	24.7	18.4	1.34
Hungary	24.1	14.4	1.67
Ireland	13.9	11.7	1.19
Italy	158.0	124.0	1.27
Latvia	5.4	4.5	1,20
Lithuania	6.5	4.3	1.51
Luxembourg	4.5	4.2	1.07
Malta	0.7	0.5	1.40
Netherlands	60.7	52.2	1.16
Poland	96.4	71.6	1.35
Portugal	22.5	17.4	1.29
Romania	43.0	30.3	1.42
Slovakia	16.4	9.0	1.82
Slovenia	7.3	5.1	1.43
Spain	119.8	80.1	1.50
Sweden	43.4	30.3	1.43
United Kingdom	177.6	129.2	1.37
Sum of indicative targets EU-28	*1526.9*	*1077.5*	*1.42*
EU-28 target 2020	*1483.0*	*1086.0*	*1.37*

People's Republic of China, on the other hand, is still a centralised and planned economy, led by the Communist Party of China. The Chinese economy grows very fast, and has been restructuring and opening during the recent years. Nowadays it is called as a socialistic market economy. Yang et al

(2016) have studied the history of China's energy efficiency policy and divided the period from the late 1970s from today into three categories:

- planned economic period (1978-1991),
- partial market economic period (1992-2002), and
- technology-oriented economic transformation period (2003-present).

In the year 2016, China has introduced the most recent 13th five-year plan (FYP), which defines the Chinese energy efficiency targets and policies up to the year 2020. Targets and policies promoting, among other things, energy efficiency have been included also in the previous FYPs, such as the 12th (2011-2015) and 11th (2006-2010) FYP. The FYPs include usually very concrete but relative targets for specific policies such as energy efficiency, and usually an important information of each FYP is that the targets for the previous five-year period have been met. On the other hand, specific information of the actual policies are usually not given, but lists of development projects is presented. The energy efficiency related concrete targets of the 13th FYP, some of them are comparable to the EU targets, are the following (Table 2):

Table 2. Energy efficiency related indicators and targets of the 13th Five-year plan in China (Source: Central Compilation & Translation Press 2016).

Indicator	2015	2020	5-year average	Type of indicator
1. GDP (trillions of yuan)	67.7	>92.7	>6.5 %	Anticipatory
2. Labour productivity (10,000 yuan per employed person)	8.7	>12	>6.6 %	Anticipatory
19. Energy consumption, reduction per unit of GDP (%)	n/a	n/a	[15]	Obligatory
20. Non-fossil energy (% of primary energy consumption)	12	15	[3]	Obligatory
21. CO_2 emissions reduction per unit of GDP (%)	n/a	n/a	[18]	Obligatory

Notes: GDP and overall labour productivity are computed using comparable prices, while absolute figures are computed using 2015 constant prices.
Figures in square brackets are five-year cumulative totals.

Energy issues are described in Part VII of the 13th FYP, "Modern infrastructure networks" and especially in Chapter 30 "Build a Modern Energy System", which includes sections dealing with the energy mix, energy storage and transportation networks, and smart energy systems. The focus is heavily in investments to specified energy production technologies supported by an extensive list of energy development projects (Central Compilation & Translation Press 2016):

- high-efficiency smart power systems,
- clean and efficient coal utlilization (includes keeping average coal consumption per kilowatt-hour of electricity under 310 grams in existing plants and under 300 grams in new plants, but includes also increasing the proportion of coal used for power production),
- renewable energy (including construction of 60 GW new regular hydropower),
- nuclear power (installed capacity will reach 58 GW with over 30 GW under construction),

- unconventional oil and gas,
- energy transmission routes,
- energy storage facilities, and
- key energy technologies and equipment.

Energy efficiency in the consumption side s referred to in other parts of the 13th FYP. In the context of resource use and energy conservation efforts, a plan will be implemented for catching up with and exceeding international energy efficiency standards with a focus on six major energy-intensive industries – the electric power, iron and steel, building materials, chemical, petroleum and petrochemical, and nonferrous metal industries. However, detailed information of that plan is not available in the FYP. In addition to this, demonstration of comprehensive energy efficiency improvement efforts by 500 major energy consumers will be supported. Here it seems to be a clear difference to the EU policies, where energy-intensive industries and energy producers belong to the emissions trading system (ETS sector), and are outside of practically all other policy efforts focusing on the non-ETS sector – including agriculture, light industries, services and the Government, and households. However, China also promotes the establishment of a national carbon emissions trading scheme, but at the same time, refers to controlling emissions in the major carbon-emitting sectors such as power, steel, building materials and chemical industries,

In the following section, historical trends of total primary energy supply (TPES) and carbon dioxide emissions (CO_2) from fuel combustion will be presented for the EU-28 and China. Also the trends of energy intensity (final energy consumption divided by gross domestic product in real prices (FEC/GDP) and the ratio of total primary energy supply and final energy consumption (TPES/FEC) will be presented for the EU-28 and China.

Energy efficiency related trends in the EU-28 and China

In this section, key trends related to energy efficiency in the EU-28 aggregate and China are presented. These trends include first carbon dioxide emissions from fuel combustion (CO_2) and total primary energy supply (TPES), which are the variables where decomposition analysis is applied to in the next section. These trends are presented also for the individual EU-28 Member States and major Chinese regions (provinces and other administrative regions). Second, the trends of macro level proxy indicators of energy efficiency are presented, i.e. the ratio of total primary energy supply and final energy consumption (TPES/FEC) and energy intensity, i.e. final energy consumption divided by gross domestic product in real prices (FEC/GDP). These proxy indicators describe the macro level, and their ability to give information about actual energy efficiency is very limited – to get a wider perspective, analysis of energy efficiency requires a more detailed information of energy use (e.g. IEA 2014; 2017b).

Improving energy efficiency has been considered as an important energy policy measure to mitigate greenhouse gas emissions, especially carbon dioxide emissions from fuel combustion (CO_2 in the following). Figure 7 compares CO_2 emissions from fuel combustion in the EU and China, and shows a slightly decreasing trend in the European Union and an increasing trend in China. In 1990, European CO_2 emissions were twice as high as in China, but in 2015 Chinese CO_2 emissions were almost three times the emissions in the EU. When comparing CO_2 emissions from fuel combustion in relation to the amount of population, EU and China have in the recent years reached the same level, approximately 6 tonnes per capita. With the current trends, in the future per capita figures will be higher in China than in the EU (Figure 8). CO_2 emissions from fuel combustion can be decreased by improving energy efficiency. The historical trend of CO_2 emissions in the EU and China shows that the EU has been more able to limit CO_2 emissions than China. It is difficult to say to which amount it is a result of more effective energy efficiency policies in the EU, but we can set a hypothesis that EU policies have been more effective during the studied period 1990-2015. In the following, we will try to test this hypothesis by carrying out further analyses.

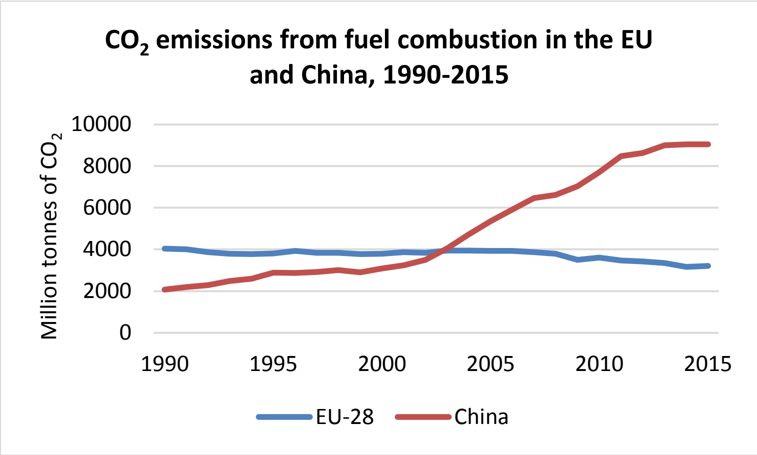


Figure 7. CO_2 emissions from fuel combustion in the EU and China, 1990-2015. Data source: IEA 2017a.

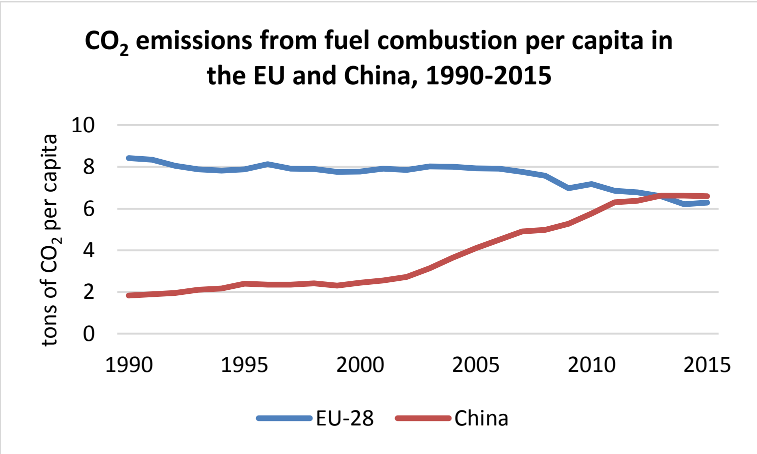


Figure 8. CO_2 emissions from fuel combustion per capita in the EU and China, 1990-2015. Data source: IEA 2017a.

Figures 9 and 10 show CO_2 emissions from fuel combustion in Chinese regions (provinces and other administrative regions) and in the EU-28 Member States, respectively. These figures show the large variety in the Chinese regions and the EU Member States. However, the large EU Member States such as Germany, United Kingdom, Italy, France, Poland and Spain cover a vast majority of the CO_2 emissions, 71 % of the total 3 200 million tonnes of CO_2 emitted in the EU in the year 2015 (Figure 9). In China, CO_2 emissions are regionally more “equally” covered, similar percentages to the EU Member States cannot be presented for Chinese administrative regions because Figure 10 covers only 20 of the 34 Chinese administrative regions. It is worth noting here, that CO_2 emissions are calculated from the use of fossil fuels. In China, there is an observed difference between the national and provincial level statistics regarding the consumption of coal (cf. Vehmas & Alexeeva 2017, Annex 1).

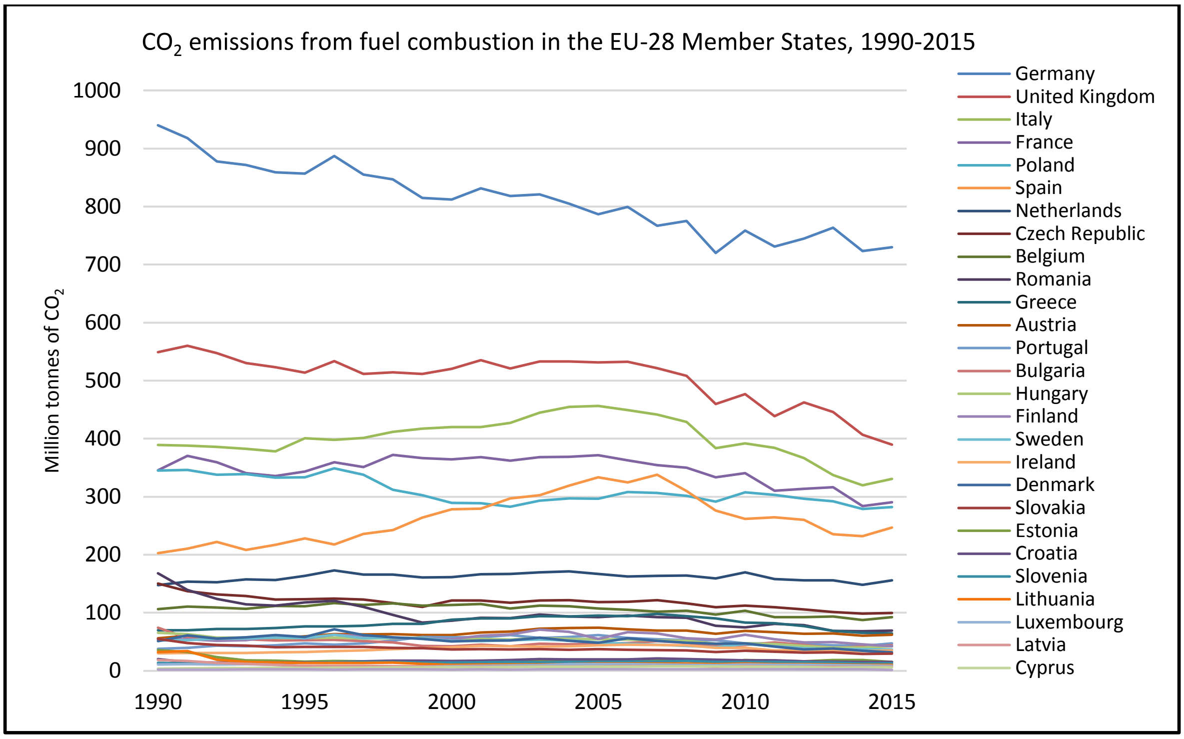


Figure 9. CO_2 emissions from fuel combustion in the EU-28 Member States, 1990-2015. Data source: IEA 2017a.

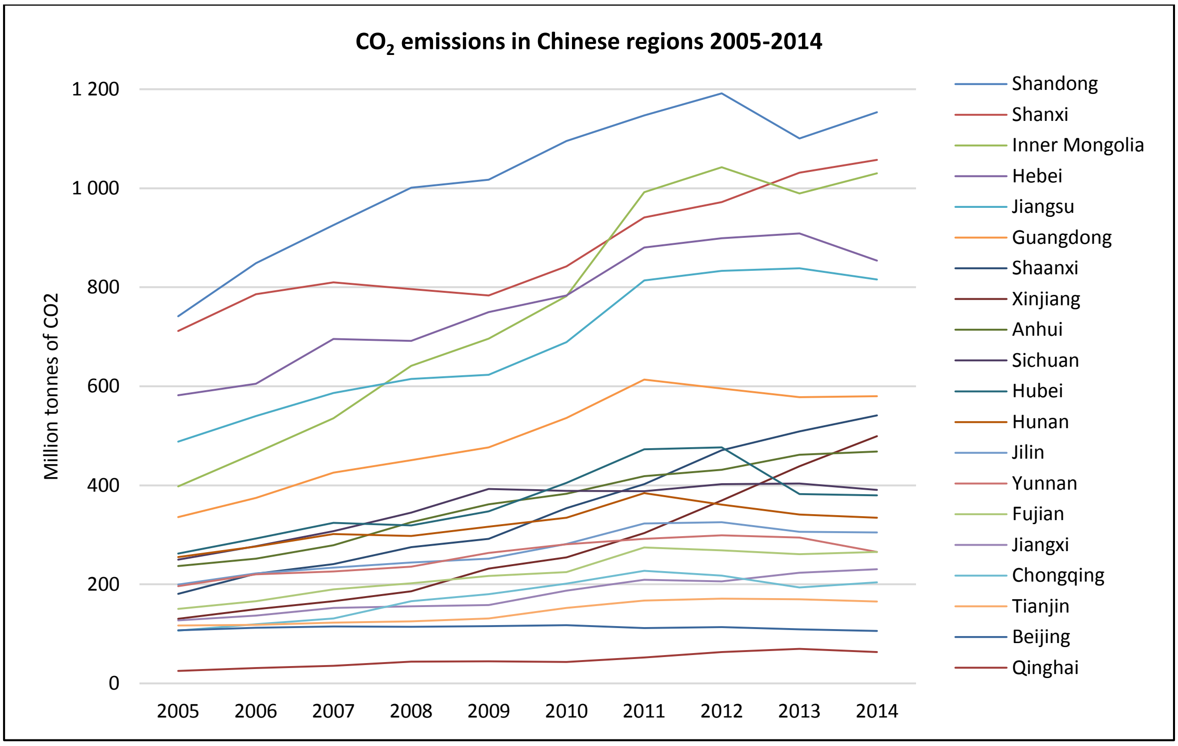


Figure 10. CO_2 emissions from fuel combustion (CO_2) in 20 Chinese regions, 2005-2014 (Vehmas & Alexeeva 2017).

CO_2 emissions from fuel combustion are emitted into atmosphere in processes where primary energy sources are transformed into energy carriers such as electricity, heat, and commercial fuels. Figure 11 shows the 1990-2015 trends of total primary energy supply (TPES) in the EU and China. The trends of TPES resemble the trends of CO_2, but the change in TPES is not as fast as the change in CO_2. This indicates that the primary energy mix used in China has turned into more carbon intensive sources such as coal, and primary energy use in the EU has turned to less carbon intensive primary energy sources such as renewables and nuclear. As a result, CO_2 intensity of primary energy (CO_2/TPES) has increased in China and decreased in the EU during the period 1990-2015 (Figure 12). These observations give further support to the hypothesis that the energy efficiency policies in the EU have been more effective than the ones in China.

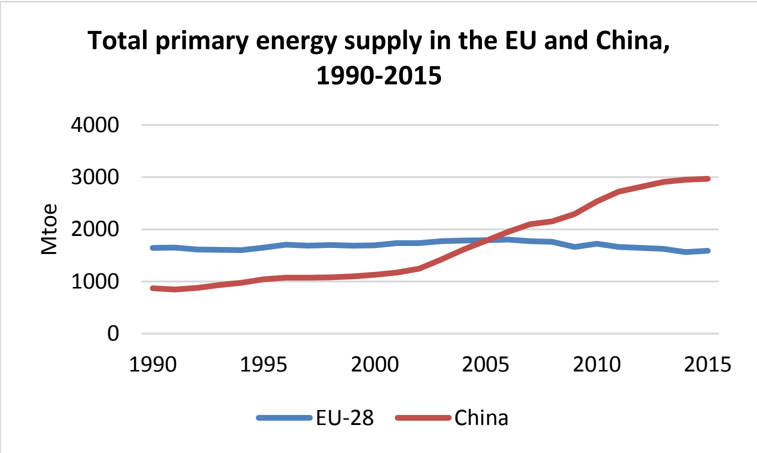


Figure 11. Total primary energy supply (TPES) in the EU and China, 1990-2015. Data source: IEA 2017a.

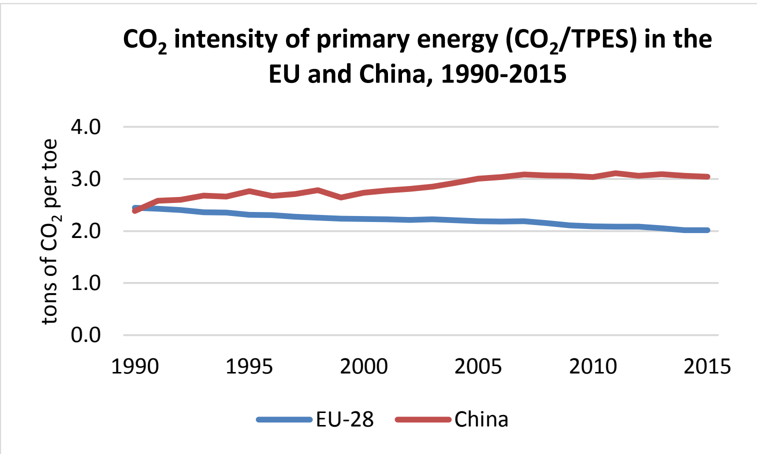


Figure 12. CO_2 intensity of total primary energy supply (CO_2/TPES) in the EU and China, 1990-2015. Data source: IEA 2017a.

Figures 13 and 14 show the trends of total primary energy supply in the 28 Member States of the European Union and in 20 Chinese administrative regions, respectively. In the EU, six large Member States covered 69 % of the total 1,600 Mtoe of primary energy in the year 2015 (Figure 13). In China, likewise CO_2 emissions, also the use of primary energy is distributed regionally more “equally”. Unfortunately, similar percentage as in the case of EU cannot be presented for China, because Figure 14 covers only 20 out of the 34 Chinese administrative regions.

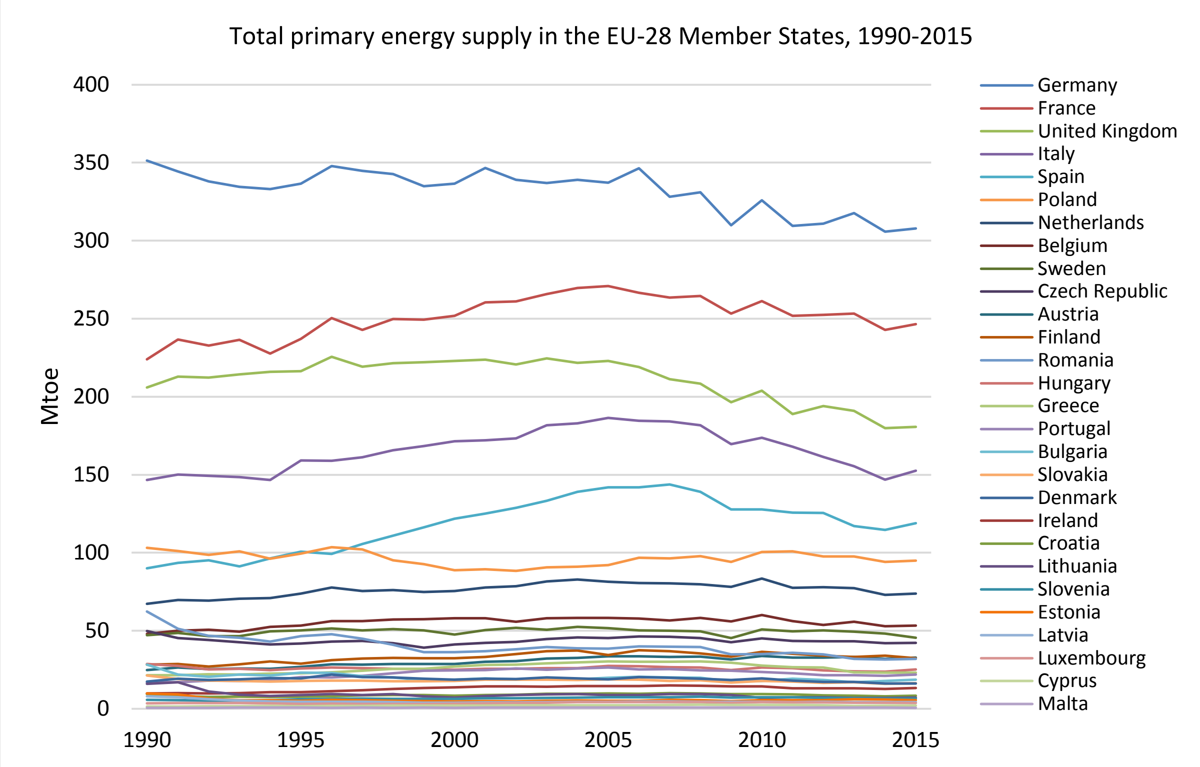


Figure 13. Total primary energy supply (TPES) in EU-28 Member States, 1990-2015. Data source: IEA 2017a.

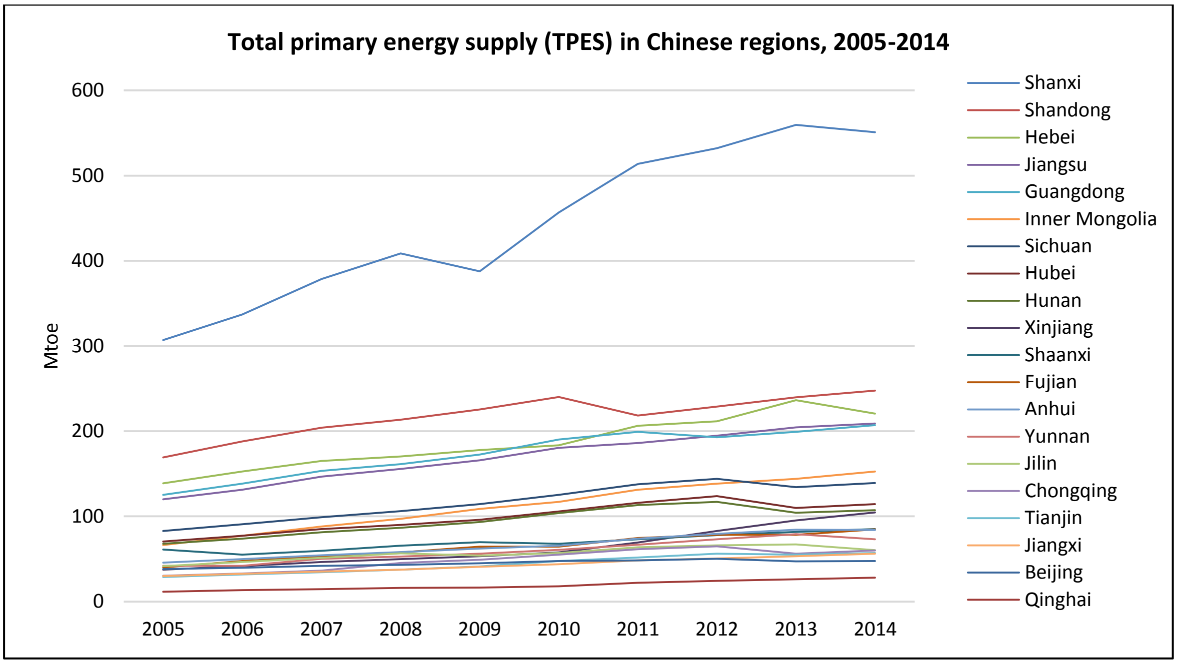


Figure 14. Total primary energy supply (TPES) in 20 Chinese regions, 2005-2014 (Vehmas & Alexeeva 2017).

In the following, trends of the macro level proxy indicators for energy efficiency will be presented. The ratio of total primary energy supply and final energy consumption (TPES/FEC) should describe the efficiency of the entire energy transformation, transferring and distribution system; how different primary energy sources are converted into different energy carriers (electricity, heat, commercial fuels), how the different energy carriers are transferred into different locations and distributed to the consumers for actual energy end-use.

In principle: the smaller the TPES/FEC ratio, the more efficient the described system. In practice, the ratio does not enable either international of temporal comparisons properly, because energy statistics treat different primary energy sources in a different way. The problem is in the treatment of some renewable energy sources and nuclear, where the TPES/FEC ratio is fixed due to difficulties in defining the amount of primary energy used for generating electricity. Electricity generated by renewable energies such as hydro, wind and solar, is calculated as primary energy with a fixed coefficient 1, and for nuclear, the coefficient is 3. So in practice, change in the mix of primary energy sources affects significantly to the value of the ratio, without any changes in actual efficiency of the entire energy system. As a result, the TPES/FEC ratio is biased because it mixes the changes in efficiency and the energy mix.

However, Figure 15 shows the trend of TPES/FEC ratio in the EU and China. The above mentioned problems are reflected in the trend of the ratio. Roughly speaking, decreasing trend of the TPES/FEC ratio in Europe is mostly caused by change in the energy mix, towards renewable energies, but in China, the increasing trend is caused by the increasing use of coal and nuclear in electricity generation; nuclear has the coefficient 3, and in coal-fired condensing power plants, the TPES/FEC ratio is also high. Due to the problems of the TPES/FEC ratio, this result does not provide additional support to the hypothesis on the difference in effectiveness of energy efficiency policies in the EU and China.

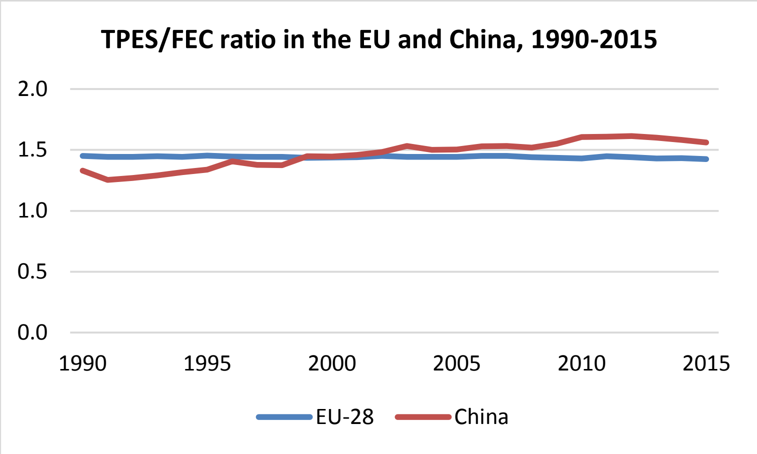


Figure 15. The ratio of total primary energy supply and final energy consumption (TPES/FEC) in the EU and China, 1990-2015. Data source: IEA 2017a.

Energy intensity is a commonly used macro level proxy indicator for energy efficiency (IEA 2014; 2017b). In the EUFORIE project, energy intensity is defined as final energy consumption divided by gross domestic product (FEC/GDP), because it is used as a driver in the decomposition analyses (see the next chapter).

Figure 16 shows the European and Chinese trends of energy intensity (FEC/GDP) during the period 1990-2015. An inverse of energy intensity (GDP/FEC) measures the economic productivity of energy consumption at the macro level of the society, and it can be claimed that the less energy is used for producing one unit of GDP, the more energy efficient the production process of that national economy is. Low intensity, however, does not mean high efficiency (IEA 2014; 2017b).

In China, energy intensity has decreased significantly during the studied period. In the EU, energy intensity has also decreased, but at a slower rate because it has been at a more low level. A significant decrease in China might not give strong support to the hypothesis that European policies on energy efficiency are more effective than the Chinese policies. However, there are many other factors, which have an effect to change in energy intensity than the explicit policies on energy efficiency. In the next section, further information in order to test the hypothesis on the effectiveness of European and Chinese energy efficiency policies will be obtained by carrying out a decomposition analysis of total primary energy supply and CO_2 emissions from fuel combustion. The idea is to find out how the changing TPES/FEC ratio and energy intensity (FEC/GDP) have affected TPES and CO_2 emissions in the EU and China.

In practice, change in energy intensity is affected not only by technical improvements in the energy consuming processes, but also by structural change over time, i.e. change in the shares of different sectors with different energy intensities in the economy. Thus, analysis of energy efficiency needs to be done also at other levels such as in different economic and industrial sectors and branches, in different production processes, inside individual sectors, in companies and households (IEA 2014; 2017b). This has been taken into account also in the EUFORIE project (see e.g. Trotta & Lorek 2015; Vehmas & Ameziane 2017; Giampietro et al 2017; Ulgiati et al 2018).

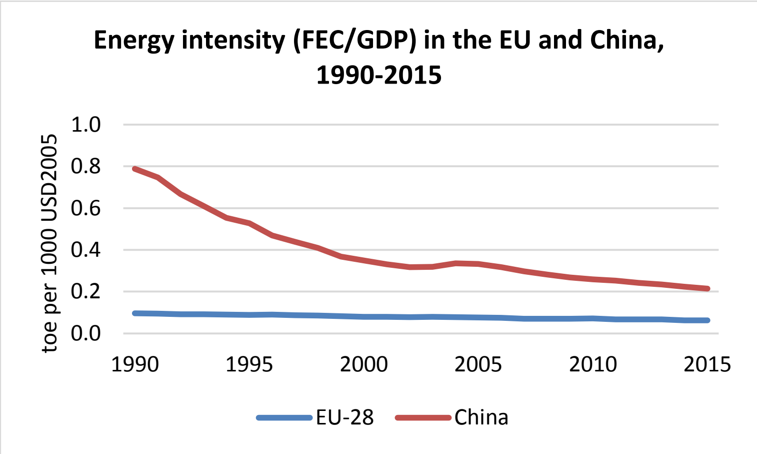


Figure 16. Energy intensity (final energy consumption divided by gross domestic product in real prices; FEC/GDP) in the EU and China, 1990-2015. Data source: IEA 2017a.

Decomposition analysis of total primary energy supply and CO_2 emissions from fuel combustion in the EU and China

The ASA decomposition approach used in this section is described in detail in Vehmas et al (2016). ASA decomposition (as all decomposition analyses) is based on case-specific master equations, which identify the drivers which have assumed to have an influence to the decomposed variable – such as total primary energy supply (TPES) and carbon dioxide emissions from fuel combustion (CO_2). The master equations used in the ASA decomposition are derived from the well-known IPAT identity (Ehrlich and Holdren 1971) and Kaya identity (Kaya 1990). In fact, the master equation of CO_2 emissions is equal to the Kaya identity. The decomposition analysis is carried out in order to find out how the changing TPES/FEC ratio and changing energy intensity (FEC/GDP) have contributed to the change in total primary energy supply (TPES) and carbon dioxide emissions from fuel combustion (CO_2). The results are used to further testing of the hypothesis about the effectiveness of energy efficiency policies in the EU and China.

TPES decomposition

Decomposition analysis of total primary energy supply (TPES) in the EU-28 and China is based on the following master equation (1):

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

where TPES is total primary energy supply, FEC is final energy consumption, GDP is gross domestic product in fixed prices, and POP is the amount of population. The decomposed effects of the factors identified in the master equation of total primary energy supply (1) are calculated as follows in equations 2-4. Each equation represents one chaining, which requires an equation for both effects. Each chaining includes thus two equations (a and b).

$$TPES / FEC = (FEC_{t-1} + \lambda 1_{tt-1} \Delta FEC_{tt-1}) \times \Delta\left(\frac{TPES}{FEC}\right)_{tt-1} \tag{2a}$$

$$FEC = \left[\left(\frac{TPES}{FEC}\right)_{t-1} + (1-\lambda 1_{tt-1})\Delta\left(\frac{TPES}{FEC}\right)_{tt-1}\right] \times \Delta FEC_{tt-1} \tag{2b}$$

$$FEC / GDP = \left[\left(\frac{TPES}{FEC}\right)_{t-1} + (1-\lambda 1_{tt-1})\Delta\left(\frac{TPES}{FEC}\right)_{tt-1}\right] \times (GDP_{t-1} + \lambda 2_{tt-1} \Delta GDP_{tt-1}) \times \Delta\left(\frac{FEC}{GDP}\right)_{tt-1} \tag{3a}$$

$$GDP = \left[\left(\frac{TPES}{FEC}\right)_{t-1} + (1-\lambda 1_{tt-1})\Delta\left(\frac{TPES}{FEC}\right)_{tt-1}\right] \times \left[\left(\frac{FEC}{GDP}\right)_{t-1} + (1-\lambda 2_{tt-1})\Delta\left(\frac{FEC}{GDPC}\right)_{tt-1}\right] \times \Delta GDP_{tt-1} \tag{3b}$$

$$GDP/POP = \left[\left(\frac{TPES}{FEC}\right)_{t-1} + (1-\lambda 1_{tt-1})\Delta\left(\frac{TPES}{FEC}\right)_{tt-1}\right] \times \left[\left(\frac{FEC}{GDP}\right)_{t-1} + (1-\lambda 2_{tt-1})\Delta\left(\frac{FEC}{GDP}\right)_{tt-1}\right] \times \left(POP_{t-1} + \lambda 3_{tt-1}\Delta POP_{tt-1}\right) \times \Delta\left(\frac{GDP}{POP}\right)_{tt-1} \tag{4a}$$

$$POP = \left[\left(\frac{TPES}{FEC}\right)_{t-1} + (1-\lambda 1_{tt-1})\Delta\left(\frac{TPES}{FEC}\right)_{tt-1}\right] \times \left[\left(\frac{FEC}{GDP}\right)_{t-1} + (1-\lambda 2)_{tt-1}\Delta\left(\frac{FEC}{GDP}\right)_{tt-1}\right] \times \left[\left(\frac{GDP}{POP}\right)_{t-1} + (1-\lambda 3_{tt-1})\Delta\left(\frac{GDP}{POP}\right)_{tt-1}\right] \times \Delta POP_{tt-1} \tag{4b}$$

In equations 2-4 above, subscript *tt-1* refers to a change between a calendar year *t* and the previous year *t-1*. Subscript t refers to absolute value of an indicator in a calendar year, and *t-1* refers to the absolute value of the previous year. Coefficients $\lambda_1 \ldots \lambda_4$ define how the joint effect of the two variables are divided into the corresponding factor in each two-factor decomposition chain. In equations 2-4, the calculated effects are separated by a and b in the equations. In all decomposition analyses carried out in the EUFORIE project, the coefficients determining the division are $\lambda_1=\lambda_2=\lambda_3=\lambda_4=\lambda_5=0.5$.

Master equation (1) for total primary energy supply (TPES) includes the following drivers:

- Driver TPES/FEC (total primary energy supply divided by final energy consumption) represents the efficiency of the energy transformation system in the analysed region. This efficiency changes when changes in the transformation process take place, e.g. when fuel use is replaced with electricity. If electricity is produced in condensing power plants, the transformation process becomes more inefficient because in condensing power plants only 35-40 % of the fuel's energy content is transformed into electricity, the rest is waste heat. Thus, a drop in the efficiency of the energy transformation process increases the need of primary energy (TPES).
- Driver FEC/GDP (final energy consumption divided by gross domestic product) describes energy intensity of the economy. Changes in this driver are due to changes in the structure of the economy, such as change from energy intensive to lighter industrial branches and services or vice versa.

- Driver GDP/POP (gross domestic product divided by number of population), GDP per capita, describes the affluence of the population.
- Driver POP (number of population) is an important driver, increasing population consumes more energy.

Ideally, total primary energy supply (TPES) consists of (i) final energy consumption (FEC), (ii) all losses when primary energy is transformed into energy carriers, and (iii) losses in the transfer and distribution of energy carriers (such as electricity) into the sites of final consumption. However, in some cases such as electricity generation from hydro, wind, solar, geothermal, and nuclear energy, measuring the amount of primary energy is difficult or impossible. In these cases different practices have been developed. In International Energy Agency statistics (IEA 2017a), which are used in the empirical analyses of this report, hydro, wind and solar power are included as electricity in the primary energy, so statistically their transformation is 100 % efficient. In the case of nuclear, on the other hand, it has been assumed that electricity is generated with a 33 % thermal efficiency. In other words, one unit of nuclear electricity requires three units of primary energy.

Special reference in the EUFORIE project is made to the drivers TPES/FEC and FEC/GDP, because they are proxy indicators reflecting energy efficiency changes at the national level. They are relevant also at other levels as indicated in work packages WP2 and WP6 of the EUFORIE project. In the following, the results from the incremental decomposition analysis of total primary energy supply (TPES) will be presented by summing up the incremental changes for three sub-periods 1990-2000 (Figure 17), 2000-2010 (Figure 18), 2010-2015 (Figure 19) and for the whole period 1990-2015 (Figure 20). In Figures 17-20, absolute incremental decomposition results have been summed up, and the percentages have been calculated from the first year's absolute TPES value. All incremental decomposition results of total primary energy supply and the drivers identified in master equation (1) during the period 1990-2015 are available in Annex 1. All data used in the TPES decomposition analysis behind the results presented in Figures 17-23 is taken from International Energy Agency (IEA 2017a).

Figure 17 shows the results of incremental TPES decomposition as a sum of annual effects for the period 1990-2000. Total primary energy supply has increased in China 30 % during this period while the increase in the EU was only 3 %. These are observed changes, the percentage numbers of the drivers are results of mathematical operations and not important as such[1]. However, they give information in terms of relative significance of the drivers in either increasing or decreasing total primary energy supply. During the period 1990-2000, GDP per capita has been the major increasing driver in the EU and in China, but a decreasing effect caused by a decrease in energy intensity has mostly compensated this increasing effect in both cases. In China, decrease in energy intensity was

[1] When long periods are considered, the numerical values of percentage changes for some drivers can be very large when presented as a percentage from the period's first year absolute value. This is why both increasing and decreasing effects can have large values, over 100 %. This is due to the way of presenting results, and could be avoided, e.g by using absolute units, or average annual change rates. The latter is very commonly used in the context of logarithmic decomposition approaches.

remarkably large during this period of fast economic growth. Population growth and increase in the TPES/FEC ratio seem to explain the increase in total primary energy supply (TPES) quite well.

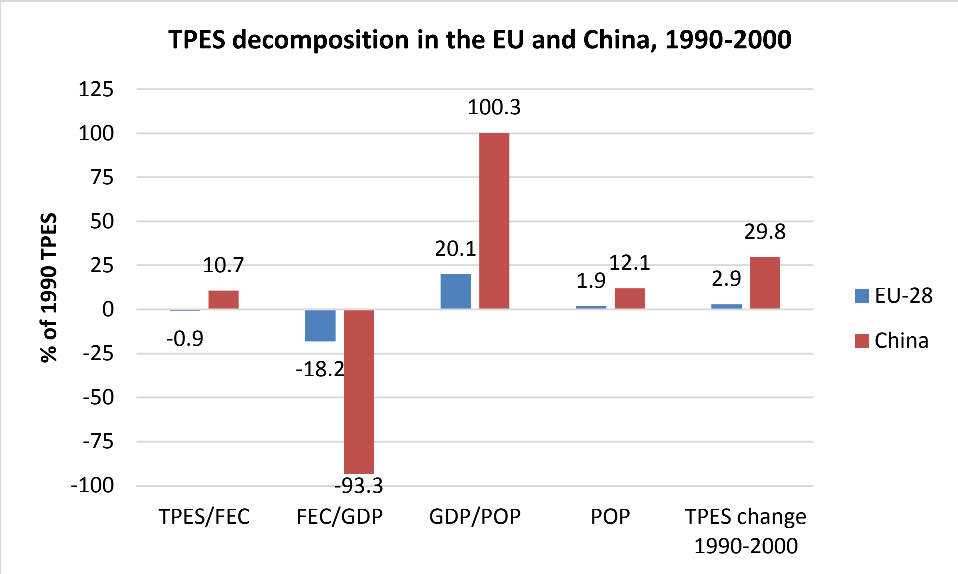


Figure 17. Decomposition results for change in total primary energy supply (TPES) in the EU and China, 1990-2000.

During the ten-year period 2000-2010, total primary energy supply stagnated in the EU but increased 46 % in China (Figure 18). In the EU, economic growth was slow because of the financial crisis at the end of the period (see Annex 1), and decreasing energy intensity totally compensated this increasing effect. In China, decreasing energy intensity could not compensate the rapid increase of TPES caused by economic growth, which, however, was slower than in the previous period (cf. Figure 17).

During the five-year period 2010-2015 Total primary energy supply decreased by 4 % in the EU, but increased 6 % in China (Figure 19). The decreasing effect in the EU came from decreasing energy intensity. Other drivers had only slight increasing effects. Economic growth (increase in GDP per capita) contributed to increasing TPES, which was only partly compensated by the decreasing energy intensity in China.

Summing up the incremental changes during the whole period 1990-2015 and showing them in percentage of the 1990 TPES value reveals the huge difference between the change in the EU and the change in China (Figure 20). Total primary energy supply (TPES) increased 240 % in China, but decreased 4 % in the EU during this 25 years period. The large difference does not only tell about the fact that the EU is a developed Western group of countries and China is a developing and industrializing country, but also refers to globalization and change in international division of labor. The huge increase in total primary energy supply in China is partly a result of foreign investments in industrial production. Thus, in China the drivers with a decreasing effect have not been able to limit the increasing TPES, which has happened in the EU. The role of globalization and relocating industrial production needs further analysis.

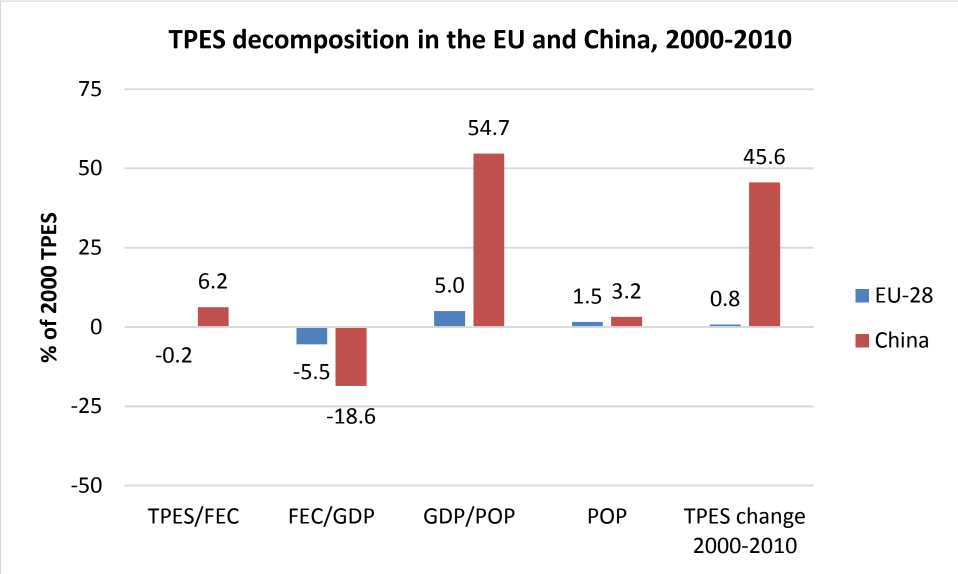


Figure 18. Decomposition results for change in total primary energy supply (TPES) in the EU and China, 2000-2010.

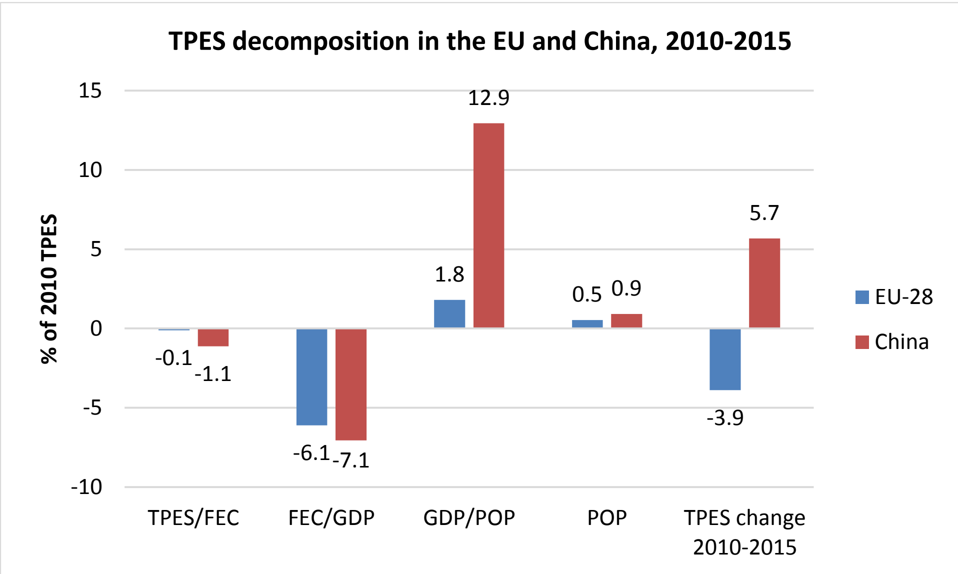


Figure 19. Decomposition results for change in total primary energy supply (TPES) in the EU and China, 2010-2015.

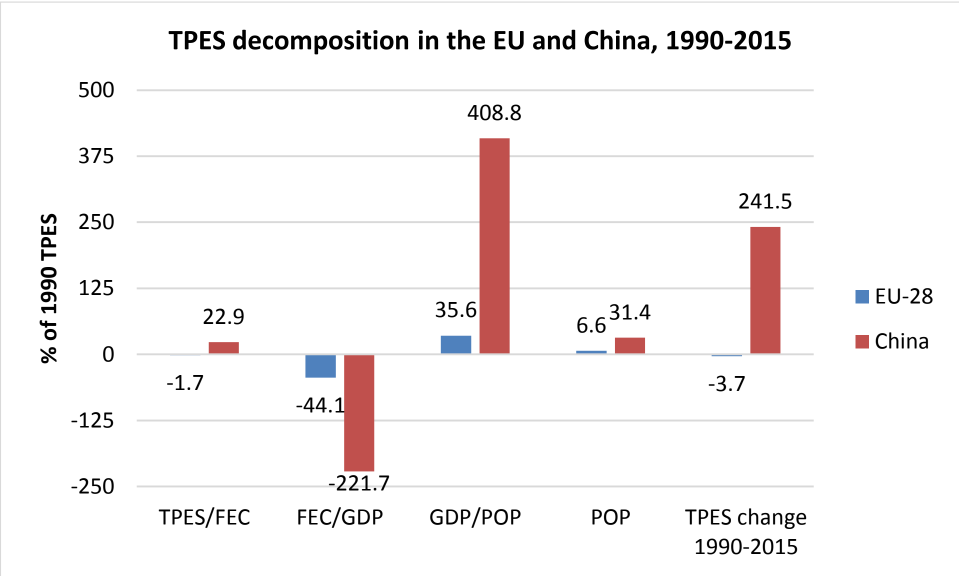


Figure 20. Decomposition results for change in total primary energy supply (TPES) in the EU and China, 1990-2015.

In Figures 17-20, decomposition results from four different periods were presented by summing up the absolute results and calculating the percentages from absolute TPES value in the first year of the period. In order to deepen the analysis, the annual changes of total primary energy supply (Figure 21) and the annual effects of energy efficiency related drivers TPES/FEC (Figure 22) and FEC/GDP (Figure 23) will be presented. In Figures 21-23, annual changes in percentage have been calculated from the previous year's absolute TPES values. Annual effects of other drivers (GDP/POP and POP) are available in Annex 1.

As the previous results from the different periods (Figures 17-20) between the years 1990 and 2015 tend to indicate, also annual changes in total primary energy supply (TPES) have been larger and mostly increasing ones in China than in the EU, where TPES has slightly decreased in most of the years during the period 1990-2015 (Figure 21). The annual changes of TPES varied between -2.6 % and 14.0 % per year in China, and between -5.8 % and 4.0 % per year in the EU. The largest annual decrease in the EU, -5.8 %, was during the financial crisis 2008-2009.

Annual contribution of change in the TPES/FEC ratio to the change in TPES has been quite a rollercoaster in China during the studied period 1990-2015 (Figure 22). Depending on the year, it has both increased and decreased TPES. However, the effect of changing TPES/FEC ratio has usually not been the most significant one in the annual change of TPES (Annex 1).

Change in energy intensity (FEC/GDP) has been the most significant driver of change in TPES with a decreasing effect both in the EU and in China (Figure 23). Change in FEC/GDP has had an increasing effect only occasionally during the studied period; in 1995-1996, 2000-2001, 2002-2003 and 2009-2010 in the EU, and in 2003-2004 and 2004-2005 in China.

Annex 1 shows that the most significant driver of change in TPES with an increasing effect has been change in GDP per capita (GDP/POP) in the EU and China. China has no exceptions during the studied period, but in the EU, GDP/POP has had a decreasing effect during the recession in 1992-1993, during the financial crisis in 2008-2009 and in 2011-2012. Change in the amount of population (POP) has had a continuous but very small increasing effect to change in TPES both in the EU and China (Annex 1).

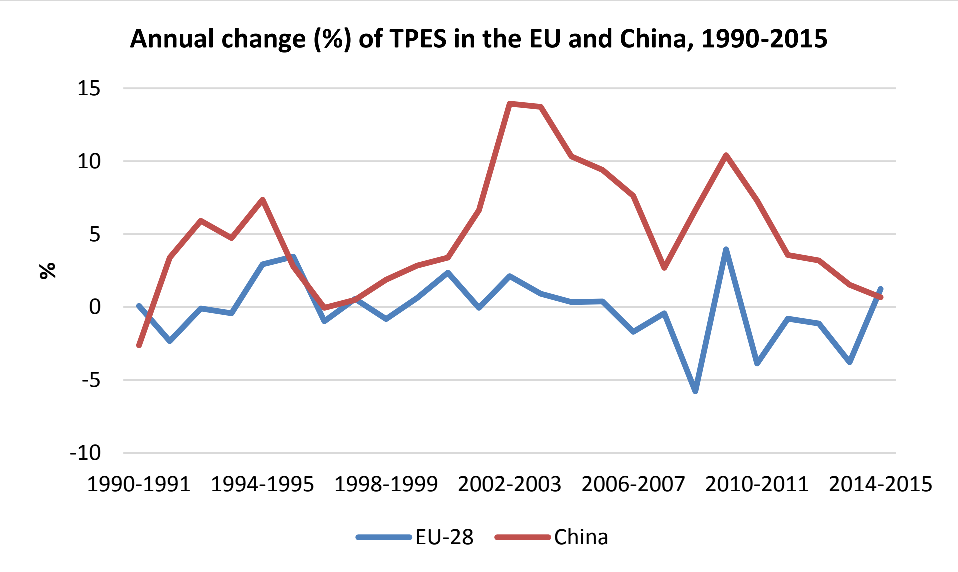


Figure 21. Annual change (%) in total primary energy supply (TPES) in the EU and China, 1990-2015. Annual percentages have been calculated from the previous year's absolute TPES values.

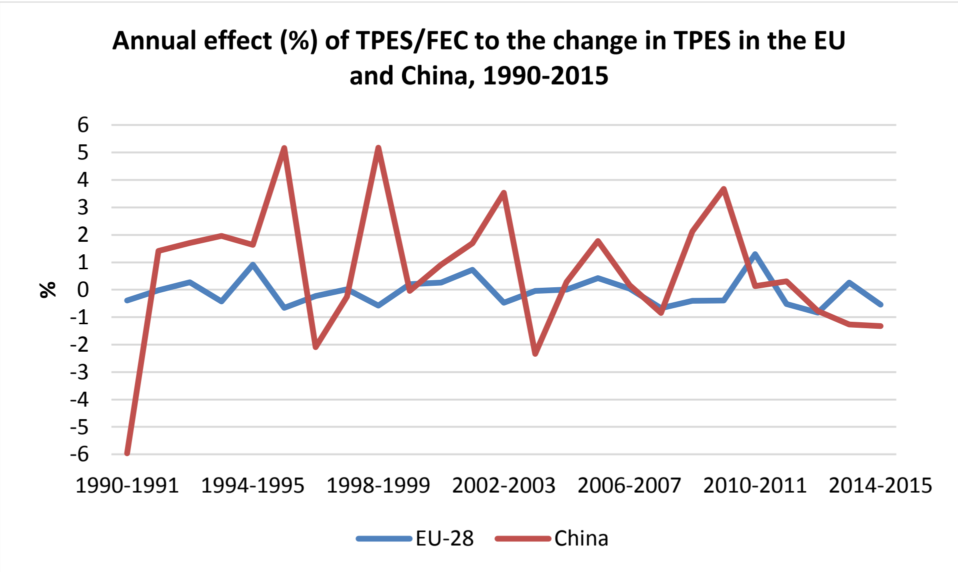


Figure 22. Annual effect of change in TPES/FEC to the change in TPES in the EU and China, 1990-2015. Annual percentages have been calculated from the previous year's absolute TPES values.

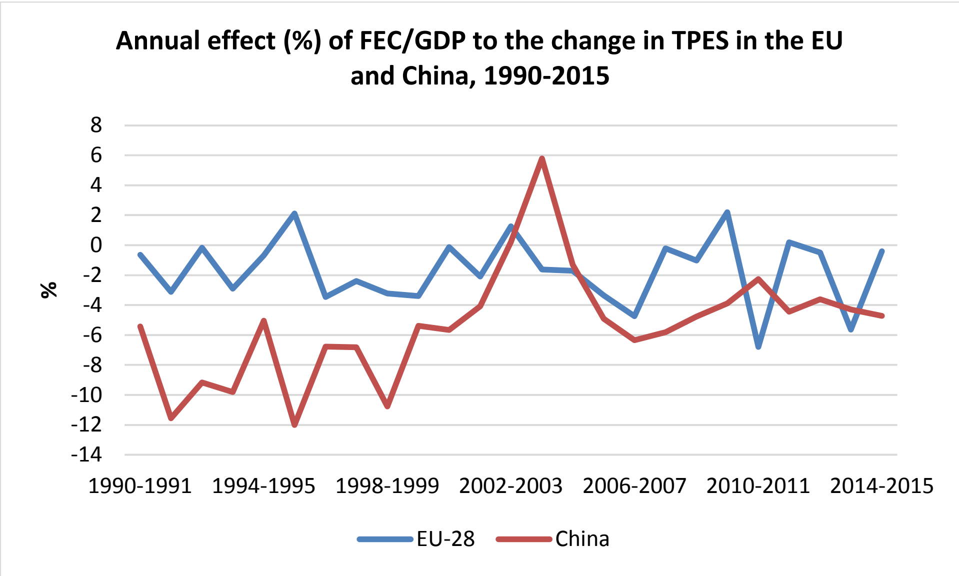


Figure 23. Annual effect of change in FEC/GDP to the change in TPES in the EU and China, 1990-2015. Annual percentages have been calculated from the previous year's absolute TPES values.

CO_2 decomposition

Decomposition of carbon dioxide emissions from fuel combustion (CO_2) in the EU-28 and China is based on the following master equation (5):

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP \tag{6}$$

The decomposed effects of the factors identified in the master equation (6) are calculated as presented in equations 7-10. Each equation represents one chaining, which requires an equation for both effects. Each chaining includes thus two equations (e.g. 7a and 7b).

$$CO2/TPES = (TPES_{t-1} + \lambda 1_{tt-1} \Delta TPES_{tt-1}) \times \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \tag{7a}$$

$$TPES = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1 - \lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times \Delta CO2_{tt-1} \tag{7b}$$

$$\begin{gathered} TPES/FEC = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1 - \lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times \\ (FEC_{t-1} + \lambda 2_{tt-1} \Delta FEC_{tt-1}) \times \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \end{gathered} \tag{8a}$$

$$FEC = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1-\lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{TPES}{FEC} \right)_{t-1} + (1-\lambda 2_{tt-1}) \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \right] \times \Delta FEC_{tt-1} \quad (8b)$$

$$FEC / GDP = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1-\lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{TPES}{FEC} \right)_{t-1} + (1-\lambda 2_{tt-1}) \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \right] \times \quad (9a)$$
$$\left(GDP_{t-1} + \lambda 3_{tt-1} \Delta GDP_{tt-1} \right) \times \Delta \left(\frac{FEC}{GDP} \right)_{tt-1}$$

$$GDP = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1-\lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{TPES}{FEC} \right)_{t-1} + (1-\lambda 2_{tt-1}) \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{FEC}{GDP} \right)_{t-1} + (1-\lambda 3_{tt-1}) \Delta \left(\frac{FEC}{GDP} \right)_{tt-1} \right] \times \Delta GDP_{tt-1} \quad (9b)$$

$$GDP / POP = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1-\lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{TPES}{FEC} \right)_{t-1} + (1-\lambda 2_{tt-1}) \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \right] \times \quad (10a)$$
$$\left[\left(\frac{FEC}{GDP} \right)_{t-1} + (1-\lambda 3_{tt-1}) \Delta \left(\frac{FEC}{GDP} \right)_{tt-1} \right] \times$$
$$\left(POP_{tt-1} + \lambda 4_{tt-1} \Delta POP_{tt-1} \right) \times \Delta \left(\frac{GDP}{POP} \right)_{tt-1}$$

$$POP = \left[\left(\frac{CO2}{TPES} \right)_{t-1} + (1-\lambda 1_{tt-1}) \Delta \left(\frac{CO2}{TPES} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{TPES}{FEC} \right)_{t-1} + (1-\lambda 2_{tt-1}) \Delta \left(\frac{TPES}{FEC} \right)_{tt-1} \right] \times$$
$$\left[\left(\frac{FEC}{GDP} \right)_{t-1} + (1-\lambda 3_{tt-1}) \Delta \left(\frac{FEC}{GDP} \right)_{tt-1} \right] \times \qquad (10b)$$
$$\left[\left(\frac{GDP}{POP} \right)_{tt-1} + (1-\lambda 4_{tt-1}) \Delta \left(\frac{GDP}{POP} \right)_{tt-1} \right] \times \Delta POP_{tt-1}$$

In equations 7-10 above, subscript *tt-1* refers to a change between a calendar year *t* and the previous year *t-1*. Subscript t refers to absolute value of an indicator in a calendar year, and *t-1* refers to the absolute value of the previous year. Coefficients $\lambda_1 \ldots \lambda_4$ define how the joint effect of the two variables are divided into the corresponding factor in each two-factor decomposition chain. In all chained two-factor decomposition analyses carried out in the EUFORIE project, the coefficients determining the division are $\lambda_1=\lambda_2=\lambda_3=\lambda_4=\lambda_5=0.5$. The two calculated effects of each two-factor decompositions are separated by letters *a* and *b* in the equations 7-10.

Master equation (6) for carbon dioxide emissions from fuel combustion (CO_2) includes the same drivers as the master equation (1) for total primary energy supply above, plus a driver CO_2/TPES (carbon dioxide emissions divided by total primary energy supply), which represents the carbon intensity of the primary energy mix. The intensity may change due to fuel switch, i.e. change from one primary energy source to another such as from fossil fuels to renewables or from coal to gas etc.

In the CO_2 decomposition, special reference is again made to the drivers TPES/FEC and FEC/GDP, because these proxy indicators describe changes in energy efficiency at the national level. Corresponding indicators are applicable and relevant also at other levels, as indicated in other work packages of the EUFORIE project.

In the following, the results from the decomposition analysis of carbon dioxide emissions from fuel combustion in the EU and China will be presented for summing up the incremental changes for three sub-periods 1990-2000 (Figure 24), 2000-2010 (Figure 25), 2010-2015 (Figure 26) and for the whole period 1990-2015 (Figure 27). The annual change in CO_2 emissions from fuel combustion and the effects of energy efficiency related drivers CO_2/TPES, TPES/FEC and FEC/GDP are presented in Figures 28-31, respectively. All incremental decomposition results for all CO_2 drivers identified in master equation (6) are available in Annex 2. All data used in the analysis behind the results presented in Figures 24-31 is taken from International Energy Agency (IEA 2017a).

In the period 1990-2000, CO_2 emissions from fuel combustion decreased 6 % in the EU, and increased 49 % in China (Figure 24). The driver GDP/POP had the largest increasing effect, and the driver FEC/GDP had almost as large but a decreasing effect to change in CO_2 emissions both in the EU and in China during this 10 years period. According to the results, the decrease in CO_2 emissions in the EU was caused, in addition to increasing GDP per capita, by decreasing CO_2 intensity of primary energy use (CO_2/TPES) during the period 1990-2000. In China, the increase in CO_2 emissions was also affected by an increase in CO_2 intensity of primary energy use, increasing TPES/FEC ratio, and population growth (POP) during the same period.

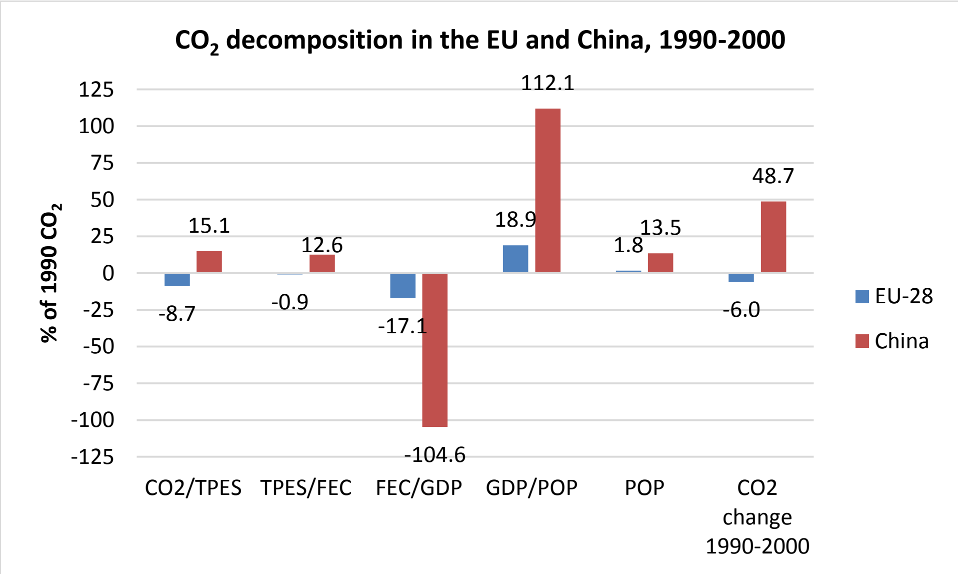


Figure 24. Decomposition results for change in CO_2 emissions from fuel combustion in the EU and China, 1990-2000.

During the other 10 years period 2000-2010, CO_2 emissions from fuel combustion increased very rapidly in China, 150 % (Figure 25). All drivers except change in energy intensity contributed to this increase, increasing GDP per capita the most. In the EU, CO_2 emissions decreased 5 % during the same period due to decreases in energy intensity (FEC/GDP) and the TPES/FEC ratio.

In the most recent five year period 2010-2015, CO_2 emissions from fuel combustion increased 26 % in China and decreased 8 % in the EU (Figure 26). Again all drivers except change in energy intensity, especially increasing GDP per capita (GDP/POP) contributed to this increase in China. In the EU, the decrease in CO_2 emissions was driven by decreasing energy intensity (FEC/GDP) and the decreasing effects CO_2 intensity of primary energy (CO_2/TPES) and TPES/FEC ratio remained marginal during this period.

When the whole period 1990-2015 is looked at in terms of percentage changes from the 1990 level, the large difference between change in CO_2 emissions and the drivers' effects becomes fully visible (Figure 27). In China, CO_2 emissions more than tripled while in the EU they decreased by 21 %. In the EU, the decreasing effect by energy intensity (FEC/GDP) was larger than the increasing effect of GDP per capita, in China the situation was vice versa. The relatively small effects of drivers CO_2/TPES and TPES/FEC were decreasing ones in the EU, and increasing ones in China during the period 1990-2015 (Figure 27).

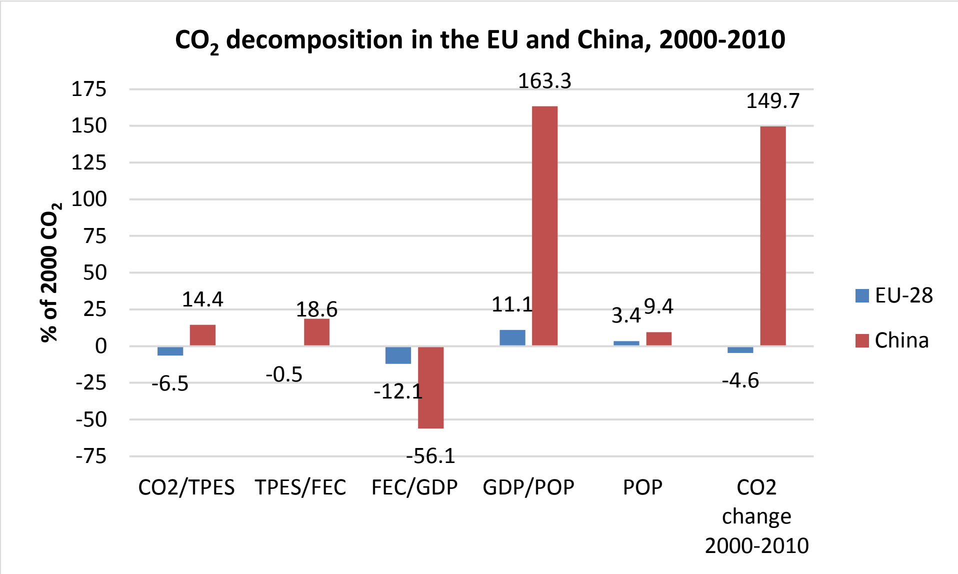


Figure 25. Decomposition results for change in CO_2 emissions from fuel combustion in the EU and China, 2000-2010.

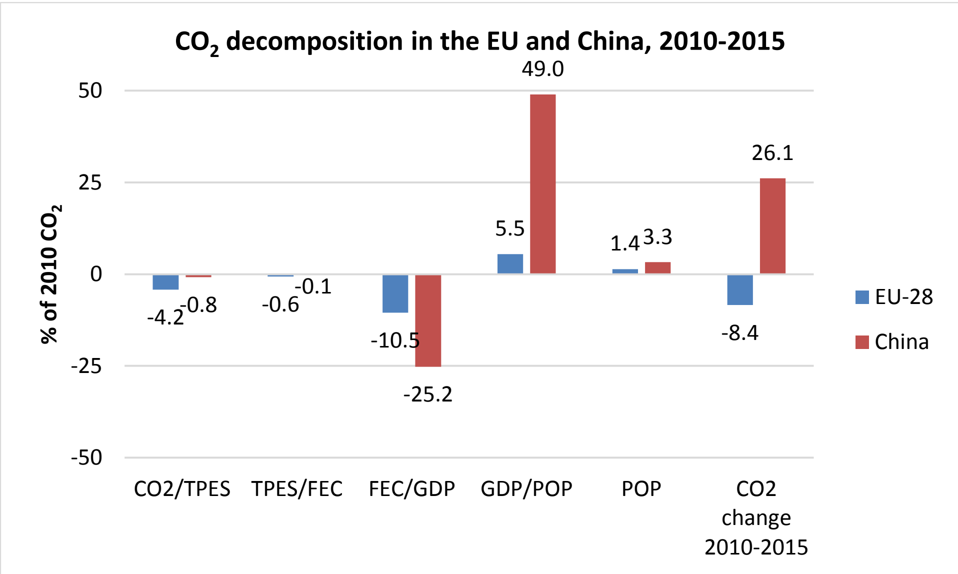


Figure 26. Decomposition results for change in CO_2 emissions from fuel combustion in the EU and China, 2010-2015.

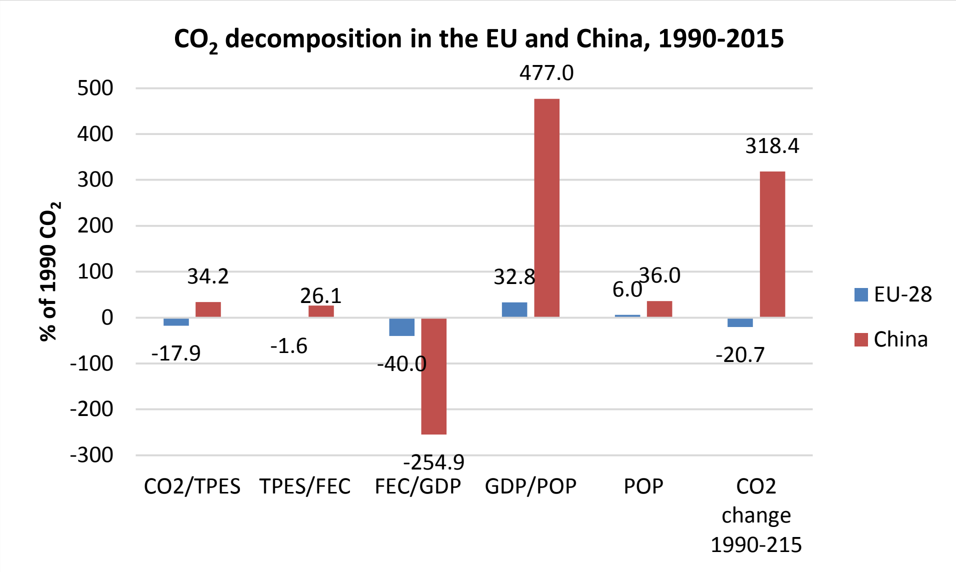


Figure 27. Decomposition results for change in CO_2 emissions from fuel combustion in the EU and China, 1990-2015.

Figure 28 shows the annual percentage changes of CO_2 emissions from fuel combustion in the EU and China. Annual changes have been usually larger in China than in the EU, the only exceptions are 1995-1996, 1998-1999, and the most recent one 2014-2015. The first two of these, 1995-1996 and 1998-1999, are the only annual decreases of CO_2 emissions in China, all other annual changes have been increasing ones in China. In the EU, CO_2 emissions have decreased in most of the years. The percentage range in the change in CO_2 emissions from fuel combustion has varied between -7.5 % and 3.2 % in the EU, and between -3.3 % and 16.6 % in China.

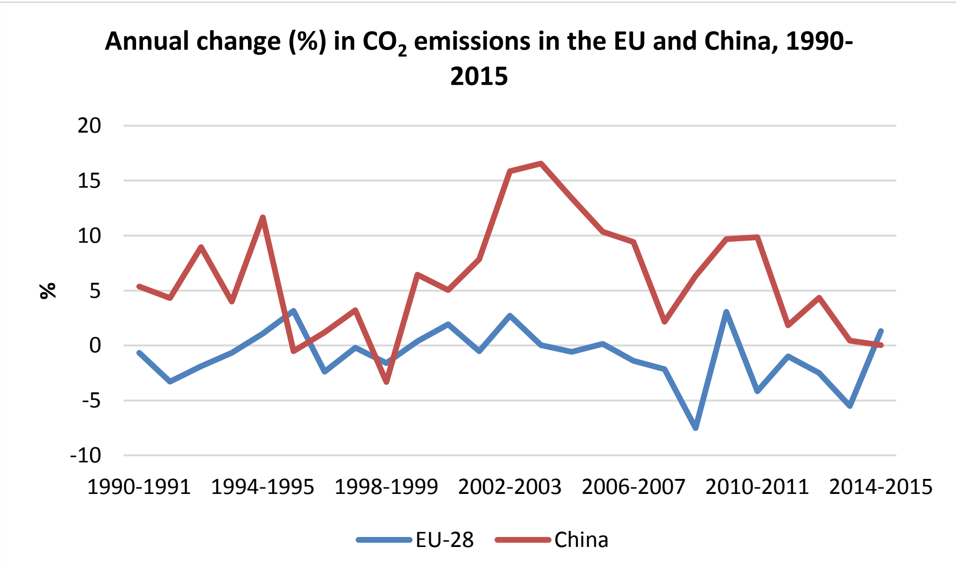


Figure 28. . Annual change (%) of CO_2 emissions from fuel combustion in the EU and China, 1990-2015. Annual percentage is calculated from the previous year's absolute CO_2 emission value.

Figures 29-31 show the annual contributions of three energy efficiency related drivers, CO_2 intensity of primary energy (CO_2/TPES; Figure 29), TPES/FEC ratio (Figure 30) and energy intensity (FEC/GDP; Figure 31). The results in Figures 29-31 are presented in percentage from the previous year's CO_2 emission value. The contributions of all drivers of CO_2 emissions from fuel combustion identified in master equation (6) above are available in Annex 2.

In the EU, the effect of driver CO_2/TPES has been most often a decreasing one during the whole period 1990-2015 (Figure 29). It has had a relatively small increasing effect only in 2002-2003 and 2014-2015. In China, the effect of driver in CO_2/TPES has been relatively larger than in the EU, and more often an increasing one (especially in 1990-1991) than a decreasing one (1998-1999 is a major exception). The significance of the TPES/FEC ratio as a driver of CO_2 emissions (Figure 30) is quite similar to the driver CO_2/TPES in the EU and China (Figure 29). Very rarely its effect has been the most significant one, neither a decreasing nor an increasing one.

Figure 31 shows the significance of energy intensity as a driver of CO_2 emissions from fuel combustion. In most of the years, it has decreased CO_2 emissions both in the EU and China. FEC/GDP has had an increasing effect only in one year (2003-2004) in China, and in the EU, it has had a slight increasing effect to CO_2 emissions in four years during the period 1990-2015: in 1995-1996, 2002-2003, 2009-2010 and 2011-2012.

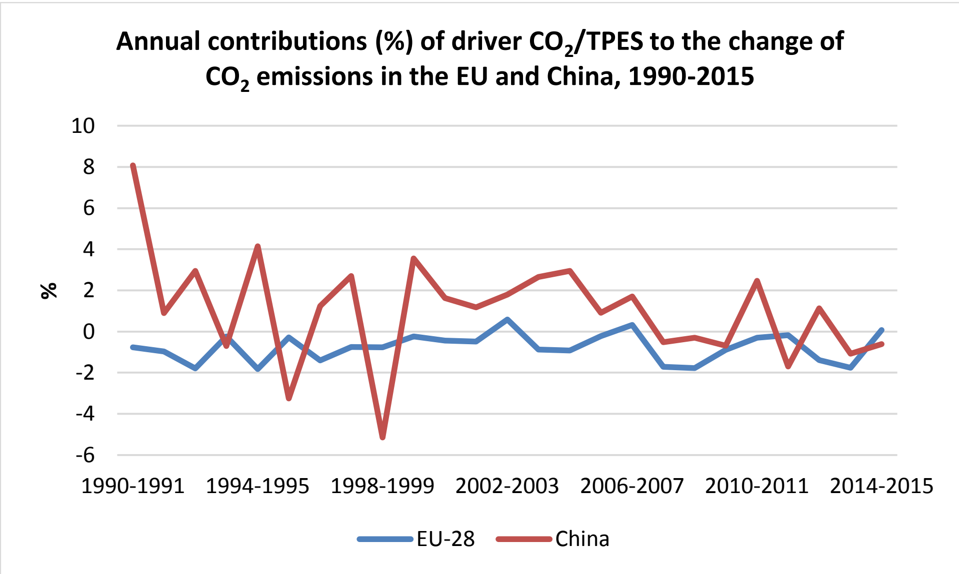


Figure 29. Annual effect of change in carbon dioxide intensity of primary energy (CO_2/TPES) to the change in CO_2 emissions from fuel combustion in the EU and China, 1990-2015. Annual percentage is calculated from the previous year's absolute CO_2 emission value.

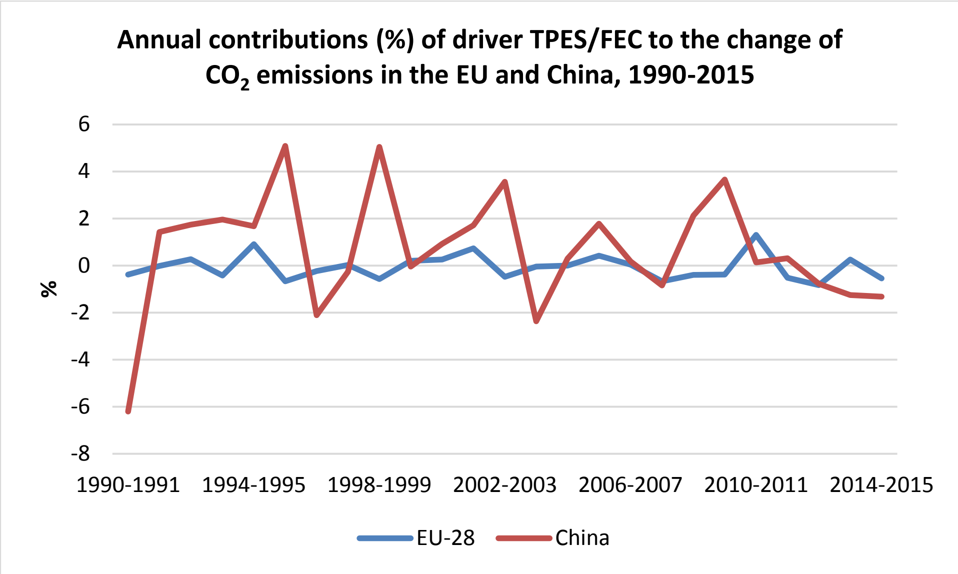


Figure 30. Annual effect of change in TPES/FEC ratio to the change in CO_2 emissions from fuel combustion in the EU and China, 1990-2015. Annual percentage is calculated from the previous year's absolute CO_2 emission value.

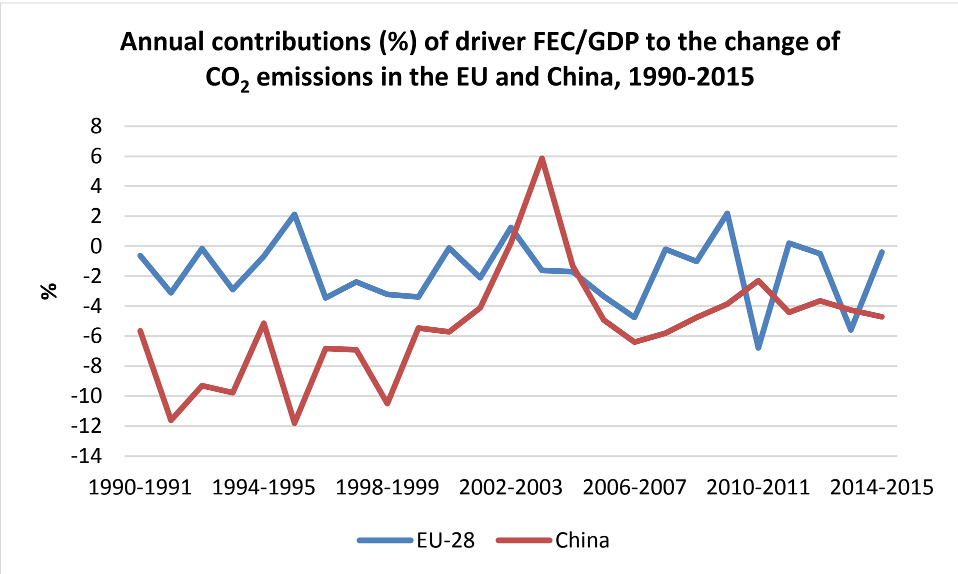


Figure 31. Annual effect of change in energy intensity (FEC/GDP) to the change in CO_2 emissions from fuel combustion in the EU and China, 1990-2015. Annual percentage is calculated from the previous year's absolute CO_2 emission value.

As a conclusion from Figures 29-31 we can say that the relative importance of the energy efficiency related drivers in the change of CO_2 emissions from fuel combustion is larger in China than in the EU, because the change in CO_2 emissions has been usually larger in China than in the EU. The effect of drivers CO_2/TPES and TPES/FEC (efficiency of the energy transformation system) varies more between increasing and decreasing ones in China than in the EU. The effect of driver FEC/GDP (energy intensity of the economy) has had quite a continuous decreasing trend during the period 1990-2015 both in China and the EU.

Future scenarios of the EU and China in the light of energy efficiency targets

In the EUFORIE project, scenarios for the future of carbon dioxide emissions and energy use have been constructed for the European Union (Vehmas et al 2017a), and for China (Chen et al 2016). The aim of these scenarios has been to look at the development with a continuation of historical trends, and with some corrective actions in order to reach the targets set in the EU and Chinese policies (cf. Chen et al 2016: Vehmas et al 2017a).

The major results are presented in Table 3 for the EU and in Table 4 for China. The targets, assumptions of the scenarios, and the format of results are different, so there is a need for further explanation and interpretation of the results (Chen et al 2016; Vehmas et al 2017a). This makes the direct comparison difficult. Some observations can, however, be made, based on the scenario analyses and the results.

In the EUFORIE project, a baseline scenario based on continuation of historical trends and four different policy scenarios (EFF1-4) have been constructed for the EU by using the LINDA model (Table 3; Vehmas et al 2017a). A baseline scenario (trend scenario) and one policy scenario have been constructed for China by using the ChinaLINDA model (Table 4; Chen et al 2016).

Table 3. Summary of the LINDA EU-28 scenarios in terms of suggested EU 2030 energy policy targets. (Source: Vehmas et al 2017a.)

Indicator	EU target 2030	LINDA EU-28 scenario				
		Baseline 2030	EFF1 2030 higher efficiency	EFF2 2030 lower efficiency	EFF3 2030 (EFF2 + commercial growth)	EFF4 2030 (EFF2 + industrial growth)
FEC	-17 % from 2005	-12.1 %	-28.0 %	-20.9 %	-21.7 %	-16.0 %
TPES	-23 % from 2005	-9.5 %	-25.5 %	-20.3 %	-20.9 %	-16.7 %
CO2	-40 % from 1990	-35.9 %	-46.7 %	-44.0 %	-44.1 %	-42.2 %
Renewables	share 27 %	23.1 %	23.6 %	23.8 %	23.8 %	24.0 %

Table 4. Projection of CO_2 emissions and final energy consumption (FEC) under the ChinaLINDA trend scenario (baseline) and ChinaLINDA policy scenario. (Source: Chen et al 2016.)

Trend scenario

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	9037	9499	9987	10502	11026	11521	12042	12588	13161	13683	14230	14803	15404	16032
FEC (Mtoe)	2970	3143	3327	3523	3693	3862	4039	4226	4423	4585	4754	4932	5119	5316

Policy scenario

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	8401	8630	8873	9131	9353	9557	9780	10023	10287	10506	10752	11026	11329	11662
FEC (Mtoe)	2594	2629	2667	2709	2741	2736	2736	2743	2756	2735	2724	2723	2731	2750

The trends of key variables in the EU-28 baseline scenario are presented in Table 5. The assumptions on sectoral economic growth, and change in electricity and fuel intensities behind the baseline scenario are presented in Tables 6-8, respectively.

Table 5. Development of gross domestic product (GDP), total primary energy use (TPES), final energy consumption (FEC), and energy intensities (TPES/GDP, FEC/GDP and TPES/FEC) in the LINDA EU-28 baseline scenario. (Source: Vehmas et al 2017a.)

	1990	2005	2015	2020	2030	2050
GDP (const. 2010 Billion US$)	9544	12911	14178	15329	17595	23771
FEC (ktoe)	1018254	1112141	981472	993323	1006547	997338
TPES (ktoe)	1398847	1547751	1411153	1418492	1361184	1265389
TPES/GDP	146,6	119,9	99,5	92,5	77,4	53,2
FEC/GDP	106,7	86,1	69,2	64,8	57,2	42,0
TPES/FEC	1,37	1,39	1,44	1,43	1,35	1,27
FEC change from 2005	-9,6 %	0,0 %	-8,8 %	-8,4 %	-12,1 %	-18,2 %
TPES change from 2005	-8,4 %	0,0 %	-11,7 %	-10,7 %	-9,5 %	-10,3 %
TPES/GDP change from 2005	22,3 %	0,0 %	-17,0 %	-22,8 %	-35,5 %	-55,6 %
FEC/GDP change from 2005	23,9 %	0,0 %	-19,6 %	-24,8 %	-33,6 %	-51,3 %
TPES/FEC change from 2005	-1,3 %	0,0 %	3,3 %	2,6 %	-2,8 %	-8,8 %

Table 6. Assumed average annual changes in sectoral value added (GDP) in the LINDA EU-28 baseline scenario. (Source: Vehmas et al 2017a.)

Annual percentual changes, GDP	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry	0.06 %	0.30 %	0.25 %	0.25 %	0.28 %	0.29 %	0.30 %
Industry	1.08 %	0.70 %	0.59 %	0.59 %	0.65 %	0.67 %	0.70 %
Transportation, communication	1.91 %	1.30 %	1.09 %	1.09 %	1.20 %	1.25 %	1.20 %
Commercial	1.03 %	2.05 %	1.72 %	1.70 %	1.85 %	1.91 %	1.75 %
Total	1.12 %	1.62 %	1.38 %	1.37 %	1.51 %	1.57 %	1.49 %

Table 7. Assumed average annual changes in sectoral electricity intensity and annual residential electricity use change in the LINDA EU-28 baseline scenario. (Source: Vehmas et al 2017a.)

Electricity intensity change	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, electricity intensity	-0.04 %	-0.04 %	-0.05 %	-0.06 %	-0.07 %	-0.08 %	-0.10 %
Industry, electricity intensity	0.00 %	-0.53 %	-0.64 %	-0.76 %	-0.92 %	-1.10 %	-1.32 %
Transportation and communication, electricity intensity	-1.97 %	-0.79 %	-0.95 %	-1.14 %	-1.37 %	-1.64 %	-1.97 %
Commercial, electricity intensity	-1.24 %	-0.08 %	-0.10 %	-0.12 %	-0.14 %	-0.17 %	-0.20 %
Residential, electricity use change	-0.85 %	2.00 %	2.00 %	1.00 %	1.00 %	0.50 %	0.00 %

Table 8. Assumed average annual changes in sectoral fuel use intensity and annual residential fuel use change in the LINDA EU-28 baseline scenario. (Source: Vehmas et al 2017a.)

Energy (fuel use) intensity change	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, fuel intensity	-1.09 %	-0.04 %	-0.05 %	-0.06 %	-0.07 %	-0.08 %	-0.10 %
Industry, fuel intensity	-1.13 %	-0.53 %	-0.64 %	-0.76 %	-0.92 %	-1.10 %	-1.32 %
Transportation and communication, fuel intensity	-2.77 %	-0.79 %	-0.95 %	-1.14 %	-1.37 %	-1.64 %	-1.97 %
Commercial, fuel intensity	-3.16 %	-0.08 %	-0.10 %	-0.12 %	-0.14 %	-0.17 %	-0.20 %
Residential, fuel use change	-3.31 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %

The baseline scenario does not lead to meeting any of the EU policy targets. Thus, policy measures are needed to change the trends. In the following, the policy scenarios (Vehmas et al 2017a) will be introduced. Tables 9-12 include the assumptions made in the energy efficiency scenarios EFF1-4 for the EU, correspondingly. Scenarios EFF1 (Table 9) and EFF2 (Table 10) assume different electricity and fuel intensities from the baseline scenario, but the assumptions on sectoral value added (GDP) are similar to the baseline scenario. Scenarios EFF3 (Table 11) and EFF4 (Table 12) assume different sectoral value added (GDP) figures from the figures in scenario EFF2, but the fuel and electricity intensities are similar to those in EFF2 (Table 10).

Table 9. Assumed electricity and fuel intensity changes in the LINDA EU-28 EFF1 scenario. (Source: Vehmas et al 2017a.)

Electricity intensity ktoe/million USD	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, electricity intensity	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %
Industry, electricity intensity	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
Transportation and communication, electricity intensity	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %
Commercial, electricity intensity	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %
Residential electricity use (not intensity)	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %
Energy (fuel use) intensity change	**2009-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %
Industry, fuel intensity	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %
Transportation and communication, fuel intensity	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %
Commercial, fuel intensity	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %
Residential, fuel use change	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %

Table 10. Assumed electricity and fuel intensity changes in the LINDA EU-28 EFF2 scenario. (Source: Vehmas et al 2017a.)

Electricity intensity change	2000-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, electricity intensity	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %
Industry, electricity intensity	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %
Transportation and communication, electricity intensity	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %
Commercial, electricity intensity	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %
Residential, electricity use change	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %
Energy (fuel use) intensity change	**2000-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %
Industry, fuel intensity	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %
Transportation and communication, fuel intensity	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %
Commercial, fuel intensity	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %
Residential, fuel use change	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %

Table 11. Assumed average annual changes in sectoral value added in the LINDA EU-28 EFF3 scenario. (Source: Vehmas et al 2017a.)

Annual percentual changes, GDP	2000-2014	2015-2019	2020-2024	2025-2029
Agriculture and forestry	0.33 %	0.30 %	0.25 %	0.25 %
Industry	0.36 %	0.00 %	0.00 %	0.00 %
Transportation, communication	2.39 %	1.50 %	1.32 %	1.09 %
Commercial	1.37 %	2.25 %	1.88 %	1.85 %
Total	1.20 %	1.62 %	1.39 %	1.38 %

Table 12. Assumed annual changes (%) in sectoral value added (GDP) in the LINDA EU-28 EFF4 scenario. (Source: Vehmas et al 2017a.)

Annual percentual changes, GDP	2000-2014	2015-2019	2020-2024	2025-2029
Agriculture and forestry	0.33 %	0.30 %	0.25 %	0.25 %
Industry	0.36 %	3.50 %	2.50 %	2.30 %
Transportation, communication	2.39 %	1.25 %	1.00 %	1.00 %
Commercial	1.37 %	1.00 %	1.00 %	1.00 %
Total	1.20 %	1.64 %	1.39 %	1.36 %

The scenario results show that the EU policy targets on CO_2 emissions and energy efficiency in 2030 are realistic, but the target of the renewables' share in energy use in 2030 seems to be more challenging with the assumed development of power plant capacity in the EU (Figure 32; Vehmas et al 2017a). However, changing the trends towards those presented in the EFF1-4 scenarios, requires change in the performance of energy users, with or without policy measures. Analysing details of possible policy measures are beyond possibilities of the LINDA model. The EU policy framework has been described above in the second chapter "Energy efficiency policies in the EU and China" of this report. Many policy options have been dealt with in other reports of the EUFORIE project (see Trotta & Lorek 2015; Spangenberg 2017; Vehmas et al 2017b).

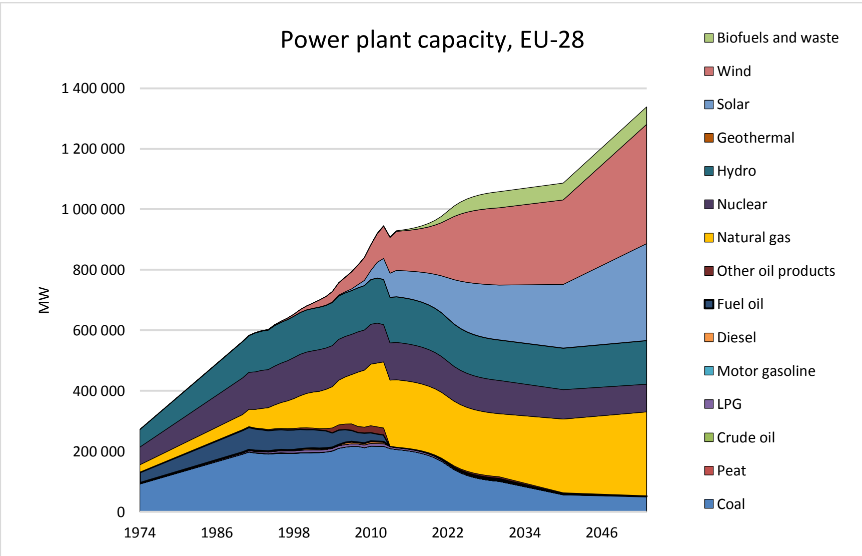


Figure 32. Development of power plant capacity by primary energy source in the LINDA EU-28 scenarios (Vehmas et al 2017).

Tables 13-15 include the assumptions made for the ChinaLINDA scenarios. Both the baseline scenario and the policy scenario assume sectoral GDP growth, which follows the target set in the 13th FYP for China in the period 2016-2020 (Table 13). Energy intensity of the baseline scenario follows the historical trends (Table 14). Table 15 shows the sectoral energy intensities, which are required for meeting the targets set for GDP growth, and relative reductions in energy consumption and CO_2 emissions following the targets set in the 13th five-year plan for China. These relative targets are for the period 2016-2020 only. In both scenarios, GDP growth slightly slows down after the year 2020 (Table 13). For most technical parameters of the ChinaLINDA model, such as fuel mix, power plant efficiencies, and construction of new power plants, a reasonable continuation of existing trends has been assumed in both scenarios (Chen et al 2016).

Table 13. Annual sectoral GDP growth rates assumed in the ChinaLINDA projection. (Source: Chen et al 2016.)

	2014-20	2020-25	2025-30
Agriculture	4.0 %	3.0 %	3.0 %
Industry	6.5 %	6.0 %	5.5 %
Transportation, communication	6.0 %	5.0 %	5.0 %
Commercial	8.0 %	7.0 %	6.0 %
Construction	9.0 %	8.5 %	8.0 %
Others	6.0 %	5.0 %	5.0 %
Total	6.5 %	5.9 %	5.5 %

Table 14. Energy intensity development projection in China in line with observed trends. (Source: Chen et al 2016.)

	2014-20	2020-25	2025-30
Agriculture	-1.2 %	-1.6 %	-2.2 %
Industry	-1.4 %	-1.9 %	-2.6 %
Commercial	-1.6 %	-2.2 %	-2.9 %
Transportation	1.7 %	0.0 %	-1.8 %
Construction	-2.2 %	-3.0 %	-4.0 %

Table 15. Energy intensity development compliant with the targets of the Chinese 13th five year plan. (Source: Chen et al 2016.)

	2014-20	2020-25	2025-30
Agriculture	-3.0 %	-4.0 %	-5.0 %
Industry	-7.0 %	-9.0 %	-11.0 %
Commercial	-6.0 %	-7.0 %	-8.0 %
Transportation	-4.0 %	-5.0 %	-6.0 %
Construction	-12.0 %	-14.0 %	-16.0 %

Tables 14 and 15 show a major difference between the intensities in the baseline and policy scenarios for China. The gap is the largest in the construction sector. This is in line with the large literature dealing with energy efficiency challenges in China. The gap is large in industry as well. Regarding Chinese policy measures, the 13th FYP includes a set of activities such as investments in new technologies and a list of development projects, which have been described above in the second chapter "Energy efficiency policies in the EU and China" of this report. In the 13th FYP of China, focus is more on concrete activities at the operational level of energy production and consumption, than in administrative, economic and informative policy instruments. The 13th FYP includes a significant initiative also in the policy instruments, i.e. establishing a national emissions trading scheme (Central Compilation & Translation Press 2016). After a set of pilots at the provincial level, China has launched the national emissions trading scheme in December 2017, and a related policy dialogue between China and the EU has been established (European Commission 2018b).

Conclusions

The aim of this deliverable was to compare energy efficiency and energy efficiency policies in the European Union and China. Energy efficiency is considered as a means to reduce energy consumption and related environmental impacts. In this deliverable, energy consumption is measured with total primary energy supply and environmental impacts is measured with carbon dioxide emissions from fuel combustion (CO_2). There is a major difference between the EU and China in both CO_2 emissions and energy use. In China, CO_2 emissions from fuel combustion as well as total primary energy supply (TPES) have strongly increased in 1990-2015, but in the EU, both have slightly decreased during the same period. Carbon intensity of total primary energy supply has increased in China, and decreased in the EU.

The TPES/FEC ratio, which describes efficiency of the entire energy transformation system, has also increased in China and decreased in the EU. In the EU, energy mix has changed towards less carbon intensive primary energy sources, but this has not happened in China yet when the period 1990-2015 is looked at. Change in the TPES/FEC ratio has thus has an increasing effect to both total primary energy supply and CO_2 emissions in China, and a slightly decreasing effect in the EU. Annual variation in these effects have been much larger in China than in the EU.

Energy intensity, in terms of final energy consumption divided by gross domestic product (FEC/GDP), has decreased in both China and the EU. In China, the decrease is much larger, from 0.75 toe/1000 USD_{2010} to 0.21 toe/1000 USD_{2010} during the period 1990-2015. In the EU, the decrease has been from 0.10 toe/1000 USD_{2010} to 0.06 toe/1000 USD_{2010} during the same period. In other words, China's energy intensity in 1990 was eight times higher than EU's energy intensity, but in 2015, China was no more than three times as energy intensive as the EU. Change in energy intensity has thus had a larger decreasing effect to total primary energy supply and CO_2 emissions in China than in the EU.

In the EUFORIE project, baseline ("business as usual") and energy efficiency scenarios for China and the EU were constructed by using the LINDA model (Chen et al 2016; Vehmas et al 2017a). Because of differences in data availability, the models are not identical. However, the energy efficiency scenarios were constructed from a starting point that specific policy targets should be met.

In the EU, the target of the share of renewable energies in the energy mix seems to be the most challenging one, because it was not met in any of the four different energy efficiency scenarios (EFF1-4). This means that the energy mix and/or technical parameters relating to the power plant capacity and load factors should be different from those assumed in the EU reference scenario (cf. European Commission 2016b). On the other hand, the energy efficiency targets in terms of primary energy and final energy use, are met in three of the four energy efficiency scenarios. Even the baseline scenario, which resembles the EU reference scenario, significant decrease in primary energy and final energy use as well as CO_2 emissions takes place.

In China, only the relative energy intensity target was analysed with the ChinaLINDA model, because the Chinese scenarios (Chen et al 2016) were constructed for a different purpose than the EU scenarios

(Vehmas et al 2017a). Thus for China, only a baseline scenario and one energy efficiency scenario were constructed. The major result from the Chinese scenarios is that there is a major gap in 2020 between sectoral energy intensities between the baseline scenario and the energy efficiency scenario. The gap is large especially in the construction sector and in the industrial sector. In these sectors, the required decrease in energy intensity is more than five times larger than the decrease observed in the baseline scenario. Economic growth in these sectors is thus of great importance if the required intensity changes are realistic. Perhaps in the next five year plan China will follow the example of EU and set absolute targets for primary and final energy use, and preferable also for CO_2 emissions. This can be expected, if the most recent news about the Northern Arctic's last bastion of sea ice breaking up (CNN 2018) related to global climate change are taken seriously.

In this deliverable, a hypothesis was set on the better effectiveness of energy efficiency policy in the EU. The trends described above give a reason to think that among other things, the development might be a result of a contribution by energy efficiency policies. When looking at the major policy documents, there is a clear difference between China and the EU. Chinese five year plans focus on relative targets and concrete actions such as investments in power plant capacity in the production side and development projects in the consumption side. EU directives focus on absolute targets, but the policy measures are left a t the disposal of Member States and the concrete actions are left for the economic actors. This is a difference in the political system, which makes actual comparison of energy efficiency policies very difficult. When the effectiveness of policies is considered, a major challenge is to isolate the share of efficiency improvement (if any) which is a result of the selected policies, and what is a result of other drivers.

A major problem in comparing energy efficiency between different countries is that economic activity and geographical territory are two different things. Because of globalization, there is no more such a thing as a national economy. The territories compared in this report, the 28 EU Member States and China, have many common economic activities. Production of many things – and related environmental impacts – takes place in the Chinese territory, but the consumption of the same things takes place, among other countries, in the EU Member States. Taking this kind of issues into account raises a question is the effectiveness of a national – or EU – energy efficiency policy a relevant question at all.

References

Central Compilation & Translation Press (2016). The 13th five-year plan for economic and social development of the People's Republic of China (2016-2020). Available at http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf.

Chen, Y., Jiang, J., Panula-Ontto, J. & Vehmas, J. (2016). Impacts of Main Economic Sectors on Energy Efficiency in the period 2015–2030 in China. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D8.2. Available at http://www.euforie-h2020-eu.

CNN (2018). The Arctic's 'last bastion' of sea ice is breaking up for the first time on record. https://edition.cnn.com/2018/08/23/world/arctic-sea-ice-breakup-greenland-trnd-wxc/index.html. Accesses 28.8.2018.

Council of the European Union (2018). Map of the European Union. http://www.consilium.europa.eu/en/documents-publications/publications/european-union-map/#.

Ehrlich, P. & Holdren, J. (1971). Impact of population growth. Science 171(3977), 1212-1217.

European Commission (2016a). Energy Efficiency Directive. Available at https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive.

European Commission (2016b). EU Reference Scenario 2016. DG for Energy, DG for Climate Action and DG for Mobility and Transport.

European Commission (2018a). 2030 climate & energy framework. Available at https://ec.europa.eu/clima/policies/strategies/2030_en.

European Commission (2018b). Emissions trading: European Commission and China hold first policy dialogue. https://ec.europa.eu/clima/news/emissions-trading-european-commission-and-china-hold-first-policy-dialogue_en.

Giampietro, M., Velasco-Fernández R. & Ripa M. (2017). Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D4.2. Available at at http://www.euforie-h2020-eu.

IEA (2014). Energy Efficiency Indicators: Fundamentals on Statistics. International Energy Agency, Paris. Available at http://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicatorsFundamentalsonStatistics.pdf.

IEA (2017a). World Energy statistics and balances Energy Agency, online data service.

IEA (2017b). Energy efficiency indicators – Highlights. International Energy Agency, Paris. Available at http://www.iea.org/publications/freepublications/publication/EnergyEfficiencyHighlights_2017.PDF.

IEA (2018). Policies and measures database: Energy efficiency/China. International Energy Agency, available at https://www.iea.org/policiesandmeasures/energyefficiency/?country=China

Kaya, Y. (1990). Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Energy and Industry Subgroup, Response Strategies Working Group. Paris: IPCC.

Lo, K. (2014). A critical review of China's rapidly developing renewable energy and energy efficiency policies. Renewable and Sustainable Energy Reviews 29, 508–516,

NBS (2017). National Bureau of Statistics, China. Easy Query online database. Available at http://data.stats.gov.cn/english/easyquery.htm?cn=E0103.

Spangenberg, J.H . (2017). Identification of promising instruments and instrument mixes for energy efficiency. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D5.2. Available at http://www.euforie-h2020.eu.

Trotta, G. & Lorek, S. (2015). Consumers and Energy Efficiency – Stock taking of policy instruments targeting household energy efficiency. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D5.1. Available at http://www.euforie-h2020.eu.

Ulgiati, S., Franzese, P.P., Fiorentino, G., Ripa, M., Viglia, S., Vassillo, C., Rallo, R., Corcelli, F., Leccisi, E., Buonocore, E., Casazza, M., Ghisellini, P. & Zucaro A. (2018). Regional case studies of energy efficiency in Europe. Analysis of the energy efficiency barriers at the regional level. European Futures for Energy Efficiency (549342 EUFORIE), Deliverable 3.1. Available at http://www.euforie-h2020.eu.

Vehmas, J. & Alexeeva, A. (2017). Provincial energy efficiency analysis in China. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable 8.4. Available at http://www.euforie-h2020.eu.

Vehmas, J. & Ameziane, M. (2017). Report on ASA analyses of energy efficiency at company level. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D6.1. Available at http://www.euforie-h2020.eu.

Vehmas, J., Luukkanen, J., Kaivo-oja, J. & Heino, H. (2016). Energy efficiency trends and their drivers in the EU-28 Member States. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable D2.1. Available at http://www.euforie-h2020.eu.

Vehmas, J., Panula-Ontto, J. & Luukkanen, J. (2017a). LINDA models: baseline and energy efficiency scenarios for the EU-28 Member States. European Futures for Energy Efficiency (649342 EUFORIE), Deliverables 2.3 and 2.4. Available at http://www.euforie-h2020.eu.

Vehmas, J., Ulgiati, S., Giampietro, M., Lorek, S., Ameziane, M., Vassillo, C., Velasco-Fernández, R., Ripa, M., Bukkens, S. & Spangenberg, J. (2017b). Summary report of the national participatory EUFORIE workshops. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable 7.1. Available at http://www.euforie-h2020.eu.

Wikivoyage (2017). List of Chinese provinces and regions. Available at https://en.wikivoyage.org/wiki/List_of_Chinese_provinces_and_regions.

WEC (2016). Energy Efficiency: A Straight Path Towards Energy Sustainability. World Energy Council, available at https://www.worldenergy.org/wp-content/uploads/2016/10/EnergyEfficiencyAStraightPathFullReport.pdf.

Yang, M., Hu, Z. & Yuan, J. (2016). The recent history and successes of China's energy efficiency policy. WIREs Energy and Environment 5(6), 715-730. DOI: 10.1002/wene.213

Annex 1. Results of incremental decomposition analysis of total primary energy supply (TPES) in the EU and China, 1990-2015

Period	TPES/FEC*		FEC/GDP*		GDP/POP*		POP*		TPES change*	
	EU-28	China	EU-28	China	EU-28	China	EU-28	China	EU-28	China
1990-1991	-0.39	-5.97	-0.64	-5.42	0.89	7.43	0.23	1.35	0.09	-2.61
1991-1992	-0.02	1.42	-3.13	-11.56	0.57	12.30	0.25	1.25	-2.32	3.40
1992-1993	0.27	1.71	-0.17	-9.17	-0.48	12.20	0.29	1.19	-0.10	5.93
1993-1994	-0.42	1.96	-2.91	-9.80	2.72	11.42	0.18	1.16	-0.43	4.73
1994-1995	0.92	1.63	-0.68	-5.04	2.53	9.65	0.18	1.13	2.94	7.37
1995-1996	-0.67	5.17	2.12	-12.01	1.88	8.55	0.13	1.07	3.46	2.78
1996-1997	-0.23	-2.09	-3.47	-6.78	2.56	7.81	0.16	1.02	-0.98	-0.04
1997-1998	0.02	-0.25	-2.39	-6.82	2.82	6.61	0.12	0.96	0.57	0.50
1998-1999	-0.58	5.18	-3.22	-10.78	2.80	6.60	0.18	0.88	-0.83	1.87
1999-2000	0.21	-0.05	-3.40	-5.38	3.62	7.47	0.20	0.80	0.63	2.85
2000-2001	0.26	0.91	-0.12	-5.66	2.07	7.41	0.17	0.74	2.37	3.40
2001-2002	0.73	1.70	-2.10	-4.09	1.07	8.34	0.26	0.69	-0.05	6.63
2002-2003	-0.47	3.53	1.25	0.21	0.97	9.55	0.37	0.67	2.12	13.96
2003-2004	-0.04	-2.34	-1.62	5.79	2.20	9.65	0.38	0.63	0.91	13.74
2004-2005	0.00	0.29	-1.71	-1.30	1.65	10.72	0.42	0.62	0.36	10.33
2005-2006	0.42	1.77	-3.35	-4.91	2.95	11.95	0.36	0.59	0.38	9.40
2006-2007	0.04	0.17	-4.75	-6.35	2.62	13.28	0.40	0.54	-1.70	7.64
2007-2008	-0.67	-0.84	-0.21	-5.81	0.07	8.83	0.39	0.52	-0.43	2.69
2008-2009	-0.40	2.12	-1.03	-4.77	-4.63	8.77	0.28	0.51	-5.78	6.64
2009-2010	-0.39	3.67	2.19	-3.88	1.86	10.12	0.32	0.51	3.97	10.42
2010-2011	1.30	0.13	-6.79	-2.26	1.40	8.94	0.22	0.50	-3.87	7.30
2011-2012	-0.52	0.31	0.20	-4.44	-0.71	7.20	0.24	0.50	-0.79	3.57
2012-2013	-0.84	-0.78	-0.50	-3.62	0.02	7.09	0.20	0.50	-1.11	3.20
2013-2014	0.26	-1.27	-5.65	-4.29	1.40	6.59	0.22	0.51	-3.77	1.54
2014-2015	-0.55	-1.33	-0.40	-4.72	1.90	6.20	0.29	0.51	1.24	0.67
1990-2000	-0.94	10.71	-18.17	-93.31	20.14	100.28	1.91	12.08	2.94	29.76
2000-2010	-0.24	6.24	-5.48	-18.56	5.00	54.69	1.55	3.19	0.83	45.56
2010-2015	-0.12	-1.12	-6.10	-7.07	1.81	12.95	0.53	0.91	-3.88	5.67
1990-2015	-1.75	22.93	-44.15	-221.65	35.60	408.77	6.63	31.44	-3.66	241.49

*All figures are presented as percentage from the first year's absolute TPES.

Annex 2. Results of incremental decomposition analysis of carbon dioxide emissions from fuel combustion (CO_2) in the EU and China, 1990-2015

Period	CO_2/TPES*		TPES/FEC*		FEC/GDP*		GDP/POP*		POP*		CO_2 change*	
	EU-28	China	EU-28	China	EU-28	China	EU-28	China	EU-28	China	EU-28	China
1990-1991	-0.77	8.07	-0.39	-6.21	-0.64	-5.65	0.89	7.74	0.23	1.40	-0.68	5.36
1991-1992	-0.97	0.90	-0.02	1.42	-3.11	-11.62	0.57	12.35	0.25	1.26	-3.28	4.32
1992-1993	-1.79	2.95	0.27	1.73	-0.17	-9.30	-0.48	12.38	0.28	1.20	-1.88	8.96
1993-1994	-0.24	-0.71	-0.42	1.95	-2.91	-9.77	2.72	11.38	0.18	1.16	-0.67	4.01
1994-1995	-1.83	4.14	0.91	1.67	-0.68	-5.14	2.51	9.84	0.17	1.15	1.09	11.66
1995-1996	-0.29	-3.26	-0.66	5.09	2.11	-11.82	1.88	8.42	0.13	1.05	3.17	-0.52
1996-1997	-1.40	1.24	-0.23	-2.11	-3.44	-6.82	2.54	7.86	0.16	1.03	-2.37	1.20
1997-1998	-0.76	2.70	0.02	-0.26	-2.39	-6.91	2.81	6.70	0.12	0.98	-0.19	3.20
1998-1999	-0.77	-5.15	-0.58	5.05	-3.21	-10.50	2.79	6.43	0.18	0.85	-1.59	-3.32
1999-2000	-0.24	3.55	0.21	-0.05	-3.39	-5.47	3.62	7.60	0.20	0.81	0.39	6.44
2000-2001	-0.43	1.63	0.25	0.92	-0.12	-5.71	2.07	7.47	0.17	0.75	1.93	5.06
2001-2002	-0.48	1.18	0.73	1.71	-2.10	-4.11	1.07	8.38	0.26	0.70	-0.53	7.85
2002-2003	0.58	1.80	-0.47	3.56	1.25	0.21	0.97	9.63	0.37	0.67	2.71	15.87
2003-2004	-0.88	2.65	-0.04	-2.37	-1.61	5.86	2.19	9.77	0.37	0.64	0.03	16.56
2004-2005	-0.92	2.95	0.00	0.29	-1.71	-1.32	1.64	10.87	0.42	0.63	-0.56	13.42
2005-2006	-0.23	0.91	0.42	1.78	-3.35	-4.93	2.95	12.00	0.36	0.59	0.15	10.34
2006-2007	0.32	1.71	0.04	0.17	-4.76	-6.40	2.62	13.39	0.40	0.55	-1.39	9.41
2007-2008	-1.72	-0.52	-0.67	-0.84	-0.21	-5.80	0.07	8.80	0.39	0.52	-2.15	2.16
2008-2009	-1.78	-0.31	-0.40	2.12	-1.02	-4.76	-4.59	8.76	0.28	0.51	-7.50	6.32
2009-2010	-0.89	-0.70	-0.39	3.66	2.18	-3.87	1.85	10.09	0.31	0.51	3.06	9.69
2010-2011	-0.31	2.46	1.30	0.13	-6.78	-2.29	1.40	9.05	0.22	0.50	-4.17	9.85
2011-2012	-0.18	-1.71	-0.52	0.31	0.20	-4.41	-0.71	7.14	0.24	0.49	-0.97	1.83
2012-2013	-1.38	1.14	-0.83	-0.78	-0.50	-3.64	0.02	7.13	0.20	0.50	-2.49	4.35
2013-2014	-1.76	-1.08	0.25	-1.26	-5.60	-4.27	1.39	6.56	0.22	0.51	-5.50	0.45
2014-2015	0.08	-0.62	-0.55	-1.32	-0.40	-4.71	1.90	6.19	0.29	0.51	1.32	0.05
1990-2015	-17.93	34.19	-1.56	26.14	-40.03	-254.86	32.83	476.98	6.02	35.99	-20.67	318.44
1990-2000	-8.72	15.05	-0.89	12.63	-17.13	-104.58	18.89	112.10	1.82	13.49	-6.02	48.69
2000-2010	-6.48	14.43	-0.49	18.59	-12.07	-56.07	11.08	163.27	3.38	9.45	-4.57	149.67
2010-2015	-4.22	-0.76	-0.61	-0.10	-10.47	-25.23	5.48	48.97	1.39	3.26	-8.42	26.15

*All figures are presented as percentage from the first year's absolute CO_2 emissions.