Utrecht University

Targeting Energy Efficiency:
Exploring energy intensity pathways towards a global target

Master's Thesis - GEO4-2321

Sustainable Development – Energy & Materials
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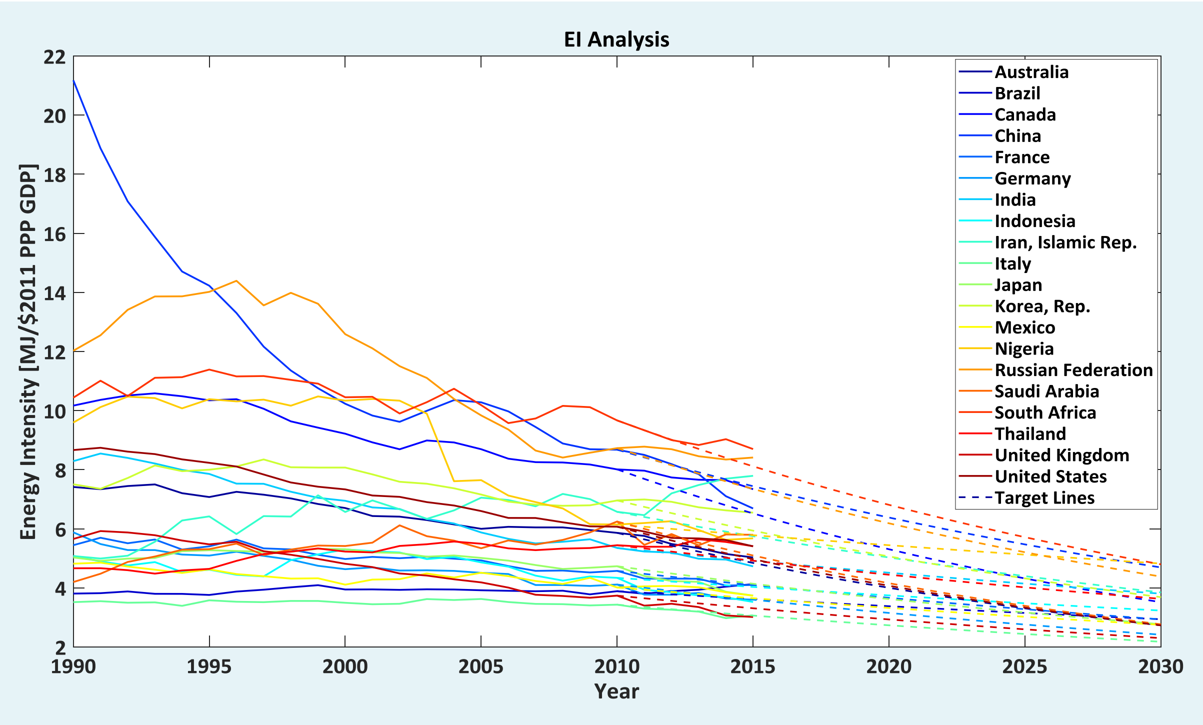

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Summary

The Sustainable Development Goals were formed in 2015 which envisioned the progress needed to transition towards a sustainable planet. Global goals and accompanying targets were hereby identified that outlined the desired progress until 2030. One of the set targets is to double the global rate of improvement in energy efficiency. This means a reduction in global energy intensity from 5.8 to 3.42 MJ per $2011 PPP GDP should be observed between 2010-2030. Pathways that explore how this target could be achieved with national efforts were however not available.

The objective of this research was therefore to expose the link between the global target and national energy efficiency commitments in order to stimulate the needed progress. A top-down allocation approach was used to translate the global target into fair and effective national targets, while a bottom-up national commitments approach was used to deduce possible future energy intensity levels from bundled information on national energy efficiency commitments in country profiles. A composite indicator allocation method was used to model six scenarios with different weightings for the energy intensity, energy use per capita, CO_2 intensity of energy use, and GDP per capita indicators. 20 identified high-impact countries with around 70% global coverage were considered in this top-down part of the research. Country profiles were made in the bottom-up part of the research for the top five high impact countries, China, the United States, India, the Russian Federation and Japan. Information on national commitments was combined with available projections for TPES and GDP to deduce the possible future energy intensity levels of these countries.

The allocation scenario in which the weighting system was corrected for the correlation between the indicators outlined a pathway that was the most fair and effective in reaching the global target among the high-impact countries. The United States, Japan and the Russian Federation showed the need for increased efforts to make improvements at the allocated target rates, while China and India are indicated to achieve their allocated energy intensity targets.

The results reveal that allocation methods from different fields of study can be adapted for allocation of the set energy efficiency target. The model also showed to be valuable for monitoring, evaluation and feedback purposes that can enhance the rate of improvement to the desired level to reach the global target.

Preface

During the Sustainability Modelling & Indicators course I was introduced to the Sustainable Development Goals, which presented a framework in which all sustainability topics were gathered and translated into global goals and targets. Through my desire to contribute to the transition towards a sustainable energy system, I was immediately drawn to the global energy efficiency target for 2030. The thing that really bothered me was that no clear pathways towards reaching this target were discussed. Without exploring how national efforts influence the target within the global context, the main message conveyed by this target seemed: let's all try our best to make improvements and hope we reach the global target collectively. For me it was therefore logical to start researching what the global target meant on a national scale, and to find out how fair and effective targets could be defined. This thesis is therefore the culmination of research done on this topic since that introduction to the Sustainable Development Goals, and I hope that it will help to speed up the progress needed to achieve the global energy efficiency target in 2030.

Table of Contents

List of Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
CAGR	Compound Annual Growth Rate
GDP	Gross Domestic Product
GTF	Global Tracking Framework
IEA	International Energy Agency
IEPPEC	International Energy Policy & Programme Evaluation Conference
IMF	International Monetary Fund
MJ	Megajoule
(I)NDCs	(Intended) Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parity
PwC	PricewaterhouseCoopers
REEI	Rate of Energy Efficiency Improvement
SDGs	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
TPES	Total Primary Energy Supply
UNSD	United Nations Statistics Department
WEO	World Energy Outlook

Country codes

AUS	Australia	**JPN**	Japan
BRA	Brazil	**KOR**	Korea, Rep.
CAN	Canada	**MEX**	Mexico
CHN	China	**NGA**	Nigeria
FRA	France	**RUS**	Russian Federation
DEU	Germany	**SAU**	Saudi Arabia
IND	India	**ZAF**	South Africa
IDN	Indonesia	**THA**	Thailand
IRN	Iran, Islamic Rep.	**GBR**	United Kingdom
ITA	Italy	**USA**	United States

Indicator/Scenario Codes

EQ	Equal
EI	Energy Intensity
EUC	Energy Use per Capita
CO2I	CO_2 Intensity
GDPC	GDP per Capita
CORR	Correlation Corrected

1 Introduction

In a world that experiences increasing global pressures approaching planetary boundaries such as climate change, resource scarcity and pollution, it is necessary to outline strategies that create a sustainable future (Rockström et al., 2009). With the formation of the United Nations Sustainable Development Goals (SDGs) in 2015, 17 global goals and 169 accompanying targets have been set for the year 2030 to transition to a sustainable planet. Goal 7 hereby specifically focusses on ensuring affordable, reliable, sustainable and modern energy for all. Five global targets have therefore been defined that envision the desired progress in access to energy systems, the share of renewables, rate of energy efficiency improvements and support for developing countries (Schmidt-Traub et al., 2015). The reason for setting this goal and accompanying targets is that energy systems are essential for human and economic development by influencing all sectors to some extent (Liu et al., 2016; Nilsson et al, 2013). Additionally, the global energy demand is continuously rising while the energy sector is already a major contributor to greenhouse gas emissions and pollution. Reaching targets for energy access, efficiency and renewable shares is considered to be one of the most important and challenging goals for global sustainability, since simultaneously reaching all targets is expected to experience complex dynamics (World Bank, 2017).

Energy efficiency is an often overlooked area even though it is commonly considered as the first and most important aspect regarding energy sustainability (Campbell et al., 2014). While maybe not being as exciting as incorporating renewable energy systems or increasing energy access, energy efficiency measures ensure that losses are minimised and are generally among the most cost-effective strategies to increase sustainable energy use. In order to measure energy efficiency, usually an input-output analysis is made on the specific energy using system. This can be quantified in multiple forms, or indicators (Pérez-Lombard et al., 2013), for different levels of aggregation (figure 1). The proposed indicator for the SDGs energy efficiency target is on the highest aggregated level concerning all countries in the global context. This is defined as the energy intensity (EI) indicator and quantified as total primary energy supply (TPES; Megajoule) per gross domestic product (GDP) in 2011 purchasing power parity dollars ($2011 PPP). This indicator thus shows how energy intensive an economy is. A sustainable global economy should aim to reduce this ratio, indicating that it is decoupling from energy use. While the energy intensity indicator is a proxy for measuring actual energy efficiency and is influenced by outside factors, it is the most commonly used indicator for evaluating energy efficiency on the most aggregated levels (Ang, 2006). This is because GDP and TPES data are among the most readily and universally available. The energy efficiency target that is set forward by the SDGs is: “Double the global rate of improvement in energy efficiency by 2030” (Schmidt-Traub et al., 2015, p. 49). Pathways that explore how this global target can be achieved are however lacking.

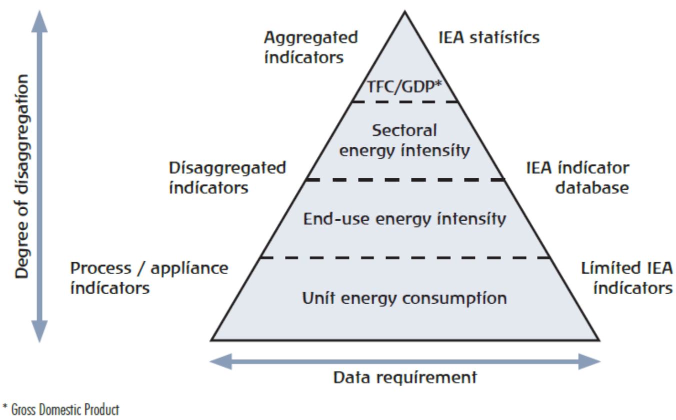

Figure 1: Energy efficiency indicators pyramid with degree of aggregation and level of data requirement (IEA, 2014b)

1.1 Problem definition

Since the global energy intensity is comprised of all national intensity levels, there is a need to expose the link between the global target and national energy efficiency commitments in order to stimulate the needed progress. However, both the top-down and bottom-up connection between the two is unclear. Translating a global target into national targets encounters issues with effort sharing (Green et al., 2014; Zhou & Wang, 2016), while national energy efficiency commitments are expressed in different forms and do not represent progress on the level of the chosen indicator (Green et al., 2014; Kern et al., 2017; Kerr et al., 2017). Thus far, no efforts have been made to translate the global target into fair and effective national targets, nor has there been an elaborate review on the way that existing national commitments influence the future energy intensity levels of different countries. Balancing the top-down and bottom-up linkages between the global target and national commitments can potentially create effective strategies to speed up the global rate of improvement in energy intensity (Green et al., 2014).

1.2 Research objective and questions

The objective of this research is thus to expose the link between the global energy efficiency target of the SDGs and existing national energy efficiency commitments. The research question therefore states: *How can the global energy efficiency target of the Sustainable Development Goals be translated into fair and effective national targets, and how do these compare to national energy efficiency commitments?*

The research is hereby divided into the top-down approach where the global target is allocated into national targets, and the bottom-up approach where possible future energy intensity levels are deduced from national commitments. Together, these approaches link the two parts of the main research question. This linkage is ultimately used to compare the resulting national energy intensity targets and possible future energy intensity levels.

This research firstly continues with elaborating on the theory and background information of the research topic. Secondly, the methods chapter describes the gathering, sources and processing of data within the research steps. The results of both approaches are then shown and compared. Lastly, the research discusses the results and ends with a conclusion.

2 Theory & Background Information

This chapter describes the relevant theories, concepts and background information for both the top-down and bottom-up approaches of the research. First, the energy efficiency target of the SDGs is discussed in more detail to further explain the global context and the need to explore pathways towards the set target. This is followed by elaborating on the available and useful allocation methods to translate this target into fair and effective national energy intensity targets. After this, the national energy efficiency commitments and international energy efficiency scoring systems are described. Lastly, the way in which country profiles can be used to deduce possible future energy intensity levels for comparison with the allocated targets is explained, and a framework that combines all discussed concepts is shown.

2.1 Top-down approach

2.1.1 *The SDGs' energy efficiency target*

The concept that this research is most linked to is the energy efficiency target of the UN Sustainable Development Goals. In 2015 a total of 17 goals and 169 accompanying targets were formed that outlined the desired sustainable transition until 2030. Within goal number 7, which states: "Ensure access to affordable, reliable, sustainable and modern energy for all", a specific target was set for global energy efficiency. Target 7.3 reads: "Double the global rate of improvement in energy efficiency by 2030" (Schmidt-Traub et al., 2015, p. 49). Below the relevant definitions (World Bank, 2017) needed to set this target can be found (figure 2).

Total primary energy supply (TPES) (in terajoules [TJ])	Production plus net imports minus international marine and aviation bunkers plus/minus stock changes (IEA definition). *Data sources:* Energy balances from IEA, supplemented by United Nations Statistics Division (UNSD) for countries not covered by the IEA.
Gross domestic product (GDP) (in 2011 purchasing power parity [PPP] U.S. dollars)	Sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. GDP is measured at PPP at constant 2011 U.S. dollars. *Data source:* World Bank's World Development Indicators (WDI).
Energy intensity of primary energy supply (in MJ per 2011 PPP $)	$\text{Energy intensity of TPES} = \frac{\text{Primary energy supply (MJ)}}{\text{GDP (2011 PPP \$)}}$ Ratio between energy supply and GDP measured at PPP. Energy intensity is an imperfect proxy for energy efficiency. It indicates how much energy is used to produce one unit of economic output. A lower ratio indicates that less energy is used to produce one unit of economic output.
Rate of primary energy intensity improvement (%)	$\text{CAGR of TPES} = \left(\frac{PEI_{t2}}{PEI_{t1}}\right)^{\frac{1}{(t2-t1)}} - 1\ (\%)$ where, PEI_{t1}: primary energy intensity in year *t1* PEI_{t2}: primary energy intensity in year *t2* Compound annual growth rate (CAGR) of primary energy intensity between two years. Represents the average annual growth rate during the period. Negative values represent decreases (or improvements) in energy intensity (less energy is used to produce one unit of economic output), while positive numbers indicate increases in energy intensity (more energy is used to produce one unit of economic output).

Figure 2: Definitions on TPES, GDP, energy intensity and rate of primary energy intensity improvement (World Bank, 2017, p. 74)

The 2030 target is hereby based on the rate of primary energy intensity improvement over 1990-2010. The observed global energy intensity went from 7.58 to 5.8 MJ per $2011 PPP GDP in this period, which translates to a compound annual growth rate (CAGR) of -1.34%. This means that a CAGR of -2.68% should be observed in the 2010-2030 time frame. This was actually conservatively set to -2.6%

to become more feasible. One reason for doing so might be that between 2010-2015 a global CAGR of -2.2% was observed, meaning that increased efforts on energy intensity improvements have to be made to go from 5.8 to the target 3.42 MJ per $2011 PPP GDP in 2030 (World Bank, 2017; IEA, 2014a; IEA, 2014b). The Sustainable Energy for All (SE4ALL) initiative was assigned to monitor the progress on the three main pillars within goal 7 (energy access, renewable shares & energy efficiency), and reviews this every two years in the Global Tracking Framework (GTF) report. Special attention is given to 20 identified high-impact countries for each pillar that are key for reaching the respective global targets (World Bank, 2017). A table of these high-impact countries for the energy efficiency target with 2015 International Energy Agency (IEA) data for TPES and GDP can be found in Appendix B.

2.1.2 *Allocation*

A top-down approach to translate the global energy efficiency target to national targets is to divide the global target according to allocation principles. Allocation and accountability theories can be found for various sustainability topics in which targets have to be translated to specific improvements. Zhou & Wang (2016) for example review the use of allocation theories for CO_2 emissions reduction targets. Multiple strategies such as the indicator, optimization, game theoretic and hybrid approaches can be applied (figure 3).

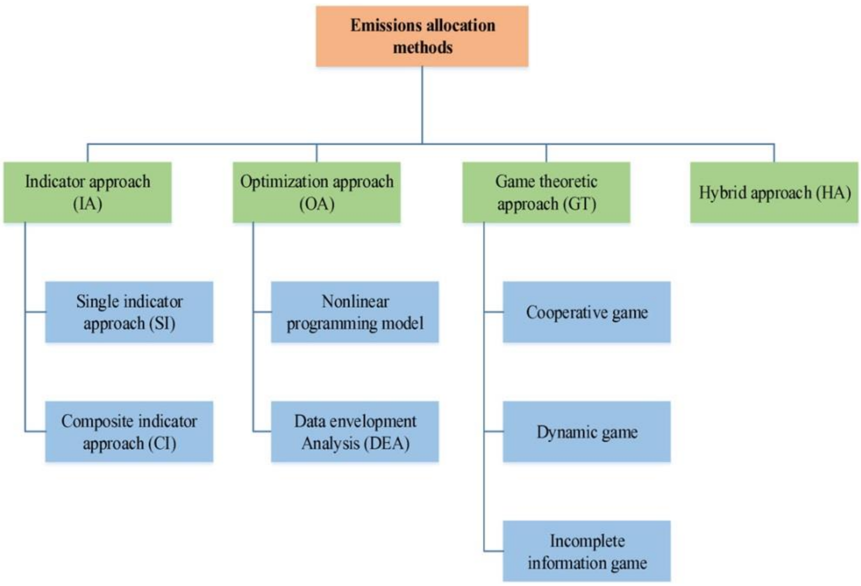

Figure 3: A visualization of emission allocation methods and approaches by Zhou & Wang (2016)

For each method there are different criteria that play a role in defining the level of allocation. These criteria are either based on the fairness or efficiency principle, meaning that the level of allocation is either proportional to represent a fair or efficient target (Zhou & Wang, 2016). While for energy efficiency the most obvious principle to adhere to is the efficiency principle, the target allocation from the global level to the national level should arguably also include the fairness principle at least to some extent. Multiple indicators that can be used to steer the allocation method with accompanying criteria and rules can be found in figure 4.

While there is no literature available that specifically focuses on allocating energy intensity targets, numerous studies that allocate energy use, CO_2 emissions and CO_2 intensity targets do exist. The vast majority of those studies use the indicator approach, both single and composite indicator, or data envelopment analysis (DEA). The single indicator approach is hereby the simplest to apply and communicate to others, but is the most subjective in the sense that only one chosen indicator is used for the allocation and thereby rarely represents all underlying factors. This subjectivity is less of an issue in the composite indicator approach since more relevant factors are combined into a single score for allocation, and thus better represents the actual situation. Issues around subjectivity however do remain in the weighting system that determines how important each indicator is for the final composite indicator scores, and the overall results are generally more difficult to communicate. The DEA removes the subjectivity of the allocation by determining the weighting system according to an optimisation approach. This is however the most complex method, and no consensus exists on which optimisation approach is the most suitable. Also, the fairness principle is under represented in the DEA approach since the optimisation aspect is inherently focussed on the efficiency principle.

Since allocating an intensity target is a relatively new topic, and has proven to require an updated methodological approach, the most relevant literature for allocating the energy intensity target can be found in studies that focus on carbon intensity reduction target allocation. Yang et al. (2017) and Zhao et al. (2017) for example allocate the carbon intensity reduction target that China has set for 2020 among industrial sectors. Yi et al. (2011) allocates the same target among different regions according to equity and development indicators. While the methodology used is not completely transferable for the topic of energy intensity allocation, these studies do show a relevant way in which a composite indicator approach can be used to allocate an intensity target.

Indicator	Allocation criterion	Allocation rule
Population	Egalitarianism	Equal adult per capita permits
		Equal per capita permits
		Equal future per capita permits with discounted historical responsibility
		Equal past and future per capita permits
		Equal per capita permits by C&C
		Equal per capita permits by CDC
Emission	Sovereignty/grandfathering	Proportional permits to historical emissions (country/firm)
	Polluter pays	Proportional reductions to a historical level
	Historical responsibility	Proportional reductions to cumulative emissions
Energy	Sovereignty/grandfathering	Proportional permits to energy consumption
		Proportional permits to energy production
GDP	Economic activity	Proportional permits to GDP
	Ability to pay	Proportional reductions to GDP
	Horizontal equity	Equal net abatement cost to GDP
Per capita GDP	Ability to pay	Proportional reduction to per capita GDP
	Vertical equity	Equal net abatement cost to per capita GDP
Emission intensity	Merit (efficiency)	Proportional reductions to emissions per unit of GDP
		Proportional reductions to emissions per unit of GDP by C&C
		Proportional permits to emissions per unit of production outputs (*also called benchmarking*)

Note: C&C = contraction & convergence; CDC = common but differentiated convergence.

Figure 4: Review of allocation indicators, criteria and rules for CO_2 emissions (Zhou & Wang, 2016)

2.2 Bottom-up approach

2.2.1 *National energy efficiency commitments*

Countries have often set their own targets for energy efficiency improvements in policy programmes. These commitments state the desired improvement to be made on a certain indicator in a set time frame. Different sectors usually receive specified targets according to the desired progress to be made. While in some cases these commitments can directly be linked to the effect on the energy intensity indicator, it is more often the case that different forms of energy efficiency commitments do not relate to this indicator very easily. The existence of long term national commitments is a recent development that has been enhanced by the Paris Agreement, which states that each country needs to put forward Nationally Determined Contributions (NDCs).[1] This NDC must include a target for CO_2 emissions reduction, but sometimes targets for energy consumption and efficiency that allow to achieve this emissions reduction are also described. It is however still an issue to evaluate the different forms of commitments and relate them to historical energy intensity developments and potential levels of improvement. This is where country profiling of energy efficiency can help to put the national commitments into perspective and reflect on possible future energy intensity levels. Rankings on international energy efficiency scoring systems are hereby very helpful to assess if countries are making an effort to enhance energy efficiency and improve their energy intensity.

2.2.2 *Energy efficiency scoring systems*

International energy efficiency scoring systems, such as the scorecards of the American Council for an Energy-Efficient Economy (ACEEE) and Regulatory Indicators for Sustainable Energy (RISE), and scoreboard of the European ODYSSEE-MURE, reveal current rankings on energy efficiency and highlight front runners and laggards (Kallakuri et al., 2016; Banerjee et al., 2017; ODYSSEE-MURE, 2018). Eichhammer et al. (2017) elaborately reviewed the methodology and rankings of the ACEEE scorecard and ODYSSEE-MURE scoreboard, reflecting on the usefulness and limitations in comparing international energy efficiency efforts. While both systems use a different weighting system to obtain the scores and rankings, these differences can be taken into account when comparing them since they both use the elements of energy efficiency policy, progress levels and current energy intensities. The main difference is however that ODYSSEE-MURE only looks at 30 European countries, while the most recent international ACEEE scorecard looks at the top 25 energy consuming countries globally (Castro-Alvarez et al., 2018). This means that the scoring systems only overlap for the United Kingdom, France, Italy and Germany within the selection of 20 high-impact countries (see section 2.1.1) for the energy intensity target. The ACEEE report includes 18 out of 20 high-impact countries, only not covering Iran, Islamic rep. and Nigeria. The RISE scorecard on energy efficiency covers 111 countries in which all high-impact countries are included, but only scores and ranks the countries on regulatory indicators. While this is a very important part for reviewing willingness to progress on energy efficiency, it is not the only factor that influences the course of energy intensity improvements within a country.

2.2.3 *Country profiling*

Where the top-down approach is quantitative and relatively simple to analyse, the bottom-up approach requires a more in-depth analysis. This approach tries to deduce future national energy intensity levels from available information on energy efficiency efforts and commitments. A strategy is to bundle all

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[1] If countries have not yet ratified the Paris Agreement their NDCs are termed Intended Nationally Determined Contributions (INDCs).

relevant information into country profiles that can be used to sketch a possible outlook for energy intensity improvements. Sectorial energy intensities can for example expose where potential areas of improvement lie (World Bank, 2017), and the energy efficiency scoring systems can be used to reflect on the level of commitment to make improvements on energy efficiency. The national commitments can be reviewed in historical context of their energy intensity development to see if these are likely to be met.

2.2.4 *Relating national commitments to energy intensity*

The last step of the bottom-up approach is to relate the national commitments to the energy intensity indicator to deduce possible future energy intensity levels. This can be done by translating the commitments to the effect they have on TPES and GDP values. Projections of GDP and TPES values for 2030 can be used as a reference to be able to relate the commitments to the energy intensity indicator. The way in which this is done differs for every form of commitments available, but can always be compared to the projected TPES in the World Energy Outlook (WEO) presented by the IEA. In this way the allocated targets can be compared to the deduced future energy intensity levels to see if there are significant differences in the desired and likely pathways of energy intensity development.

2.3 Conceptual framework

The overall combination of concepts within the two approaches is visualised below in the resulting conceptual framework (figure 5). The top-down and bottom-up approaches are hereby indicated with the blue dashed lines. The main concepts are marked in orange, transformations in red, and resulting outputs in green. The intermediate strategy to bundle information into country profiles for the bottom-up approach is marked in purple. The next chapter describes the methods linked to this conceptual framework in order to obtain the research results.

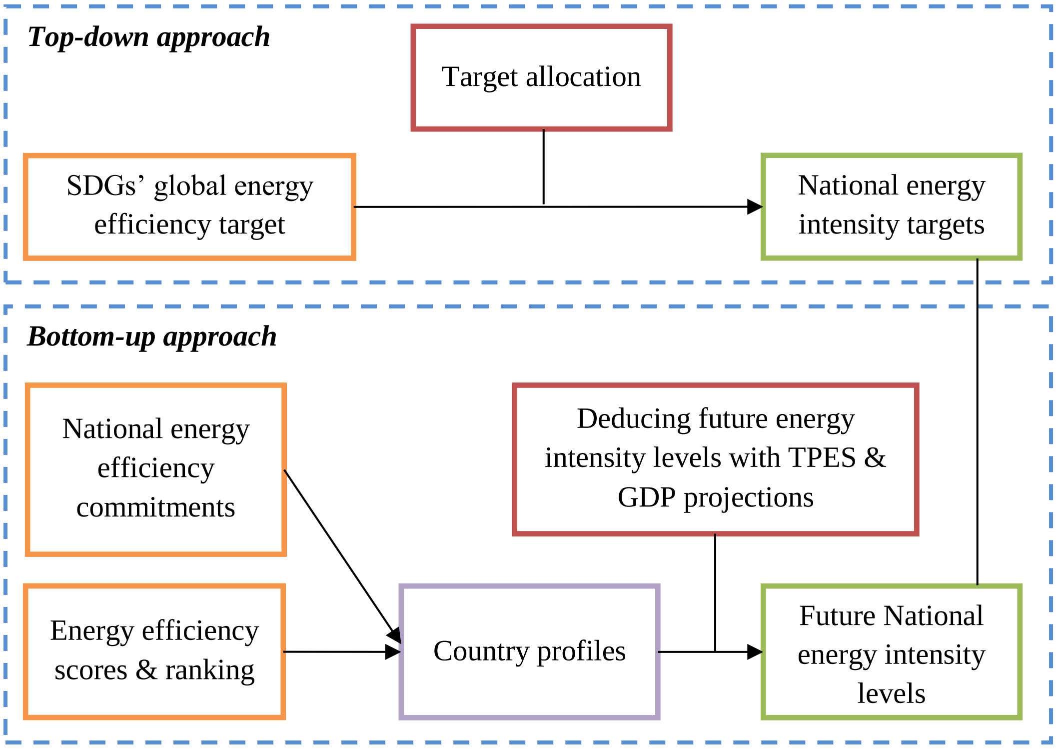


Figure 5: The conceptual framework of this research

3 Methods

This chapter describes the gathering, sources and processing of data within the research steps. Firstly, the allocation method used to translate the global target into fair and effective national targets is elaborated on. Secondly, the country profiling which is used to deduce possible future energy intensity levels is discussed. Lastly, the way in which these targets and possible future intensity levels are compared is explained.

3.1 Allocating the global target into national targets

The composite indicator allocation method used in Yi et al. (2011) was adapted to be applicable to the energy intensity target allocation topic. This method was chosen because it is able to incorporate multiple underlying factors while still being relatively easy to communicate. The selection of countries included in this top-down approach is explained first. The allocation method as used in this research is then described, followed by the evaluation and sources of the data used.

3.1.1 *Countries included*

For the top-down allocation approach the selection of countries included is limited to the 20 high-impact countries for reaching the energy efficiency target as identified by the SE4ALL initiative (Appendix B). Collectively, this selection of countries make up more than 70% of global TPES, GDP and resulting energy intensity. Adding more countries to this selection of 20 would have diminishing contribution to the cumulative coverage. This research therefore targets these high-impact countries in the top-down allocation approach to achieve high global coverage with manageable data intensity.

3.1.2 *Allocation method*

For the high-impact countries the combined energy intensity reduction target for 2030 of 2.6% per year (~ 41% reduction from 2010 value) is allocated with a composite indicator allocation method. The four indicators that were chosen to obtain the composite indices are: Energy Intensity (EI: [MJ/ $2011 PPP GDP]), Energy Use per Capita (EUC: [kg of oil equivalent per capita]) , CO_2 Intensity of Energy Use (CO2I: [kg per kg of oil equivalent energy use]) & GDP PPP per Capita (GDPC: [constant 2011 international $ per capita]) representing the merit, egalitarianism, polluter pays and ability to pay criterion respectively. Hereby each individual country (i) receives a comprehensive index Xi (formula 1) based on the proportional 2010 indicator values for each country to the mean value (formula 2: single indicator scores EIsi, EUCsi, CO2Isi & GDPCsi), multiplied with a weighted factor (Wa, Wb, Wc & Wd) of which the sum equals 1.

$$Xi = Wa * EIsi + Wb * EUCsi + Wc * CO2Isi + Wd * GDPCsi \qquad (1)$$

Where the single indicator (si) index scores are calculated with (EI as example):

$$EIsi = \frac{EIi}{mean\ EI} \qquad (2)$$

Six scenarios are explored based on different weighting factors for each indicator (table 1); one where all have equal weights (EQ: 0.25), four scenarios where one indicator has preference (EI, EUC, CO2I & GDPC respectively: 0.4), and finally a scenario where the weights are corrected to account for the correlation between the indicator scores (CORR: 0.34, 0.16, 0.33 & 0.17 respectively). These different scenarios represent the effect of subjectivity towards the importance of certain indicators on the resulting allocation.

Table 1: Different weightings for the six allocation scenarios

Scenario	Wa	Wb	Wc	Wd
Sc_EQ	0.25	0.25	0.25	0.25
Sc_EI	0.4	0.2	0.2	0.2
Sc_EUC	0.2	0.4	0.2	0.2
Sc_CO2I	0.2	0.2	0.4	0.2
Sc_GDPC	0.2	0.2	0.2	0.4
Sc_CORR	0.34	0.16	0.33	0.17

Table 2 & 3 show the pairwise linear correlation coefficient rho and corresponding p-values (pval) of the four indicators. The statistically highly significant (pval < 0.001) and strongly positive correlation (rho: 0.866) between indicators EUC and GDPC (marked in designate that the weighting system should be corrected to account for this correlation for a scenario that aims to have equal impact of indicator scores on the overall allocation. Because the correlation between the EUC and CO2I indicators is not statistically significant on the 95% confidence level (pval > 0.05), but is significant at the 90% confidence level (pval < 0.1), the moderate positive correlation (rho: 0.4) is only very slightly taken into account for adjusting the weights. The choice was made to adjust the weights in the CORR scenario so that the EI, CO2I and EUC + GDPC indicator weights are almost equal (0.34, 0.33 and 0.33 respectively), slightly favouring the EI and GDPC indicators to stress the merit and ability to pay criterion. From a methodological standpoint this scenario approaches objectivity since the indicator score impacts for allocation are almost equalised.

Table 2 & 3: Indicator correlation rho and pval

rho		Indicators			
		EI	**EUC**	**CO2I**	**GDPC**
Indicators	**EI**	1			
	EUC	0,293	1		
	CO2I	0,400	0,176	1	
	GDPC	-0,162	0,866	0,071	1

pval		Indicators			
		EI	**EUC**	**CO2I**	**GDPC**
Indicators	**EI**	1			
	EUC	0,210	1		
	CO2I	0,080	0,458	1	
	GDPC	0,496	0,000	0,766	1

The target is thus based on a ~41% combined reduction of energy intensity in year 2030 (EI_{2030}) from the 2010 (EI_{2010}) value (formula 3), where R is the residual of one minus the reduction target (1 - 0.41 = 0.59).

$$EI_{2030} = R * EI_{2010} \quad (3)$$

The Ri of each individual country is obtained via the comprehensive index with formula 4.

$$Ri = 1 - ((1 - R) * Xi) \quad (4)$$

Formula 3 can then be applied to obtain the individual country EIi_{2030} levels, but because there is a difference in potential contribution to the overall target for each country, a correction factor (a) is needed to get the correct values (formula 5). An obtained correction factor close to 1 hereby reflects a good representation of modelled $TPES_{2030}$.

$$EIi_{2030} = Ri * EIi_{2010} * a \quad (5)$$

The correction factor is obtained by first calculating the pooled $TPES_{2030}$ value from the determined EI_{2030} and sum of projected $2011 PPP GDP for 2030 ($GDP_{2030}$) with formula 6, and then calculating the correction factor with formula 7, where the denominator represents the summation of modelled $TPESi_{2030}$ values.

$$TPES_{2030} = EI_{2030} * GDP_{2030} \quad (6)$$

$$a = \frac{TPES2030}{\sum EIi2010 * Ri * GDPi2030} \quad (7)$$

The required rate of energy efficiency improvement (REEI) to reach the EIi_{2030} levels are then calculated with the CAGR between the EIi_{2030} and EIi_{2010} levels (formula 8).

$$REEIi = \left(\frac{EIi2030}{EIi2010}\right)^{1/(2030 - 2010)} - 1\ (\%) \quad (8)$$

The more negative the REEIi value, the higher the rate of improvement on energy intensity. Positive REEI values represent a growth in energy intensity.

3.1.3 *Evaluation and sources of data*

A Matlab model that was developed in an assignment for the Sustainability Modelling & Indicators course (Boks & Spitsbaard, 2017) to assess historical and future developments of the energy intensity indicator was adapted to visualise and evaluate the sets of allocated targets in a historical context. The full script can be found in Appendix A. The indicator data used in this research is made available by shared efforts of the International Energy Agency (IEA), United Nations Statistics Division (UNSD) and World Development Indicators (WDI) database (World Bank, 2018a). The EI dataset currently includes the historical levels of energy intensity from 1990-2015 for 217 countries and 47 aggregates. The full available range of the energy intensity indicator was used for the 20 high-impact countries as well as the 2010 values of the other indicators. All indicator values for 2010 can be found in table 4.

The only long term GDP PPP projections available that reached up to and over 2030 for all high impact countries are from the PricewaterhouseCoopers (PwC) report: "The long view: how will the global economic order change by 2050?" (Hawksworth et al., 2017). While other data sources for GDP projections are preferred, such as the International Monetary Fund (IMF) or the Organisation for Economic Co-operation and Development (OECD), these sources did not have GDP projections in PPP terms for 2030. Table 5 compares the 2030 PPP GDP projections from PwC with calculated 2030 values from measured 2010 GDP PPP and expected average annual growth rates of the available selection of high-impact countries as reported in the WEO 2016 report (IEA, 2016b, p. 42; Table 1.2: *Real GDP growth assumptions by region*). Both projections are hereby expressed in $2011 PPP GDP by applying reported rates of inflation (World Bank, 2018a). This shows that the PwC projections are within a reasonable range with calculations from the WEO 2016 report for the available selection of countries. The PwC projections are therefore suitable and used in this research for all high-impact countries in the top-down allocation method. Different future GDP values also do not affect the robustness of this method, since long term GDP projections are generally uncertain and the effect of the GDP_{2030} values in the allocation method is only reflected in the correction factor. This means that the underlying allocation method remains intact. The inter-relationships of the model outputs are therefore unaffected, only the absolute values of modelled $TPES_{2030}$ and $TPESi_{2030}$ change with different GDP_{2030} values.

Table 4: 2010 indicator values (World Bank, 2018)

2010 Indicator Values	**Indicators**			
Country	**EI (MJ/$2011 PPP GDP)**	**EUC (kg of oil equivalent per capita)**	**CO2I (kg per kg of oil equivalent energy use)**	**GDPC (constant 2011 international $ per capita)**
Australia	5.86	5793	3.06	41385
Brazil	3.89	1351	1.58	14539
Canada	8.01	7788	2.02	40699
China	8.68	1955	3.36	9526
France	4.58	4017	1.35	36872
Germany	4.12	3997	2.32	40429
India	5.35	563	2.48	4405
Indonesia	4.34	875	2.02	8433
Iran, Islamic Rep.	6.58	2740	2.81	17943
Italy	3.43	2931	2.33	36201
Japan	4.74	3893	2.35	35750
Korea, Rep.	6.96	5045	2.27	30352
Mexico	4.01	1490	2.66	15535
Nigeria	6.15	756	0.76	5150
Russian Federation	8.73	4819	2.43	23108
Saudi Arabia	6.25	6763	2.80	45421
South Africa	9.67	2748	3.34	11888
Thailand	5.45	1753	2.39	13487
United Kingdom	3.74	3231	2.43	36367
United States	6.07	7161	2.44	49373
Standard deviation	1.830	2191	0.623	14830

Table 5: 2030 GDP PPP (expressed in $2011) projection from PwC and calculated from WEO

Country	**PwC 2030 GDP PPP**	**WEO 2030 GDP PPP**	**Difference (%)**
Brazil	6,49E+12	5,68E+12	-12,5%
China	4,06E+13	4,63E+13	13,8%
India	2,43E+13	2,61E+13	7,5%
Japan	5,78E+12	5,37E+12	-7,1%
Russian Federation	6,56E+12	6,70E+12	2,1%
South Africa	1,52E+12	1,26E+12	-17,4%
United States	2,53E+13	2,43E+13	-4,0%

3.2 Deducing possible future energy intensity levels

The bottom-up approach to deduce possible future energy intensity levels from available energy efficiency information is through country profiles. The countries included for this approach is explained first, followed by the description of elements discussed in the profiles. Finally, the data sources that were used for creating the country profiles are listed.

3.2.1 *Countries included*

The top five of the high-impact countries: China, the United States, India, the Russian Federation and Japan collectively represent around 50% of the world for both TPES and GDP. These are therefore the most important to look at in more detail to find out if national incentives are aligned with the global energy efficiency target. These top five high-impact countries are therefore chosen for country profiling in the bottom-up approach. In this way the global coverage is sufficient while allowing to elaborate on these most impactful countries.

3.2.2 *Country profiling*

Five country reports are therefore set up with chapters that report on historical energy intensity levels, national commitments, rankings of energy efficiency scoring systems and World Energy Outlook scenarios. The World Energy Outlook 2030 GDP projections were calculated as described in section 3.1.3. This is used in the WEO chapters to determine the range of projected TPES/GDP, where the TPES scenario values are converted to MJ from million tonnes of oil equivalent for comparison. The preceding information is then combined to deduce the possible future energy intensity levels from these projected ranges in the final chapters of the country reports.

3.2.3 *Data sources*

Historical energy intensity levels and yearly growth were obtained from the indicator database described in subsection 3.1.3. The GDP and TPES projections were taken from the WEO 2016 report (IEA, 2016b). The rankings for the energy efficiency scoring systems were taken from Banerjee et al. (2017) for RISE, Kallakuri et al. (2016) and Castro-Alvarez (2018) for the ACEEE 2016 and 2018 reports, and ODYSSEE-MURE (2018) for the 2015 Odyssee and MURE rankings. The (I)NDC for each country was obtained from the United Nations Framework Convention for Climate Change (UNFCCC, 2018) and IEA (IEA, 2018) websites.

3.3 Comparing results

The last part of the research quantitatively compares the allocated energy intensity targets with the possible future energy intensity levels deduced in the country reports. The according REEI values from the deduced energy intensity levels were calculated with formula 8 from subsection 3.2.2. This allows to evaluate if the desired energy intensity levels and rates of improvements are likely to be achieved.

4 Results

This chapter describes the results for the target allocation, possible future energy intensity scores, and the comparison between the two. The next chapter discusses these results in a broader perspective.

4.1 Target allocation

This section shows the pathways in which the combined 2010 EI level of 6.13 MJ per $2011 PPP GDP for the high-impact countries can be reduced to 3.62 in 2030 with the national targets resulting from the allocation scenarios. The single indicator (si) index scores with according rank for each high-impact country are shown in table 6 below. This is used as the basis for the calculations in the different weighting scenarios. This section further discusses the output scores related to the comprehensive index (Xi), target 2030 EI levels, target rate of energy efficiency improvement (REEI) and distance to target REEI from the measured 2010-2015 REEI. After this the CORR scenario results are elaborated on in more detail.

Table 6 shows that countries have a diverse rank range on the single indicator index scores. Indonesia for example scores very consistently near the lower ranks (15-18) resulting in a rank range of 3, while Canada and China score more diversely on the indicators with a rank range of 16. These rank ranges combined with the variable standard deviations within the indicators determine how the different weightings in the scenarios influence the target results. The EI and CO2I indicators have low standard deviations compared to the EUC and GDPC indicators, meaning that the relative rankings and scores of the latter two are more influential in determining the target modelling results.

Table 6: Si scores with (rank) for each high-impact country

Si scores with (rank)	Indicators				Rank range
Country	EI	EUC	CO2I	GDPC	
Australia	1.01 (10)	1.66 (4)	1.30 (3)	1.60 (3)	7
Brazil	0.67 (18)	0.39 (17)	0.67 (18)	0.56 (14)	4
Canada	1.37 (4)	2.24 (1)	0.86 (17)	1.57 (4)	16
China	1.49 (3)	0.56 (14)	1.42 (1)	0.37 (17)	16
France	0.79 (14)	1.15 (7)	0.57 (19)	1.43 (6)	13
Germany	0.71 (16)	1.15 (8)	0.98 (14)	1.56 (5)	11
India	0.92 (12)	0.16 (20)	1.05 (7)	0.17 (20)	13
Indonesia	0.74 (15)	0.25 (18)	0.86 (16)	0.33 (18)	3
Iran, Islamic Rep.	1.13 (6)	0.79 (13)	1.19 (4)	0.69 (12)	9
Italy	0.59 (20)	0.84 (11)	0.99 (13)	1.40 (8)	12
Japan	0.81 (13)	1.12 (9)	1.00 (12)	1.38 (9)	4
Korea, Rep.	1.19 (5)	1.45 (5)	0.96 (15)	1.17 (10)	10
Mexico	0.69 (17)	0.43 (16)	1.13 (6)	0.60 (13)	11
Nigeria	1.05 (8)	0.22 (19)	0.32 (20)	0.20 (19)	12
Russian Federation	1.50 (2)	1.38 (6)	1.03 (10)	0.89 (11)	9
Saudi Arabia	1.07 (7)	1.94 (3)	1.18 (5)	1.76 (2)	5
South Africa	1.66 (1)	0.79 (12)	1.42 (2)	0.46 (16)	15
Thailand	0.93 (11)	0.50 (15)	1.01 (11)	0.52 (15)	4
United Kingdom	0.64 (19)	0.93 (10)	1.03 (9)	1.41 (7)	12
United States	1.04 (9)	2.06 (2)	1.03 (8)	1.91 (1)	8
Standard deviation*	0.314	0.629	0.264	0.574	

*** Note:** The listed standard deviations are for the entire columns, not for individual scores

4.1.1 *All scenarios*

Table 7 shows the resulting comprehensive indicator index (Xi) scores for each allocation scenario. These are obtained by applying the according weights in table 1 to the different relative single indicator index scores in table 6. The standard deviation reveals a levelling effect of the weighting system after indicator combination. The highest standard deviations are hereby found in the scenarios where EUC and GDPC have weights of 0.4, and the lowest standard deviation found in the CORR scenario where EUC and GDPC have lower weights compared to EI and CO2I.

These comprehensive index scores show that Nigeria, Indonesia, Brazil and India consistently receive a low burden for contributing to the global target. Canada, Saudi Arabia and the United States on the other hand have the highest index scores, indicating that the fastest rates of improvement should be observed in these countries.

Table 7: Xi scores in each allocation scenario for all high-impact countries

Xi scores	Allocation Scenarios					
Country	**Sc_EQ**	**Sc_EI**	**Sc_EUC**	**Sc_CO2I**	**Sc_GDPC**	**Sc_CORR**
Australia	1.39	1.31	1.45	1.37	1.43	1.31
Brazil	0.57	0.59	0.53	0.59	0.57	0.61
Canada	1.51	1.48	1.66	1.38	1.52	1.38
China	0.96	1.07	0.88	1.05	0.84	1.13
France	0.98	0.94	1.02	0.90	1.07	0.88
Germany	1.10	1.02	1.11	1.08	1.19	1.01
India	0.58	0.64	0.49	0.67	0.49	0.71
Indonesia	0.54	0.58	0.49	0.61	0.50	0.63
Iran, Islamic Rep.	0.95	0.99	0.92	1.00	0.90	1.02
Italy	0.96	0.88	0.93	0.96	1.04	0.90
Japan	1.08	1.02	1.09	1.06	1.14	1.02
Korea, Rep.	1.19	1.19	1.25	1.15	1.19	1.15
Mexico	0.71	0.71	0.65	0.79	0.69	0.78
Nigeria	0.45	0.57	0.40	0.42	0.40	0.53
Russian Federation	1.20	1.26	1.24	1.17	1.14	1.22
Saudi Arabia	1.49	1.41	1.58	1.43	1.54	1.36
South Africa	1.08	1.20	1.02	1.15	0.96	1.24
Thailand	0.74	0.78	0.70	0.80	0.70	0.82
United Kingdom	1.00	0.93	0.99	1.01	1.08	0.95
United States	1.51	1.42	1.62	1.41	1.59	1.35
Standard deviation	0.328	0.293	0.385	0.288	0.363	0.265

Table 8 lists the resulting Ri scores. These reflect the ratios of the EIi_{2010} values that should be achieved by 2030 before the correction factor (a) is applied. A ratio of 0.59 is the global average, so values above the average represent a soft target while lower ratios represent a stricter target. Quite extreme ratios for Canada and the United States can be observed in the EUC and GDPC scenarios. This exemplifies the amplification effect that the indicator standard deviations combined with the indicator correlation has on the allocation results. The CORR scenario again has the lowest standard deviation, indicating that the effort sharing is more equally distributed.

Table 8: Ri scores for each scenario

Residual (Ri) scores	Allocation Scenarios					
Country	**Sc_EQ**	**Sc_EI**	**Sc_EUC**	**Sc_CO2I**	**Sc_GDPC**	**Sc_CORR**
Australia	0.43	0.46	0.41	0.44	0.41	0.46
Brazil	0.77	0.76	0.78	0.76	0.77	0.75
Canada	0.38	0.39	0.32	0.44	0.38	0.44
China	0.61	0.56	0.64	0.57	0.66	0.54
France	0.60	0.61	0.58	0.63	0.56	0.64
Germany	0.55	0.58	0.55	0.56	0.51	0.58
India	0.76	0.74	0.80	0.73	0.80	0.71
Indonesia	0.78	0.76	0.80	0.75	0.79	0.74
Iran, Islamic Rep.	0.61	0.60	0.62	0.59	0.63	0.58
Italy	0.61	0.64	0.62	0.61	0.57	0.63
Japan	0.56	0.58	0.56	0.57	0.53	0.58
Korea, Rep.	0.51	0.51	0.49	0.53	0.51	0.53
Mexico	0.71	0.71	0.73	0.67	0.72	0.68
Nigeria	0.82	0.77	0.84	0.83	0.84	0.78
Russian Federation	0.51	0.48	0.49	0.52	0.53	0.50
Saudi Arabia	0.39	0.42	0.35	0.42	0.37	0.44
South Africa	0.56	0.51	0.58	0.53	0.61	0.49
Thailand	0.70	0.68	0.72	0.67	0.71	0.66
United Kingdom	0.59	0.62	0.60	0.59	0.56	0.61
United States	0.38	0.42	0.34	0.42	0.35	0.45
Standard deviation	0.134	0.120	0.158	0.118	0.149	0.109

Table 9 shows the target 2030 EI levels resulting from the allocation scenarios with according correction factors (a). These values represent the TPES/GDP ratio that should be achieved by each country in every allocation scenario. The colour indicates the relative level of the EI ratio resulting from the target improvements, where red represents a relatively high and green represents a relatively low EI ratio. This shows that China, Nigeria, the Russian Federation and South Africa will have the highest 2030 EI levels, mostly because of the high initial 2010 EI levels (see table 4). For Nigeria it is however mainly the result of very soft targets because it ranks 19th on two and 20th on one indicator (see table 6), showing that due to allocation it is allowed more gradual improvements. European countries, Japan and the United states on the other hand have relatively low 2030 EI levels. This is mainly because of the combined high scores on the per capita indicators EUC and GDPC, and low 2010 EI values. The standard deviation and correction factor show that the EI and CORR scenarios result in the most harmonised effort sharing and closest representation of modelled 2030 TPES values.

Table 9: Target 2030 EI (MJ/$2011 PPP GDP) levels for all scenarios

Target 2030 EI	Allocation Scenarios					
Country	**Sc_EQ**	**Sc_EI**	**Sc_EUC**	**Sc_CO2I**	**Sc_GDPC**	**Sc_CORR**
Australia	2.44	2.68	2.28	2.53	2.28	2.74
Brazil	2.88	2.92	2.90	2.91	2.80	2.94
Canada	2.96	3.12	2.46	3.44	2.83	3.52
China	5.10	4.85	5.29	4.88	5.35	4.69

France	2.64	2.78	2.55	2.85	2.41	2.94
Germany	2.19	2.37	2.14	2.27	1.98	2.42
India	3.96	3.91	4.08	3.83	4.01	3.81
Indonesia	3.26	3.27	3.32	3.22	3.24	3.24
Iran, Islamic Rep.	3.89	3.89	3.92	3.84	3.91	3.85
Italy	2.02	2.18	2.03	2.06	1.85	2.18
Japan	2.56	2.73	2.51	2.64	2.38	2.77
Korea, Rep.	3.44	3.53	3.25	3.64	3.35	3.69
Mexico	2.75	2.83	2.80	2.68	2.71	2.75
Nigeria	4.86	4.67	4.90	5.02	4.84	4.83
Russian Federation	4.29	4.19	4.11	4.50	4.38	4.38
Saudi Arabia	2.36	2.63	2.10	2.56	2.16	2.77
South Africa	5.21	4.89	5.36	5.06	5.53	4.80
Thailand	3.67	3.67	3.72	3.62	3.65	3.63
United Kingdom	2.13	2.30	2.13	2.17	1.96	2.30
United States	2.24	2.53	1.95	2.52	1.99	2.73
Standard deviation	1.018	0.860	1.107	0.962	1.160	0.837
Correction factor (a)	0.968	0.992	0.954	0.988	0.940	1.005

Table 10 reveals the target rate of energy efficiency improvement (REEI) in terms of the CAGR of energy intensity over the period from 2010-2030 needed to obtain the target 2030 EI levels. As expected; Canada, Saudi Arabia and the United States require the highest rates of improvement in all scenarios. Since the shared REEI is -2.6%, every lower value indicated with the red colour represents a higher burden to contribute to the global target, while the values with the blue colour represent soft targets and lower burdens. Brazil, India, Indonesia, Mexico and Nigeria for example have relatively low burdens with modest required rates of improvement.

Table 10: Target REEI values (%) for each scenario

Target REEI	**Allocation Scenarios**					
Country	**Sc_EQ**	**Sc_EI**	**Sc_EUC**	**Sc_CO2I**	**Sc_GDPC**	**Sc_CORR**
Australia	-4.29	-3.83	-4.61	-4.11	-4.62	-3.74
Brazil	-1.49	-1.42	-1.46	-1.44	-1.62	-1.39
Canada	-4.86	-4.61	-5.73	-4.14	-5.06	-4.03
China	-2.63	-2.87	-2.44	-2.84	-2.39	-3.03
France	-2.71	-2.46	-2.89	-2.34	-3.15	-2.19
Germany	-3.11	-2.71	-3.21	-2.93	-3.60	-2.62
India	-1.50	-1.56	-1.35	-1.65	-1.43	-1.69
Indonesia	-1.42	-1.40	-1.34	-1.48	-1.45	-1.46
Iran, Islamic Rep.	-2.59	-2.59	-2.56	-2.65	-2.57	-2.64
Italy	-2.61	-2.26	-2.61	-2.53	-3.05	-2.25
Japan	-3.03	-2.72	-3.13	-2.87	-3.39	-2.64
Korea, Rep.	-3.46	-3.34	-3.73	-3.19	-3.58	-3.13
Mexico	-1.87	-1.73	-1.78	-2.01	-1.95	-1.87
Nigeria	-1.17	-1.36	-1.13	-1.01	-1.19	-1.20
Russian Federation	-3.49	-3.61	-3.70	-3.26	-3.39	-3.39

Saudi Arabia	-4.75	-4.24	-5.30	-4.36	-5.16	-3.99
South Africa	-3.04	-3.35	-2.91	-3.19	-2.76	-3.44
Thailand	-1.96	-1.95	-1.89	-2.02	-1.97	-2.00
United Kingdom	-2.77	-2.41	-2.79	-2.69	-3.19	-2.40
United States	-4.86	-4.29	-5.52	-4.30	-5.42	-3.91
Standard deviation	1.151	1.019	1.405	0.982	1.283	0.903
Range	3.69	3.25	4.60	3.35	4.23	2.83

Figure 6 shows the boxplot of the resulting REEI scores, summarising the minimum, maximum, median and first and third quartiles for each scenario. The large range in REEI values for the EUC and GDPC scenarios can clearly be seen through the indicator correlation effect, resulting in particularly ambitious rates of improvement for Canada and the United states (-5.73 and -5.42% respectively). The highest maximum is observed in the CO2I scenario where the extremely low CO2I indicator score for Nigeria results in an allocated REEI of -1.01%. The most equalised scenarios are clearly EI and CORR, which show the lowest median and range values. Especially the CORR scenario results show a very equal distribution of targets that seem to best represent a fair and effective allocation scenario.

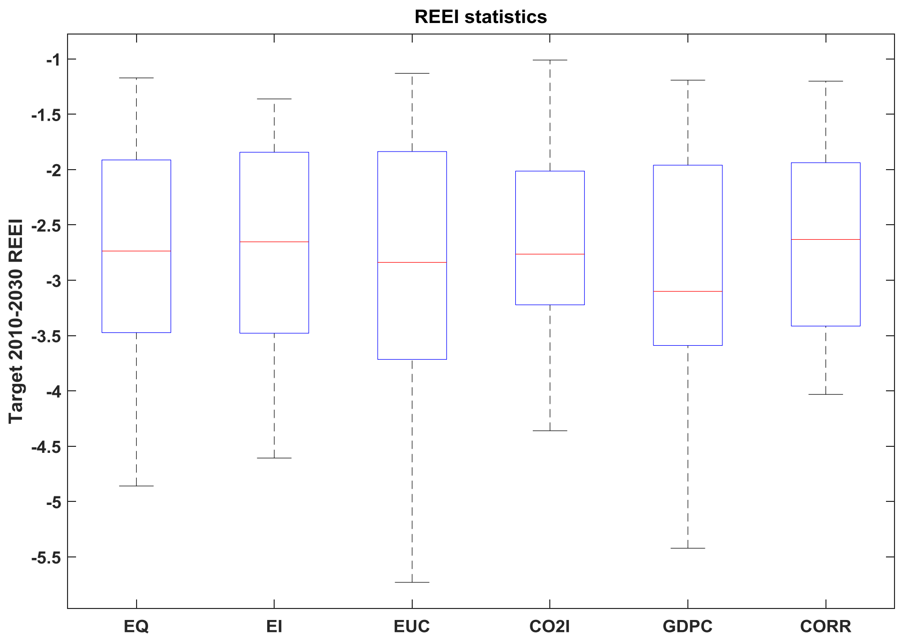


Figure 6: REEI boxplot statistics for all scenarios

Table 11 shows the ranking of REEI scores. It can be observed that the rank range is significantly smaller than the initial rank range of the single indicator scores in table 6. No rank range above 7 is observed and four countries have a rank range of 0, meaning that effort sharing relationships between the scenarios are largely consistent. The top 3 ranks are reserved for Canada, Saudi Arabia and the United States in all scenarios. These countries are therefore expected to be front runners in reducing their energy intensities in this composite allocation method. Nigeria, India and Indonesia on the other hand receive the lowest REEI ranks. The burden of contributing to the global target is therefore lowest for these countries with more gradual rates of improvement on their energy intensities. The low rank ranges also represents the need for defining national targets, since countries clearly have different effort sharing burdens and therefore need to know what role they play within the global context. The CORR scenario hereby shows the most objective ranking of effort sharing burdens, while the other scenarios represent ranking results for cases where certain indicators are deemed more important than others.

Table 11: REEI scores rankings

REEI rankings	Allocation Scenarios						Rank range
Country	Sc_EQ	Sc_EI	Sc_EUC	Sc_CO2I	Sc_GDPC	Sc_CORR	
Australia	4	4	4	4	4	4	0
Brazil	18	18	17	19	17	19	2
Canada	1	1	1	3	3	1	2
China	12	8	14	10	14	8	6
France	11	12	10	14	10	14	4
Germany	7	10	7	8	5	11	6
India	17	17	18	17	19	17	2
Indonesia	19	19	19	18	18	18	1
Iran, Islamic Rep.	14	11	13	12	13	9	5
Italy	13	14	12	13	11	13	3
Japan	9	9	8	9	8	10	2
Korea, Rep.	6	7	5	7	6	7	2
Mexico	16	16	16	16	16	16	0
Nigeria	20	20	20	20	20	20	0
Russian Federation	5	5	6	5	7	6	2
Saudi Arabia	3	3	3	1	2	2	2
South Africa	8	6	9	6	12	5	7
Thailand	15	15	15	15	15	15	0
United Kingdom	10	13	11	11	9	12	4
United States	2	2	2	2	1	3	2

Table 12 shows the results of difference in the observed REEI between 2010-2015 and the allocated target 2030 REEI. The red colour hereby indicates improvements that are short of the allocated REEI values, while the blue colour indicates that countries improved close to or faster than allocated. China, India, Indonesia, Japan, Nigeria and the United Kingdom all improved their energy intensity at a higher rate than allocated to them in the scenarios. This means that within the global context these countries contributed more than their allocated effort sharing burden to reach the set target. All other countries however did not reach their necessary levels of improvement, explaining how the global rate of improvement was short of the required -2.6% per year. The clearest examples of countries falling behind the required improvement level are Iran and Brazil. These two countries actually increased their energy intensity levels in the 2010-2015 period, thereby enhancing the burden on other countries to make more rapid improvements. Other countries such as Canada, Korea, the Russian Federation, Saudi Arabia, Thailand and the United States did improve on their energy intensity, but not nearly close enough to the desired rate needed to simultaneously reach the global target. The other European countries, France, Germany and Italy, show that they are on track to meet the required level of improvement on their energy intensity levels with a little more effort. Mexico, Australia, Thailand and South Africa should be able to reach the allocated targets if they implement energy efficiency enhancing strategies as they are not too far off the target.

Table 12: Distance from 2010-2015 REEI to target REEI (%) for all scenarios

Distance from REEI	Allocation Scenarios					
Country	**Sc_EQ**	**Sc_EI**	**Sc_EUC**	**Sc_CO2I**	**Sc_GDPC**	**Sc_CORR**
Australia	1.27	0.82	1.60	1.09	1.61	0.72
Brazil	2.69	2.62	2.66	2.64	2.83	2.59
Canada	3.13	2.87	4.00	2.40	3.33	2.30
China	-2.45	-2.20	-2.63	-2.23	-2.68	-2.05
France	0.54	0.29	0.72	0.17	0.98	0.03
Germany	0.49	0.09	0.59	0.30	0.97	0.00
India	-0.95	-0.88	-1.09	-0.79	-1.01	-0.75
Indonesia	-2.67	-2.68	-2.74	-2.60	-2.64	-2.62
Iran, Islamic Rep.	6.05	6.05	6.02	6.11	6.03	6.10
Italy	0.41	0.05	0.40	0.33	0.85	0.04
Japan	-1.57	-1.87	-1.47	-1.73	-1.21	-1.96
Korea, Rep.	2.25	2.13	2.52	1.97	2.37	1.91
Mexico	0.45	0.32	0.36	0.59	0.53	0.45
Nigeria	-0.39	-0.20	-0.44	-0.56	-0.37	-0.36
Russian Federation	2.75	2.87	2.96	2.52	2.65	2.65
Saudi Arabia	3.27	2.75	3.81	2.88	3.68	2.50
South Africa	0.95	1.26	0.82	1.10	0.67	1.35
Thailand	1.83	1.83	1.77	1.89	1.85	1.88
United Kingdom	-1.44	-1.80	-1.42	-1.52	-1.02	-1.81
United States	2.57	2.00	3.23	2.01	3.13	1.62

While all scenarios are valuable to reflect on since they showcase the effect of subjectivity towards certain indicators, the CORR scenario is particularly useful to elaborate on in more detail because it equalises the impact of the indicator scores through the adjusted weights. This means that the enhancing effect of correlation between different indicator scores is removed. In the scenario outputs this is exemplified with a correction factor closest to 1 and the lowest standard deviation and range values. The resulting 2030 EI and REEI targets are therefore most harmonised in this scenario, reflecting an allocation pathway towards the set target that is both fair and effective. The next subsection therefore looks at the CORR scenario results in more detail to exemplify the scenario that seems to outline the most relevant pathway for the high-impact countries to take in order to reach the global energy efficiency target.

4.1.2 *Allocation scenario: CORR*

Table 13 shows the EI analysis results for the most relevant allocation scenario CORR. A striking observation is the highly negative REEI value for China, revealing that between 2010-2015 the energy intensity of China went down on average with 5.07% per year from 8.68 to 6.69 MJ per $2011 PPP GDP. Since China is the most impactful country within the global context for reaching the set target, this is a very positive trend. Even though the CORR scenario allocates the strictest targets to China compared to the other scenarios, the required 3.03% improvement per year on its energy intensity has clearly been surpassed. It is however the question of China can keep this high rate of improvement going for a longer period of time, and if other countries are going to show improvements at these same high rates. The fact that on a global level the improvement on energy intensity between 2010-

2015 was only 2.2% per year must mean that other impactful countries are not reaching the same rates of improvement.

The United States, India and the Russian Federation did indeed not reach the global target of 2.6% improvement per year. While India does score better than the allocated 1.69% improvement per year, the United States and the Russian Federation fall behind their target rates of improvement. This combined with all the other listed countries that did not improve as fast as their allocated targets therefore negate and outweigh the efforts that frontrunners such as Japan, the United Kingdom and China made. Since these high-impact countries dominate the global context, the balance between the current efforts clearly needs to be revised. Especially the future efforts of China need to be monitored as they have the most impact on the required effort sharing. Once China falls behind it would namely become extremely difficult to reach the global target.

Table 13: EI analysis results for allocation scenario CORR

Allocation Scenario: CORR	EI (MJ/$2011 PPP GDP)		REEI (%)		Target 2030 EI (MJ/$2011 PPP GDP)
Country	EI 2010	EI 2015	2010-2015	Allocated Target	
Australia	5.86	5.03	-3.02	-3.74	2.74
Brazil	3.89	4.13	1.20	-1.39	2.94
Canada	8.01	7.34	-1.73	-4.03	3.52
China	8.68	6.69	-5.07	-3.03	4.69
France	4.58	4.10	-2.17	-2.19	2.94
Germany	4.12	3.60	-2.62	-2.62	2.42
India	5.35	4.73	-2.44	-1.69	3.81
Indonesia	4.34	3.53	-4.08	-1.46	3.24
Iran, Islamic Rep.	6.58	7.79	3.46	-2.64	3.85
Italy	3.43	3.07	-2.20	-2.25	2.18
Japan	4.74	3.74	-4.60	-2.64	2.77
Korea, Rep.	6.96	6.55	-1.21	-3.13	3.69
Mexico	4.01	3.74	-1.42	-1.87	2.75
Nigeria	6.15	5.68	-1.57	-1.20	4.83
Russian Federation	8.73	8.41	-0.74	-3.39	4.38
Saudi Arabia	6.25	5.80	-1.48	-3.99	2.77
South Africa	9.67	8.70	-2.09	-3.44	4.80
Thailand	5.45	5.41	-0.12	-2.00	3.63
United Kingdom	3.74	3.02	-4.20	-2.40	2.30
United States	6.07	5.41	-2.29	-3.91	2.73

Figure 7 visualises the CORR scenario results in the context of the historical energy intensity levels for the high-impact countries. The historical energy intensity data ranges from 1990 to 2015 and shows a general downward trend, representing that economies tend to decouple from energy use. The allocated target energy intensity lines for the high-impact countries start at 2010 and show crossovers in the 2010-2030 timeframe between countries that receive highly different allocated targets. Canada for example receives the most ambitious target in the CORR scenario and requires to drop from 8.01 in 2010 to only 3.52 MJ per $2011 PPP GDP in 2030, hereby crossing numerous countries including India and Thailand which start at lower energy intensities in 2010 but receive softer targets. This visualisation helps to monitor and evaluate if countries are on track to reach the allocated targets by showing the gap between the measured EI values and the allocated target lines. Future EI data can therefore easily be added to the model and visualised for effective monitoring, evaluation and communication to others.

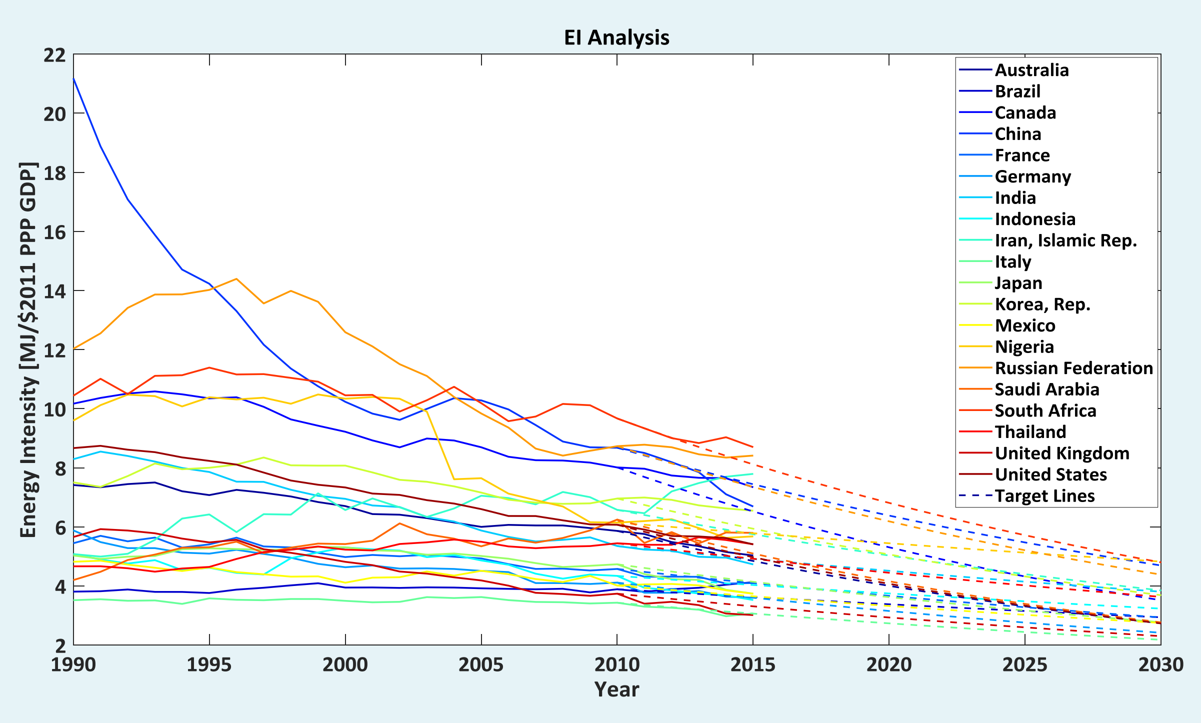


Figure 7: Visualisation of the CORR scenario results in context of historical energy intensity levels

Figure 8 separately visualises the measured 2010 (squares) and projected 2030 (circles) TPES and GDP values on a logarithmic scale for all high-impact countries. The diagonal lines represent the combined average energy intensity ratios for the high-impact countries of 6.13 and 3.62 MJ per $2011 PPP GDP respectively. The most important information to be gained from this figure is the relative distance towards these ratio lines. High parallel distances from above the line indicate high energy intensity levels, while high parallel distances from below the line indicate low energy intensities. The second graph shows that the countries are more equally distributed along the average ratio than in the first graph, indicating a harmonisation in contribution to the global target.

Figure 9 combines the separate graphs in figure 8 into one for a selection of high-impact countries. The diagonal line hereby represents the pooled target EI_{2030} ratio of 3.62. The lines between the squares and circles indicate the trajectory that each country is supposed to make on the TPES/GDP axis. The United States which receives an ambitious improvement target in the CORR scenario therefore crosses the 3.62 ratio line from above to well below it, representing the trajectory from 6.07 to 2.73 MJ per $2011 PPP GDP. For all countries a growth in GDP is projected, which can be seen from the general shift to the right on the GDP axis from 2010 to 2030 values. The resulting TPES from the target 2030 energy intensity levels on the other hand shows more variability. For all developing countries, such as Nigeria, Indonesia and India, an increase in TPES can be expected. For highly developed countries such as the United States, Italy and Japan it is however required that reductions in TPES are realised in order to reach the target. Because the future GDP and TPES values are of course to be determined, the exact positions of the 2030 values will change. Within the CORR scenario it is however required that the relative distance towards the 3.62 line will remain the same, indicating that the energy intensity remains at the target level. If future GDP levels of Germany for example turn out to become higher, the 2030 position on the graph for Germany will have to move parallel to the 3.62 line to the right in order to remain the same balance within the allocation results of the CORR scenario.

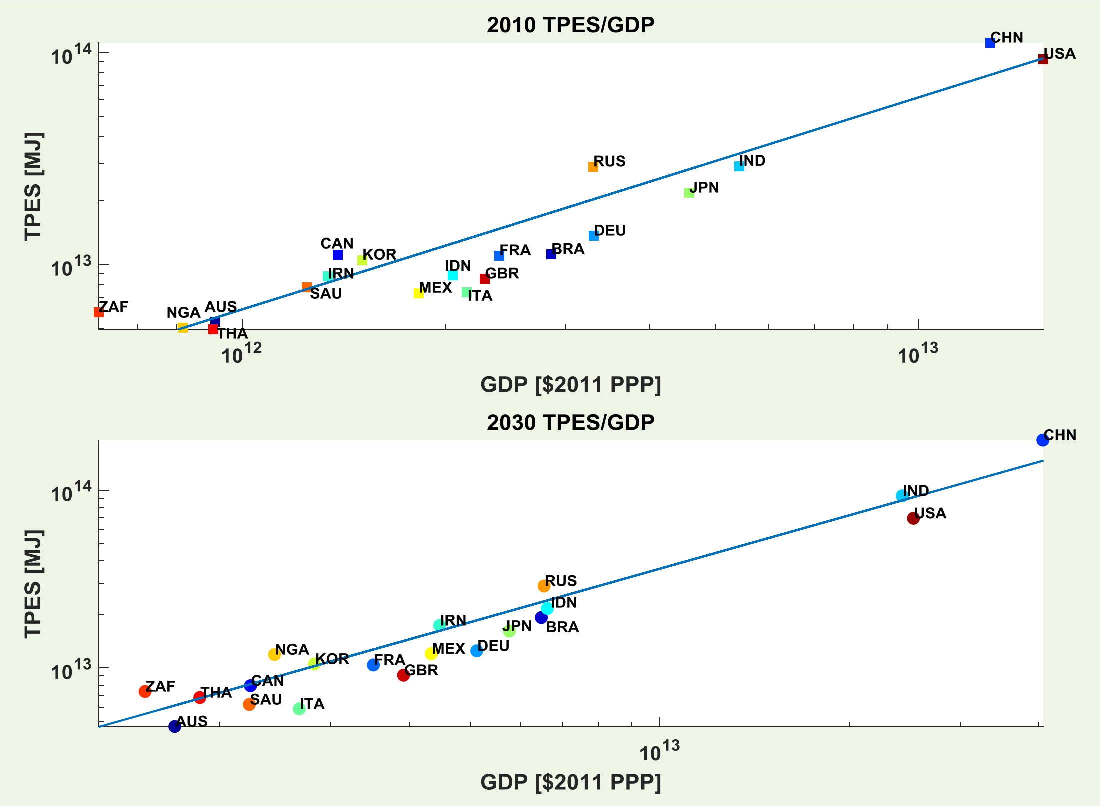


Figure 8: Measured 2010 (squares) and projected 2030 (circles) values for TPES and GDP in the CORR scenario for all high-impact countries

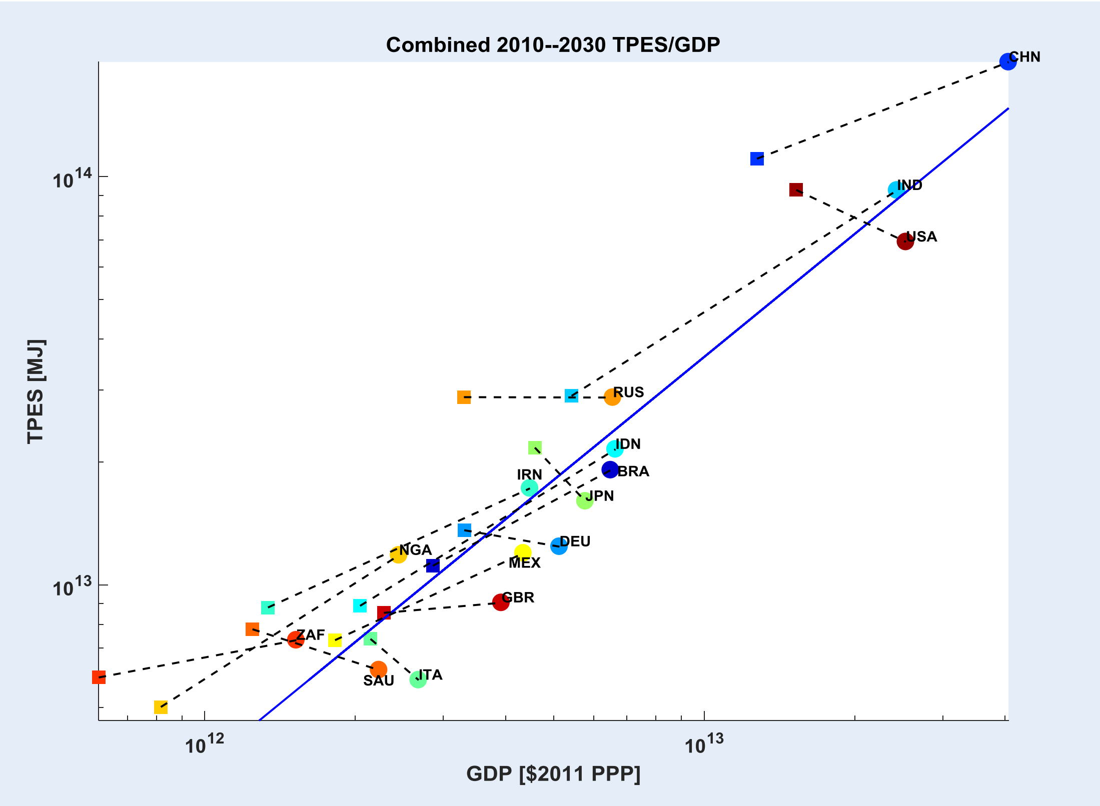


Figure 9: Combined measured 2010 (squares) and projected 2030 (circles) values for TPES and GDP in the CORR scenario for a selection of high-impact countries

4.2 Possible future energy intensity levels

This section describes the results of the bottom-up approach to deduce possible future energy intensity levels from country profiles. First, an overview of the rankings for the high-impact countries in different energy efficiency scoring systems is shown. Graphs for historical EI levels and growth for the five profiled countries are also presented. These can be used to relate to the information discussed in the country profiles for China, the United States, India, the Russian Federation and Japan. The range of projected and possible future energy intensity levels for each of these countries are shown at the bottom of their respective country profiles. Section 4.3 compares these possible future energy intensity levels with the results from the preceding target allocation section 4.1 and puts these into the perspective of the climate and SDGs target.

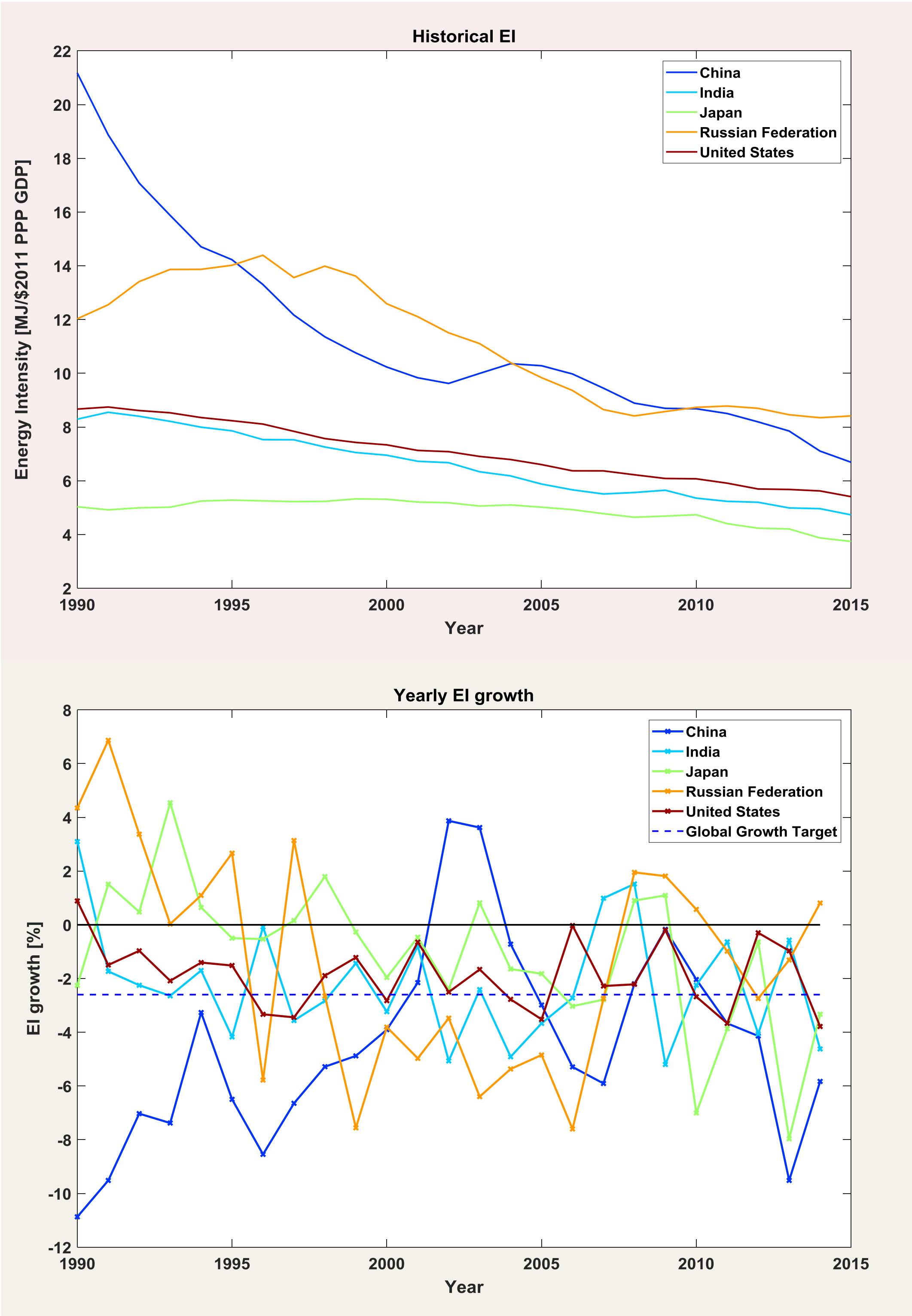
4.2.1 *Energy efficiency rankings and historical energy intensity*

Table 14 gives an overview of the available rankings for the high-impact countries in multiple energy efficiency scoring systems. Red colours indicate low rankings within that scoring system, and therefore highlight the greatest need and room for improvement for these countries. The blue colours indicate high rankings and showcase countries that perform well on certain energy efficiency aspects. The RISE scoreboard hereby reflects on the regulatory framework in place to enhance energy, while the ACEEE and ODYSSEE-MURE ranking systems also include indicators for national efforts and current energy efficiency levels. The blank spots indicate that the country is not included in the number of ranked countries for that scoring system.

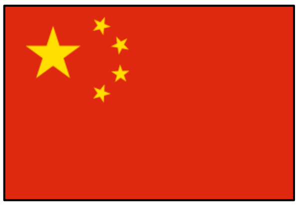
Table 14: Rankings of different energy efficiency scoring systems for all high-impact countries

Energy Efficiency Rankings	Energy Efficiency Scoring System							
	RISE	ACEEE		ODYSSEE	MURE			
Country	2016	2016	2018	Odyssee 2015	Savings	Potentials	2020 EE targets	Input
Australia	14	16	18					
Brazil	42	22	20					
Canada	4	10	10					
China	20	6	8					
France	11	4	3	12	8	5	10	17
Germany	7	1	1	18	2	2	2	14
India	31	14	15					
Indonesia	64	18	17					
Iran, Islamic Rep.	26							
Italy	13	3	1	15	7	1	1	9
Japan	21	2	5					
Korea, Rep.	5	8	13					
Mexico	6	19	12					
Nigeria	104							
Russian Federation	17	17	21					
Saudi Arabia	45	23	25					
South Africa	18	21	23					
Thailand	28	20	22					
United Kingdom	9	5	4	1	10	3	9	20
United States	1	8	10					
# of ranked countries	111	23	25	30				

Figures 10 and 11 show the historical energy intensity level and yearly growth for the top five high-impact countries. The country profiles in the next subsection describe the most significant historical trends for each country and its relevance for deducing the possible future energy intensity levels.



Figures 10 & 11: The historical energy intensity level and yearly growth of the top five high-impact countries



4.2.2 *Country profile: China*

Historical energy intensity

China has made the most improvement on its energy intensity out of all the profiled countries. This can mainly be attributed to the very high intensity level of 21.18 MJ per $2011 PPP GDP in 1990. From 1990-2015 there were only two years where the energy intensity of China increased (2002-2004), while for many years the rate of improvement was more than double the global growth target rate. China is hereby the main example that sustained improvement at high rates can be realised.

National commitments

The NDC of China goes into great detail on progress made and intended contributions to combat climate change for the Paris Agreement. It does however not give a clear target for energy consumption or intensity reductions. The 13th Five-Year Plan which runs from 2016-2020 on the other hand did include the target to reduce the energy use per unit of GDP by 15% compared to 2015, translating to an improvement rate of roughly 3.2% per year. This target was slightly lower than the 16% reduction issued in the 12th Five-Year Plan that ran from 2011-2015, which was clearly achieved.

Energy efficiency scoring system rankings

China ranks 20th out of 111 countries in the RISE scoreboard for the energy efficiency pillar with a score of 68. This means that the regulatory framework for increasing energy efficiency is sound, but could be improved on in certain aspects. China scores high on indicators for 'National Energy Efficiency Planning' and 'Financing Mechanisms', showing the effectiveness of the Five-Year Plans. Room for improvement is available on multiple indicators, of which 'Building energy codes' scores the lowest. Transport and industry are however identified as the main sectors for improvement.

The ACEEE's scorecard ranks China on the 6th spot in 2016 and on the 8th spot in 2018, being overtaken by the Netherlands and Spain. This however still puts China at above average within the list of 25 highest energy consuming countries. The lowest score is received for the industry sector.

World Energy Outlook

Table 15 below shows the results of the WEO 2016 Total Primary Energy Demand projections for 2030 divided by the two different GDP projections for China. The total projected range therefore is **3.91-3.13** MJ per $2011 PPP GDP.

Table 15: 2030 TPES/GDP from WEO 2016 scenario projections for China

2030 TPES/GDP (MJ/$2011 PPP GDP)	WEO Scenarios		
	Current Policies	New Policies	450
	3.91	3.56	3.13

Possible future energy intensity level

Since China has shown consistency in improving its energy intensity level at high rates, and still has enough room for improvement, intensity levels between the New Policies and 450 scenarios are possible. An EI level closer to the New Policies projections is more probable since the 450 scenario is very ambitious. Taking all information into account, a possible 2030 energy intensity level of **3.5** MJ per $2011 PPP GDP is deduced for China.

4.2.3 *Country profile: United States*

Historical energy intensity

The energy intensity of the United States has undergone a gradual and consistent decline. Compared to the other profiled countries the EI line seems almost straight. Unfortunately the improvement rate has rarely been significantly faster than the global growth target. The historical consistency in reducing the energy intensity therefore has to be coupled with increased efforts in order to reach the global target.

National commitments

The NDC of the United States unfortunately only mentions a target for greenhouse gas emissions reduction. Historically there have however been strong energy policy programmes that had a (partial) focus on increasing energy efficiency. The ACEEE plays a major role in this by being the main organisation focussed on enhancing knowledge on and implementing energy efficiency measures. The main question that currently plays is how the Trump Administration is affecting the national commitments of the United States since it has announced to withdraw from the Paris Agreement and revise the Clean Power Plan. National commitments for increasing energy efficiency are therefore largely unclear and likely to change in the near future.

Energy efficiency scoring system rankings

The United States holds the top spot on the RISE scoreboard with a score of 88, showing that a robust regulatory framework for enhancing energy efficiency is in place. The only indicator that scores below high standards is for ‘Carbon Pricing’. It therefore seems that with more effective utilization of this regulatory framework higher improvement rates should be achievable. The industry, services and transport sectors are all identified to have high potential for improvements.

The ACEEE ranks the United States on the 8th spot in 2016 and on the 10th spot in 2018, similarly to China dropping two places on the list. Transportation and industry are hereby identified as the sectors where most improvements are to be gained.

World Energy Outlook

Table 16 below shows the results of the WEO 2016 Total Primary Energy Demand projections for 2030 divided by the two different GDP projections for the United States. The total projected range therefore is **3.9-3.22** MJ per $2011 PPP GDP.

Table 16: 2030 TPES/GDP from WEO 2016 scenario projections for the United States

2030 TPES/GDP (MJ/$2011 PPP GDP)	WEO Scenarios		
	Current Policies	New Policies	450
	3.90	3.67	3.22

Possible future energy intensity level

Because it is unclear how future national commitments are going to unfold for the United States it is reasonable to be conservative in the level of improvement. Current policies are also being revised and it is therefore more likely that intensity levels between the Current and New Policies scenarios are going to be observed. Taking all information into account, a possible 2030 energy intensity level of **3.7** MJ per $2011 PPP GDP is deduced for the United States.

4.2.4 *Country profile: India*

Historical energy intensity

The energy intensity of India runs a similar course to that of the United states, with a relatively consistent decline over time. Higher peaks in EI growth are however observed, with three years having an increase in energy intensity and twelve years having improvement rates above the global growth target. Six of those years have improvement rates above 4% per year, with a peak of double the global growth target. The historical EI level of India is hereby very low for a country that is developing at a high rate.

National commitments

India's submitted INDC has a very strong focus on energy efficiency; with the first sections under 'Mitigation strategies' being 'Clean and efficient energy system' and 'Enhancing energy efficiency in industries'. It however mainly discusses what past and running programmes have achieved. The only energy related future target is to save '10% of current energy consumption by the year 2018-19'. The main message within the INDCs is that ambitious target are desired, but have to be achievable within the tumultuous development that India is experiencing.

Energy efficiency scoring system rankings

The RISE scoreboard puts India on the 31st spot with 60 points, just falling short of the 67 points required to be considered as a high performing country. It has the lowest score out of the profiled countries, but shows that with some improvements this disparity can be made up. A 0 score was for instance given to the 'Building energy codes' and 'Carbon pricing' indicators. The biggest area of improvement is the power sector, which experiences a relatively high percentage (23%) of losses.

The ACEEE ranks India on the 14th spot in 2016 and on the 15th spot in 2018. It scores very high in the transportation sector, while the buildings sector shows the most room for improvements.

World Energy Outlook

Table 17 below shows the results of the WEO 2016 Total Primary Energy Demand projections for 2030 divided by the two different GDP projections for India. The total projected range therefore is **2.5-2.04** MJ per $2011 PPP GDP.

Table 17: 2030 TPES/GDP from WEO 2016 scenario projections for India

2030 TPES/GDP (MJ/$2011 PPP GDP)	WEO Scenarios		
	Current Policies	New Policies	450
	2.50	2.33	2.04

Possible future energy intensity level

The future energy intensity level for India is hard to deduce from the available information. Ambitious targets are acceptable only if they do not hinder the catch up in level of development. Rapid developments are historically however usually coupled with higher energy intensities, but with effective monitoring and evaluation this does not necessarily have to be the case. An EI level between the Current and New Policies scenario is thus achievable. Taking all information into account, a possible 2030 energy intensity level of **2.45** MJ per $2011 PPP GDP is deduced for India.

4.2.5 *Country profile: Russian Federation*

Historical energy intensity

The energy intensity of the Russian Federation followed an unusual course compared to the other profiled countries. 1990-1998 is associated with a significant increase in energy intensity, except for 1996-1997 in which the energy intensity suddenly declined with 5.78%. After this there is a period with very high rates of improvement until 2009, resulting in a steep decline in energy intensity. The most recently documented years both show instances with moderately increasing and decreasing EI levels, marking the end of a period with fast improvements with a levelling off in energy intensity.

National commitments

The INDC of the Russian Federation is not very detailed and only states a weak target for emissions (25-30% reduction from 1990 levels by 2030). It has also not ratified the Paris Agreement yet, showing a reluctant stance in committing to the target. The Russian Federation is hereby heavily criticised for not committing to long term goals.

Energy efficiency scoring system rankings

The RISE scoreboard does put the Russian Federation at spot 17 with a score of 70, ranking in the high performing category. This means that the regulatory framework does allow for energy efficiency improvements to be realised, exemplified by the period with high rates of improvement. The main indicators to improve on are ‘Carbon pricing’ and ‘Minimum energy efficiency performance standards’. Significant improvements can be made in all sectors.

The ACEEE ranks the Russian Federation on the 17th spot in 2016 and on the 21st spot in 2018, expressing the most recent downward trend in national efforts by granting five fewer points to the ‘Change in energy intensity (2010-2015)’ metric. It now ranks as one of the worst performing large energy consuming countries.

World Energy Outlook

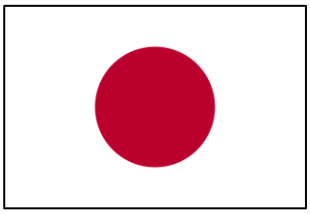
Table 18 below shows the results of the WEO 2016 Total Primary Energy Demand projections for 2030 divided by the two different GDP projections for the Russian Federation. The total projected range therefore is **4.63-4.18** MJ per $2011 PPP GDP.

Table 18: 2030 TPES/GDP from WEO 2016 scenario projections for the Russian Federation

2030 TPES/GDP (MJ/$2011 PPP GDP)	WEO Scenarios		
	Current Policies	**New Policies**	**450**
	4.63	4.46	4.18

Possible future energy intensity level

Currently it does not look like the Russian Federation is committed to decrease its energy intensity significantly. It has the regulatory framework to make fast improvements, but does not seem to be willing to utilise this to make improvements in energy efficiency and intensity. The Current Policies projection in the WEO 2016 might even be too positive. Taking all information into account, a possible 2030 energy intensity level of **4.8** MJ per $2011 PPP GDP is deduced for the Russian Federation.



4.2.6 *Country profile: Japan*

Historical energy intensity

The energy intensity of Japan has been and still is the lowest out of all the profiled countries. From 1990-2000 there were mainly years in which the energy intensity increased. After that mild improvements were made until the most recent years, where between 2010-2015 the energy intensity decreased with 4.6% per year from 4.74 to 3.74 MJ per $2011 PPP GDP. It is hereby one of the high-impact countries that show that improvements on EI at high rates are still possible at low initial energy intensity levels.

National commitments

Japan's submitted INDC underlines that the greenhouse gas emissions and primary energy supply per GDP levels are among the lowest for developed countries. While no specific target is set for energy consumption or intensity, it is stated that 20-40% reduction on these indicators is expected until 2030 due to additional emission reduction measures. This roughly translates to 1.3-2.96% improvement per year.

Energy efficiency scoring system rankings

The RISE scoreboard ranks Japan directly below China on the 21th spot. Japan receives low scores on the 'Incentives and mandates' indicators for both the public sector and utilities. It does still belong to the high performing countries with a score of 68, but shows that improvements in the regulatory framework for enhancing energy efficiency are still possible.

The ACEEE ranks Japan on the 2nd spot in 2016 and on the 5th spot in 2018, receiving high scores for the national efforts and industry metrics. In 2018 Japan dropped 3 spots being overtaken by the European countries: Italy, France and the United Kingdom. The buildings and transportation sectors show the most room for improvement.

World Energy Outlook

Table 19 below shows the results of the WEO 2016 Total Primary Energy Demand projections for 2030 divided by the two different GDP projections for Japan. The total projected range therefore is **3.2-2.78** MJ per $2011 PPP GDP.

Table 19: 2030 TPES/GDP from WEO 2016 scenario projections for Japan

2030 TPES/GDP (MJ/$2011 PPP GDP)	WEO Scenarios		
	Current Policies	New Policies	450
	3.20	3.11	2.78

Possible future energy intensity level

Because Japan seems committed to their national targets it is expected that the New Policies scenario is applicable. Since Japan already has a low energy intensity and the industry sector approaches limitations for improvements, the 450 scenario is probably not achievable. Taking all information into account, a possible 2030 energy intensity level of **3.1** MJ per $2011 PPP GDP is deduced for Japan.

4.3 Comparing allocated targets and possible future energy intensity levels

This section compares the results of the allocation scenarios with the deduced future energy intensity levels from the country profiles for the top five high-impact countries. The energy intensity targets from the allocation scenarios hereby outline the individual efforts to be made within the pathways for the 20 high-impact countries for reaching the global target. Within the global context it should however be considered that the envisioned improvements have to be made within this selection of high-impact countries. A shift of energy intensive industry from within the 20 high-impact countries to countries outside this selection will for example not contribute to global improvements.

The deduced possible future energy intensity levels indicate if the envisioned progress in the allocation scenarios will be reached according to available information on national energy efficiency commitments. Table 20 shows the allocated energy intensity targets in each scenario for 2030 for each of the profiled countries from section 4.1.1 next to the deduced energy intensity levels from the country reports in subsections 4.2.2-4.2.6. The red colours hereby indicate high energy intensity levels, while the green colours indicate low energy intensities. China and India are both expected to have a lower energy intensity level in 2030 than is allocated to them in the scenarios. This is a positive outlook for the future since they are the 1st and 3rd most influential countries in the global context for reaching the target. The deduced energy intensity levels for the United States, the Russian Federation and Japan are above the allocated scenario results. Especially for the United States there is quite a gap towards the desired energy intensity level for 2030.

When compared to the 450 scenario from the WEO, it is curious to observe that the target of the SDGs is reached before the climate targets. China is for example is already reaching its SDGs target for energy efficiency improvements with the deduced 2030 EI level between the New Policies and 450 scenarios from the WEO 2016. This indicates that the SDGs target is not aligned with the climate target, which is more ambitious.

Table 20: Allocated and deduced 2030 energy intensity levels

2030 EI (MJ/$2011 PPP GDP)	Allocation Scenarios						Country Profile
Country	**EQ**	**EI**	**EUC**	**CO2I**	**GDPC**	**CORR**	**Deduced**
China	5.10	4.85	5.29	4.88	5.35	4.69	3.50
United States	2.24	2.53	1.95	2.52	1.99	2.73	3.70
India	3.96	3.91	4.08	3.83	4.01	3.81	2.45
Russian Federation	4.29	4.19	4.11	4.50	4.38	4.38	4.80
Japan	2.56	2.73	2.51	2.64	2.38	2.77	3.10

The according EI levels are also reflected in the resulting REEI rates in table 21, which lists the expected REEI for each country from the deduced energy intensity levels next to the allocated REEIs. The blue colours indicate fast improvement rates, while the red colours indicate slow improvement rates. It is hereby important to notice that the United States and Japan are expected to make improvements with a rate below the global 2.6% per year target. The Russian Federation is however still expected to improve its energy intensity with a rate of 2.95% per year, India with 3.83% per year and China with 4.44% per year.

Table 21: Allocated and deduced 2030 REEI

2010-2030 REEI (%)	Allocation Scenarios						Country Profile
Country	**EQ**	**EI**	**EUC**	**CO2I**	**GDPC**	**CORR**	**Deduced**
China	-2.63	-2.87	-2.44	-2.84	-2.39	-3.03	-4.44
United States	-4.86	-4.29	-5.52	-4.30	-5.42	-3.91	-2.44
India	-1.50	-1.56	-1.35	-1.65	-1.43	-1.69	-3.83
Russian Federation	-3.49	-3.61	-3.70	-3.26	-3.39	-3.39	-2.95
Japan	-3.03	-2.72	-3.13	-2.87	-3.39	-2.64	-2.26

China

This comparison of results also clearly shows that China is the most impactful country for reaching the global target. The CORR scenario having the most equalised results is partly explained by the target that China receives. Compared to the other scenarios it is the most ambitious target for China, thereby decreasing the remainder of the global target to be allocated to other countries significantly. This is a direct result of the weighting system being corrected to lower values for the per capita indicators EUC and GDPC where China has low rankings, and higher values for the intensity indicators EI and CO2I where China has high rankings. This again shows that it is of utmost importance that China leads the way in reducing the global energy intensity. The most recent years show very positive results, but it is certainly not a guarantee that this trend will continue until 2030. The deduced energy intensity level for China is namely reliant on continuous improvements at high rates, which would change the results significantly if these are not being realised. Making sure that China keeps improving at these high rates is therefore the most important aspect for achieving the global target.

Collectively, the top five high-impact countries both show positive and negative outlooks for reaching the global energy efficiency target. It is therefore especially important for these countries to realise their influence and respective roles for making improvements within the global context. The CORR scenario represents the most fair and effective pathway for reaching the global target among the 20 high-impact countries. China and India are hereby expected to reach their allocated 2030 EI targets, while the United States, the Russian Federation and Japan require increased efforts to make progress at the desired allocated improvement rates.

5 Discussion

This chapter discusses the research results in a broader perspective. The limitations of the research are stated first. After this the theoretical and policy implications are elaborated on with general advice and recommendations for further research.

5.1 Limitations of the research

This research is limited to the high-impact countries for the target allocation part of the research. The model can however be adjusted to include all countries and/or aggregates for which the required data is available. Because the global energy intensity level is below the pooled energy intensity of the high-impact countries, this would lead to slightly higher target rates of improvement. In combination with the second part this was however outside the scope for this research.

For the bottom-up approach the research is limited to five countries, China, the United States, India, the Russian Federation and Japan. Additional high quality data and information on national efforts can further increase the validity of the deduced energy intensity levels. Including more countries will also increase the global coverage of the bottom-up approach. Within the global context there is however a trade-off between including additional countries and obtaining impactful results. This is because every country that is added represents a diminishing share of the total coverage. This does not mean that it is not important for these countries to contribute to the global target, but does mean that reduced impact on the results is obtained with the same amount of additional effort. While this research does not represent the entirety of the global target, the coverage obtained is sufficient to justify the results.

The GDP projections for 2030 remain highly uncertain and limit the accuracy of the research results. The main message is however that the method will still work with different GDP values, and inter-relationships of modelled outputs remain the same. When more accurate projections become available this will also be visible in the quality of the modelled results.

This research is also limited in its representation of underlying factors for enhancing energy efficiency and intensity. A shift of energy intensive industry from the selected high-impact countries towards countries outside this selection is for example not accounted for. Multiple studies and reports have also stated that energy intensity is not a suitable indicator to measure actual energy efficiency because many factors such as the climate and structure of economy influence it (Ang, 2006; IEA, 2016a; Proskuryakova & Kovalev, 2015; Moreau & Vuille, 2018). These results are not corrected for such factors which could alter the modelling outcomes. The aim of the top-down allocation approach was however to show that pathways towards the global target with fair and effective national targets can be defined. This aim was fulfilled in the research.

5.2 Theoretical implications

The research results show that pathways towards the global energy efficiency target can be explored by applying a composite allocation method to obtain national targets. The methods used for carbon emissions and intensity reduction targets allocation can therefore be transformed to be applicable for allocating the energy intensity target. This also builds on the available literature on the SDGs by translating the global target to the national scope.

The most fair and effective pathway resulted from the CORR scenario in which the weighting system was corrected for the linear pairwise correlation between the indicator scores. The other scenarios reflect subjectivity towards certain indicators through the weighting system. Even the EQ scenario unintentionally values the per capita indicators EUC and GDPC more because of this underlying correlation. This stresses the importance to check the indicators used for their inter-relationships beforehand. This is in line with the available guidebooks on developing composite indicators by the Joint Research Centre and OECD (Saisana & Tarantola, 2002; Nardo et al., 2005).

Further research can build on these results by experimenting with different relevant indicators, alternative allocation approaches/methods and addition of countries. The use of a multiple criteria decision analysis is for example commonly used for composite indicator construction (Zhou & Ang, 2009), as well as different DEA (Sueyoshi et al., 2017; Mardani et al., 2017; Peng et al., 2017) or hybrid approaches (Hatefi & Torabi, 2010). The country profiles can also become more accurate with additional information on national efforts and commitments. Including the 'Efficiency Policy Progress Index' (IEA, 2017) to the scoring system analysis would for example increase its validity.

To gain allocation results that represent the fairness principle even more, specific underlying factors such as the influence of climate and structure of the economy should also be included. Future research can also aim to find out how the global target can still be reached while allowing certain countries to increase their energy intensity. A benefit would also be if studies aim to find out how the energy efficiency targets can effectively be linked to the greenhouse gas emissions reduction targets in the submitted (I)NDC documents. Wu et al. (2017) for example explore how the NDC targets for China can be reached by combining a trading scheme for emissions and policies for renewable energy. Conducting more studies like these could open up the discussion to include energy consumption and efficiency targets in future (I)NDC editions.

5.3 Policy implications

Among the high-impact countries the recent improvements have not been fast enough to reach the global target when compared to the allocated rates of improvement. Every year in which the collective improvement rate is lower than 2.6% will accumulate the efforts to be made until 2030. A recent report states that currently 2.7% improvement per year on energy intensity needs to be realised from 2015-2030 to achieve the global target (World Bank, 2018b). Monitoring, evaluation and feedback for the high-impact countries on their progress is therefore key to ensure the target improvements.

This research is valuable for all these purposes. The model can be updated with new data to monitor the progress and evaluate if countries are making improvements at their allocated target rates. This information can then be used to give feedback on policy effectiveness and help to increase efforts to enhance energy efficiency. The target allocation results for this research were revealed in a poster presentation at the 2018 International Energy Policy & Programme Evaluation Conference (IEPPEC) in Vienna, where positive feedback was given on the outlook for usability of the research for evaluation purposes.

Adding national energy efficiency and intensity targets to the (I)NDCs would stimulate additional research and efforts to reach the global target. China is the most impactful country globally and showcases the influence of the submitted NDCs on new research. The number of studies conducted that focus on reaching targets for China is namely vast. Lu et al. (2017) for example focusses on optimising the energy structure of Hangzhou City to realise a low carbon city, and Zhou et al. (2014) conducts an efficiency analysis on the provincial and regional level to allocate the CO_2 emissions reduction target. These are in addition to the papers from Chinese sources described in the allocation theory section 2.2. When an energy intensity target is developed for China, it is therefore likely that numerous studies will be conducted that focus on optimising allocation scenarios to reach this target too.

6 Conclusion

The research question states: *How can the global energy efficiency target of the Sustainable Development Goals be translated into fair and effective national targets, and how do these compare to national energy efficiency commitments?* Top-down allocation and bottom-up national commitments approaches were used to obtain national energy efficiency targets and deduce possible future energy intensity levels. Six scenarios where explored in the top-down composite indicator allocation approach based on different weightings for the energy intensity, energy use per capita, CO_2 intensity of energy use, and GDP per capita indicators. The allocation scenario in which the weighting system was corrected for the correlation between the chosen indicators resulted in the most fair and effective pathway towards the global energy efficiency target for a selection of 20 high-impact countries. The top five of those high-impact countries, China, the United States, India, the Russian Federation and Japan were reviewed in more detail in the bottom-up approach where possible future energy intensity levels were deduced from country profiles. The combined results show that China and India are expected to reach the energy intensity targets that were allocated to them in the scenarios, while the United States, the Russian Federation and Japan need additional efforts to stimulate the progress needed to make improvements at their allocated target rates.

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Appendices

Appendix A: Matlab model

```
%% Description
% Energy Intensity script allocating the SDGs global energy efficiency target
% By: David Boks
% Last modified: 10-08-2018

%% Clear Workspace
clear
close all
clc

%% Load Data
load EEData.mat
load WDICO2IntensityEU.mat
load WDIEI.mat
load WDIEU.mat
load WDIGDPCapita.mat
load GDPLTPPWC.mat
load WDIGDP2010.mat
load WDIInflation.mat
load WDIALLEI

%% Remove Countries With Incomplete Data
Countries = WDIALLEI.CountryName;
EnergyIntensity = table2array(WDIALLEI(:,5:end));
NanLocs = find(isnan(mean(EnergyIntensity,2)));
EnergyIntensity(NanLocs,:) = [];
Countries(NanLocs) = [];

%% High Impact Countries
Country = WDIEI.CountryName;
HIC = {'Australia';'Brazil';'Canada';'China';'France';'Germany';...
    'India';'Indonesia';'Iran, Islamic Rep.';'Italy';'Japan';'Korea, Rep.';...
    'Mexico';'Nigeria';'Russian Federation';'Saudi Arabia';'South Africa';...
    'Thailand';'United Kingdom';'United States'};
HIC_CC = {'AUS','BRA','CAN','CHN','FRA','DEU','IND','IDN','IRN','ITA','JPN'...
    ,'KOR','MEX','NGA','RUS','SAU','ZAF','THA','GBR','USA'};

idx = find(ismember(Countries, HIC));
CountryIndex = idx;

%% Choice of Scenario
Scenarios = 1:6;
Scenario = 6; %nr of allocation scenario (1-6(EQ/EI/EUC/CO2I/GDPC/CORR))

%% Historical Data Years
FirstYear = 1990;
StartYear = 2010;
EndYear = 2015;

%% Target Years
ModelStart = 2010;
ModelEnd = 2030;

MStart = ModelStart - 1989;
MEnd = ModelEnd-1989;

Start = StartYear - 1989;
Final = EndYear - 1989;
Titles = {['EI_',num2str(StartYear)], ['EI_', num2str(EndYear)],...
    ['EI_Target_',num2str(ModelEnd)]};
```

```
%% Known 2010 & 2030 Values
% Year 2010
EI_i_2010 = WDIEI.YR2010;
EU_i_2010 = WDIEU.YR2010;
CO2Intensity_i_2010 = WDICO2Intensity.YR2010;
GDPCapita_i_2010 = WDIGDPCapita.YR2010;
GDP_i_2010 = WDIGDP2010.YR2010;
World_EI_2010 = EnergyIntensity(228,21);
TPES_i_2010 = EI_i_2010.*GDP_i_2010;
HIC_EI_2010 = sum(TPES_i_2010)/sum(GDP_i_2010);
HIC_TPES_2010 = sum(TPES_i_2010);
HIC_GDP_2010 = sum(GDP_i_2010);

% Year 2030
GDP_i_2030_2016USD = GDPLTPPWC.GDP2030(1:20)*10^9;
GDP_i_2030 = GDP_i_2030_2016USD.*(1.+(WDIInflation.YR2016/100)).*...
    (1.+(WDIInflation.YR2015/100)).*(1.+(WDIInflation.YR2014/100)).*...
    (1.+(WDIInflation.YR2013/100)).*(1.+(WDIInflation.YR2012/100));
World_EI_Target_2030 = World_EI_2010*(0.974^20);
HIC_EI_Target_2030 = HIC_EI_2010*(0.974^20);
HIC_TPES_2030 = HIC_EI_Target_2030*sum(GDP_i_2030);
HIC_GDP_2030 = sum(GDP_i_2030);

%% Allocation Calculations
% Single Indicator Allocation
EI_Alloc = EI_i_2010./mean(EI_i_2010);
EU_Alloc = EU_i_2010./mean(EU_i_2010);
CO2IEU_Alloc = CO2Intensity_i_2010./mean(CO2Intensity_i_2010);
GDPCapita_Alloc = GDPCapita_i_2010./mean(GDPCapita_i_2010);

% Composite Indicator Allocation
Comp_Alloc = (EI_Alloc+EU_Alloc+CO2IEU_Alloc+GDPCapita_Alloc)./4;
CompEI_Alloc = (0.4.*EI_Alloc)+(0.2.*EU_Alloc)+(0.2.*CO2IEU_Alloc)+...
    (0.2.*GDPCapita_Alloc);
CompEU_Alloc = (0.2.*EI_Alloc)+(0.4.*EU_Alloc)+(0.2.*CO2IEU_Alloc)+...
    (0.2.*GDPCapita_Alloc);
CompCO2IEU_Alloc = (0.2.*EI_Alloc)+(0.2.*EU_Alloc)+(0.4.*CO2IEU_Alloc)+...
    (0.2.*GDPCapita_Alloc);
CompGDPCapita_Alloc = (0.2.*EI_Alloc)+(0.2.*EU_Alloc)+(0.2.*CO2IEU_Alloc)+...
    (0.4.*GDPCapita_Alloc);
CorrComp_Alloc = (0.34.*EI_Alloc)+(0.16.*EU_Alloc)+(0.33.*CO2IEU_Alloc)+...
    (0.17.*GDPCapita_Alloc);
CombCompAlloc = [Comp_Alloc, CompEI_Alloc, CompEU_Alloc, CompCO2IEU_Alloc,...
    CompGDPCapita_Alloc, CorrComp_Alloc];

ci = zeros(size(CombCompAlloc));
a = zeros(length(Scenarios),1);
TPES_i_2030 = zeros(size(CombCompAlloc));
EI_i_2030 = zeros(size(CombCompAlloc));
CAGR = zeros(size(CombCompAlloc));

for i = 1:length(Scenarios)
    ci(:,i) = 1-((1-(0.974^20)).*CombCompAlloc(:,i));
    a(i,1) = HIC_TPES_2030/(sum(EI_i_2010.*ci(:,i).*GDP_i_2030));
    TPES_i_2030(:,i) = EI_i_2010.*ci(:,i).*GDP_i_2030*a(i);
    EI_i_2030(:,i) = TPES_i_2030(:,i)./GDP_i_2030;
    CAGR(:,i) = (((EI_i_2030(:,i)./EI_i_2010).^(1/20))-1)*100;
end

%% REEI Calculations
ALLREEI = (((EnergyIntensity(:, Final) ./ ...
        EnergyIntensity(:, Start)).^(1/(Final-Start))) - 1) .* 100;
REEI = (((EnergyIntensity(CountryIndex, Final) ./ ...
        EnergyIntensity(CountryIndex, Start)).^(1/(Final-Start))) - 1) .* 100;
HIC_ConvergenceREEI = (((HIC_EI_Target_2030./EnergyIntensity(CountryIndex,21))...
    .^(1/20))-1).*100;
```

```
% Yearly REEI
YearlyREEI = zeros(length(EnergyIntensity),length(FirstYear:EndYear)-1);
for i = 2:length(FirstYear:EndYear)
    YearlyREEI(:,i-1) = ((EnergyIntensity(:,i)./EnergyIntensity(:,i-1)) - 1)...
        * 100;
end

%% Targets
% Target EI calculation
ModelResult(CountryIndex,MStart) = EnergyIntensity(CountryIndex,MStart);
for j = (MStart+1):MEnd
    ModelResult(CountryIndex,j) = ModelResult(CountryIndex,j-1)...
        .* (1 + (CAGR(:,Scenario)/100));
end

% Target REEI
TargetREEI = (((ModelResult(CountryIndex, MEnd) ./ ...
    EnergyIntensity(CountryIndex, 21)).^(1/(MEnd-21))) - 1) .* 100;
DistFromTargetREEI = REEI-CAGR;

%% Tables
% Indicator Values Table
IndValTable = table(Country, EI_i_2010, EU_i_2010, CO2Intensity_i_2010,...
    GDPCapita_i_2010,'VariableNames',{'Country', 'EI', 'EU', 'CO2I', 'GDPCapita'});

% Composite Allocation Table
compTable = table(WDIEI.CountryName, Comp_Alloc, CompEI_Alloc, CompEU_Alloc,...
    CompCO2IEU_Alloc, CompGDPCapita_Alloc, CorrComp_Alloc, 'VariableNames',...
    {'Country','combined', 'CompEI', 'CompEU', 'CompCO2I', 'CompGDPCapita',...
    'CorrComp'});

% Allocation Table
AllocTable = table(Country, EI_Alloc, EU_Alloc, CO2IEU_Alloc, GDPCapita_Alloc,...
    'VariableNames',{'Country', 'EI_Alloc', 'EU_Alloc', 'CO2I_Alloc',
'GDPCapita_Alloc'});

% CAGR Table
CAGRTable = table(Country, CAGR(:,1), CAGR(:,2), CAGR(:,3), CAGR(:,4),...
    CAGR(:,5), CAGR(:,6),'VariableNames',{'Country', 'CAGR_Eq', 'CAGR_EI',...
    'CAGR_EU', 'CAGR_CO2I', 'CAGR_GDPCap', 'CAGR_Corr'});

% Yearly REEI Tables
YearlyREEITable =
table(Countries,YearlyREEI(:,1),YearlyREEI(:,2),YearlyREEI(:,3),...

YearlyREEI(:,4),YearlyREEI(:,5),YearlyREEI(:,6),YearlyREEI(:,7),YearlyREEI(:,8),...
    YearlyREEI(:,9),YearlyREEI(:,10),YearlyREEI(:,11),YearlyREEI(:,12),...
    YearlyREEI(:,13),YearlyREEI(:,14),YearlyREEI(:,15),YearlyREEI(:,16),...
    YearlyREEI(:,17),YearlyREEI(:,18),YearlyREEI(:,19),YearlyREEI(:,20),...
    YearlyREEI(:,21),YearlyREEI(:,22),YearlyREEI(:,23),YearlyREEI(:,24),...
    YearlyREEI(:,25),'VariableNames',{'Country','y1990','y1991','y1992',...
    'y1993','y1994','y1995','y1996','y1997', 'y1998', 'y1999', 'y2000',...
    'y2001', 'y2002', 'y2003', 'y2004', 'y2005','y2006', 'y2007', 'y2008',...
    'y2009',  'y2010',  'y2011',  'y2012',  'y2013','y2014'});

HIC_Yearly_REEI_Table = YearlyREEITable(idx,:);
HIC_Yearly_REEI = cell2mat(table2cell(HIC_Yearly_REEI_Table(:,2:end)));

% REEI Progress Table
REEI_ProgressTable = table(Country,
DistFromTargetREEI(:,1),DistFromTargetREEI(:,2),...
    DistFromTargetREEI(:,3),DistFromTargetREEI(:,4),DistFromTargetREEI(:,5),...

DistFromTargetREEI(:,6),'VariableNames',{'Country','S1','S2','S3','S4','S5','S6'});
```

```matlab
% EI/REEI Table
EI_REEI_Table = table(Country, ...
    EnergyIntensity(CountryIndex, Start), EnergyIntensity(CountryIndex, Final),...
    REEI,TargetREEI,ModelResult(CountryIndex, MEnd), 'VariableNames',...
    {'Country', Titles{1}, Titles{2}, 'REEI', 'Target_REEI' Titles{3}})

%% Visualizations
% Yearly REEI Plot
years = FirstYear:EndYear-1;
HIC_YearlyREEIPlot = plot(years,HIC_Yearly_REEI([4,7,11,15,20],:),'-x',...
    'LineWidth',2);
hold on
target = ones(1,length(years))*-2.6;
zeroline = zeros(1,length(years));
p1 = plot(years,target,'LineWidth',1.6);
p2 = plot(years,zeroline,'LineWidth',1.6);
set (p1, 'Color','b','LineStyle','--');
set (p2, 'Color','k');
legend(HIC([4,7,11,15,20]),'Global Growth Target');
xlabel('Year');
ylabel('EI growth [%]');
title('Yearly EI growth');
hold off

% EI Line Plot
figure;
EIplot = plot(FirstYear:EndYear, EnergyIntensity(CountryIndex, 1:Final));
cm = jet(20);
for i = 1:length(Country)
    set(EIplot(i), {'Color', 'LineWidth'}, {cm(i,:), 2})
end
hold on
EIplot2 = plot(ModelStart:ModelEnd,ModelResult(CountryIndex,MStart:MEnd,1)','--');
for i = 1:length(Country)
    set(EIplot2(i), {'Color', 'LineWidth'}, {cm(i,:), 1.5})
end
legend(Countries{CountryIndex},'Target Lines');
set(EIplot,'LineWidth',1.6);
title('EI Analysis');
xlabel('Year');
ylabel('Energy Intensity [MJ/$2011 PPP GDP]');

% EI Scatter Plots
% 2010
figure;
subplot(2,1,1);
scatter(GDP_i_2010,TPES_i_2010,100,cm,'filled','s');
hold on
plot(TPES_i_2010./HIC_EI_2010,TPES_i_2010,'LineWidth',1.6);
title('2010 TPES/GDP')
set(gca,'xlim',[min(TPES_i_2010./EI_i_2010) max(TPES_i_2010./EI_i_2010)],...
    'ylim',[min(GDP_i_2010.*EI_i_2010) max(GDP_i_2010.*EI_i_2010)],'xscale',...
    'log','yscale','log');
xlabel('GDP [$2011 PPP]');
ylabel('TPES [MJ]');
text(GDP_i_2010,TPES_i_2010,HIC_CC,'rotation', 0,'FontSize',12,'FontWeight',...
    'bold','HorizontalAlignment','left','VerticalAlignment','baseline');
hold off

% 2030
subplot(2,1,2);
scatter(GDP_i_2030,TPES_i_2030(:,Scenario),100,cm,'filled');
hold on
plot(TPES_i_2030(:,Scenario)./HIC_EI_Target_2030,TPES_i_2030(:,Scenario),...
    'LineWidth',1.6);
title('2030 TPES/GDP');
set(gca,'xscale','log','yscale','log','xlim',[0 max(GDP_i_2030)],'ylim',...
```

```
    [0 max(TPES_i_2030(:,Scenario))]);
xlabel('GDP [$2011 PPP]');
ylabel('TPES [MJ]');
text(GDP_i_2030,TPES_i_2030(:,Scenario),HIC_CC,'rotation', 0,'FontSize',12,...

'FontWeight','bold','HorizontalAlignment','left','VerticalAlignment','baseline');
hold off

% Combined 2010-2030
figure;
sel = [2 4 6 7 8 9 10 11 13 14 15 16 17 19 20];
EIscatter2010 =
scatter(GDP_i_2010(sel),TPES_i_2010(sel),200,cm(sel,:),'filled','s');
hold on
EIscatter2030 = scatter(GDP_i_2030(sel),TPES_i_2030(sel,Scenario),200,...
    cm(sel,:),'filled');
set(gca,'xscale','log','yscale','log','xlim',[0 max(GDP_i_2030)],'ylim',...
    [0 max(TPES_i_2030(:,Scenario))])
plot(TPES_i_2030(:,Scenario)./HIC_EI_Target_2030,TPES_i_2030(:,Scenario),...
    '-b','LineWidth',1.6);
for i = 1:length(Country)
    TotEIplot(i,i) = plot([GDP_i_2010(i),GDP_i_2030(i)],[TPES_i_2010(i),...
        TPES_i_2030(i,Scenario)],'--k','LineWidth',1.6);
end
xlabel('GDP [$2011 PPP]');
ylabel('TPES [MJ]');
title('Combined 2010--2030 TPES/GDP');
text(GDP_i_2030(sel),TPES_i_2030(sel,Scenario),HIC_CC(sel),'rotation',...
    0,'FontSize',12,'FontWeight','bold','HorizontalAlignment','left',...
    'VerticalAlignment','baseline');

%% Statistics
% Indicator Stats
% Correlation
CorrelationCheck = [EI_i_2010, EU_i_2010, CO2Intensity_i_2010, GDPCapita_i_2010];
[rho, pval] = corr(CorrelationCheck);

[~,iii] = sort(CorrelationCheck,'descend');
[~,rr] = sort(iii);
Indicator_rank_table = table(Country,rr(:,1),rr(:,2),rr(:,3),rr(:,4),...
    'VariableNames',{'Country','EI','EU','CO2I','GDPCap'});
Indicator_rank_range = range(rr,2);
Indicator_std = std(CorrelationCheck);

% Single indicator allocation std
SingleAlloc = [EI_Alloc, EU_Alloc, CO2IEU_Alloc, GDPCapita_Alloc];
SingleAlloc_std = std(SingleAlloc);

% Composite indicator std
ComposAlloc = [Comp_Alloc, CompEI_Alloc, CompEU_Alloc,...
    CompCO2IEU_Alloc, CompGDPCapita_Alloc, CorrComp_Alloc];

ComposAlloc_std = std(ComposAlloc);

% Ri std
Ri_std = std(ci);

% EI 2010/2030 std
EI_2030_std = std(EI_i_2030);

% CAGR Stats
CAGR_std = std(CAGR);

figure;
boxplot(CAGR);
xticklabels({'Eq','EI','EU','CO2I','GDPCap','Corr'});
```

```
ylabel('Target 2010-2030 EI CAGR');
title('CAGR boxplot');

CAGR_range = range(CAGR);
[~,ii] = sort(CAGR,'ascend');
[~,r] = sort(ii);
CAGR_rank_table = table(Country,r(:,1),r(:,2),r(:,3),r(:,4),r(:,5),r(:,6),...
    'VariableNames',{'Country','Eq','EI','EU','CO2I','GDPCap','Corr'});
CAGR_rank_range = range(r,2);

CAGR_range = range(CAGR);
[~,ii] = sort(CAGR,'ascend');
[~,r] = sort(ii);
CAGR_rank_table = table(Country,r(:,1),r(:,2),r(:,3),r(:,4),r(:,5),r(:,6),...
    'VariableNames',{'Country','Eq','EI','EU','CO2I','GDPCap','Corr'});
CAGR_rank_range = range(r,2);
```

Appendix B: High-impact countries

IEA 2015 Indicators	2015 TPES			2015 GDP			2015 EI
High-Impact Country	**TPES (Mtoe)**	**Share of world (%)**	**Cumulative coverage (%)**	**GDP PPP (billion USD)**	**Share of world (%)**	**Cumulative coverage (%)**	**TPES/GDP PPP (toe/thousand 2010 USD)**
China	2973	21.79	21.79	18050	17.18	17.18	0.16
United States	2188	16.03	37.82	16597	15.80	32.99	0.13
India	851	6.24	44.06	7365	7.01	40.00	0.12
Russian Federation	710	5.20	49.26	3103	2.95	42.95	0.23
Japan	430	3.15	52.41	4462	4.25	47.20	0.10
Germany	308	2.26	54.66	3473	3.31	50.51	0.09
Brazil	298	2.18	56.85	2960	2.82	53.33	0.10
Korea, Rep.	273	2.00	58.84	1742	1.66	54.98	0.16
Canada	270	1.98	60.82	1515	1.44	56.43	0.18
France	247	1.81	62.63	2456	2.34	58.76	0.10
Iran, Islamic Rep.	237	1.73	64.36	1264	1.20	59.97	0.19
Indonesia	225	1.65	66.01	2621	2.50	62.46	0.09
Saudi Arabia	222	1.62	67.64	1554	1.48	63.94	0.14
Mexico	187	1.37	69.01	1990	1.89	65.84	0.09
United Kingdom	181	1.32	70.34	2477	2.36	68.20	0.07
Italy	153	1.12	71.45	2015	1.92	70.11	0.08
South Africa	142	1.04	72.50	669	0.64	70.75	0.21
Nigeria	139	1.02	73.52	1007	0.96	71.71	0.14
Thailand	135	0.99	74.51	1022	0.97	72.68	0.13
Australia	125	0.92	75.43	1078	1.03	73.71	0.12
World	13647			105035			0.13