

SYNERGIES BETWEEN RENEWABLE ENERGY AND ENERGY EFFICIENCY

A WORKING PAPER BASED ON REMAP 2030

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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. IRENA serves as the Renewable Energy Hub for the Sustainable Energy for All (SE4All) initiative.

About C2E2

The Copenhagen Centre on Energy Efficiency (C2E2) is a research and advisory institution dedicated to accelerating the uptake of energy efficiency policies, programmes and actions globally. C2E2 serves as the Energy Efficiency Hub of the Sustainable Energy for All (SE4All) Initiative. The Centre's prime responsibility is to support SE4All's objective of doubling the global rate of energy efficiency improvement by 2030.

Acknowledgements

This working paper has benefited from the valuable comments of Benoit Lebot from the International Partnership for Energy Efficiency Cooperation (IPEEC); Ruud Kempener and Elizabeth Press from IRENA; and Jyoti P. Painuly and Timothy Clifford Farrell from C2E2. This report was also reviewed during the REmap Action Teams event held in the margins of the ninth meeting of the IRENA Council in June 2015.

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Report citation

IRENA and C2E2 (2015), Synergies between renewable energy and energy efficiency, Working paper, IRENA, Abu Dhabi and C2E2, Copenhagen.

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KEY FINDINGS

- The United Nations' Sustainable Energy for All (SE4All) initiative is grounded on three interlinked global objectives: 1) ensuring universal access to modern energy services, 2) doubling the global rate of improvement in energy efficiency, and 3) doubling the share of renewables in the global energy mix.
- This working paper is the first outcome of the co-operation between the Copenhagen Centre on Energy Efficiency (C2E2) – the energy efficiency hub of the SE4All initiative – and the International Renewable Energy Agency (IRENA), the renewable energy hub of the initiative.
- The working paper looks at the synergies and trade-offs between the energy efficiency and renewable energy objectives of SE4All. The quantitative assessments are analysed using data for eight countries (China, Denmark, France, Germany, India, Italy, the United Kingdom and the United States), which covers half of global energy use.
- This analysis is based on three pillars. The first two identify how the SE4All energy efficiency and renewable energy objectives can be reached separately in the cases where 1) the development of either energy efficiency or renewables follows business as usual, and 2) this development follows accelerated deployment. A third analysis looks at the synergies and trade-offs that result from deploying both renewable energy and energy efficiency measures at the same time.
- According to IRENA's REmap analysis, implementation of the accelerated deployment of renewables in line with the SE4All objective (in this paper, the "REmap Options") shows that in the eight countries analysed, the share of modern renewable energy increases by a factor of two to four between 2010 and 2030 beyond a business-as-usual case where both energy efficiency improvements and renewables deployment follow current policies (in this paper, the "Reference Case").
- Through the deployment of these renewable energy technologies, the energy intensity (energy use per unit of gross domestic product) of selected countries would decrease by 5-10% by 2030 in comparison to business as usual, where only autonomous improvements of energy efficiency are assumed.
- Based on energy-saving potential estimates of the International Energy Agency (IEA), accelerated deployment of energy efficiency can double the improvement rates in energy intensity of the selected European Union countries and India. For the United States and China, however, even higher deployment of efficiency measures are required to reach such levels.
- Lower energy demand from measures to accelerate energy efficiency contributes to increasing the renewable energy share of all countries, assuming that renewable energy use will grow following business as usual. This is particularly the case for countries where low demand growth is projected to 2030, such as Germany or the United States.
- Accelerated deployment of energy efficiency and renewable energy creates a synergy for increasing both the renewable energy share and annual improvements in energy intensity. When the potentials of energy efficiency and renewables are combined, the growth in total primary energy supply (TPES) can be reduced by up to 25% compared to business as usual in 2030. Energy efficiency measures would account for 50-75% of the total energy savings.
- Renewable power sector technologies and efficiency measures to reduce power demand will play the key role in both TPES savings and realising higher shares of renewables in the analysed countries.

- Realization of the accelerated renewable energy potential alone is not sufficient to achieve neither of the two SE4All objectives. Although some countries could achieve a doubling of their energy efficiency improvement rate through energy efficiency measures alone, it is not possible to achieve a doubling of the renewable energy share through renewable energy deployment alone.
- There is a potential trade-off between improvements in energy efficiency that reduce overall energy demand, and renewables, since energy efficiency measures could potentially reduce the demand for new renewable energy capacity as well, and thereby limit absolute deployment levels.
- To meet the two SE4All objectives for renewable energy and energy efficiency, total investment needs in the analysed regions amount to an estimated USD 700 billion per year on average between 2012 and 2030, with 55% of the total investments related to energy efficiency measures, and 45% related to renewables.
- Several other indicators besides energy intensity and the renewable energy share in total final energy consumption (TFEC) can be used to measure changes in energy efficiency and renewables; they are discussed briefly in this paper.
- This working paper ends with recommendations for policy makers suggesting the need to expand this exercise to more countries and to update the energy efficiency potential as new technology data is available.

1 INTRODUCTION

In 2012, the United Nations General Assembly declared 2014-2024 to be the Decade of Sustainable Energy for All (SE4All), underscoring the importance of energy issues for sustainable development and for the elaboration of the post-2015 development agenda. In 2011, the UN Secretary-General set up a High-Level Group on SE4All to develop a global, multi-stakeholder action agenda based on three interlinked objectives: 1) ensuring universal access to modern energy services, 2) doubling the global rate of improvement in energy efficiency and 3) doubling the share of renewables in the global energy mix. The target year of SE4All objectives is 2030, and the base year is 2010.

Several thematic and regional hubs have been nominated to support this global agenda, and act as information centres to support organisations interested in scaling up efforts in their constituencies, learning from each other and avoiding duplication.

The International Renewable Energy Agency (IRENA) and the Copenhagen Centre on Energy Efficiency (C2E2) have been established as the thematic hubs for renewable energy and energy efficiency, respectively.

This first collaborative effort between IRENA and C2E2 focuses on deepening the understanding of how renewable energy and energy efficiency, when employed in concert, can help realise the interlinked objectives of the initiative.

This collaboration included the analysis that built on IRENA's work in 2013 and early 2014, which explored technology pathways, as well as policy and finance needs, to realise the SE4All renewable energy objective through IRENA's global renewable energy roadmap, *REmap 2030*. As the Energy Efficiency Hub for the SE4All initiative, C2E2 aims to contribute to this work in partnership with IRENA by quantifying and incorporating the potential of deploying energy efficiency technologies and analysing their possible synergies with renewable energy.

REmap 2030, launched in June 2014 at the first SE4All Forum, shows that doubling the renewable energy

share in the global energy mix from 18% in 2010 to 36% by 2030 is technically feasible. Achieving a doubling is only possible through a combination of accelerated renewable energy deployment, energy efficiency improvements and modern energy access. The study also shows that doubling is affordable even when externalities related to fossil fuel use are accounted for (IRENA, 2014a).

Increased investment and deployment of renewables that also accounts for increased energy access has the potential to reach a share of about 30% of the global energy mix by 2030. However, to achieve the 36% objective would require accelerated action under the energy efficiency objective.

On the other hand, if all renewable energy technology options (hereafter "REmap Options") identified in *REmap 2030* are implemented, the rate of improvement in global energy intensity between 2010 and 2030 would increase from 1.3% in business-as-usual to 1.6% per year in *REmap 2030*. The additional improvement in energy intensity is due to better efficiency of renewable energy technologies compared to their fossil fuel counterparts. This shows that renewable energy also can contribute to SE4All's energy efficiency objective. Therefore, the synergy between renewable energy and energy efficiency actions is crucial for the achievement of SE4All objectives, and it is important to analyse its potential in more detail.

The various aspects of the synergies between energy efficiency and renewable energy have received only limited attention from policy makers and the research community. So far only some research addressed the importance of this topic. In its Green Paper issued in March 2013, the European Commission noted that higher levels of energy efficiency can help to attain the European Union's (EU) renewable energy targets. The document also highlighted the possible trade-offs. For example, higher-than-expected renewable energy use can lower the carbon price and thus reduce investments in energy efficiency measures (EC, 2013). Prindle *et al.* (2007) discuss the timing, economic, geographic and power system synergies. The Fifth Assessment Report

of the Intergovernmental Panel on Climate Change (IPCC, 2015) shows that energy efficiency measures and renewable energy are core components of the solution to mitigating climate change. Country analyses of *REmap 2030* point to similar conclusions and to the need to deploy both technologies in order to realise significant reductions of fossil fuel use and carbon dioxide (CO₂) emissions (IRENA, 2014b, 2015).

The main aim of this working paper is to quantify the potential synergies between the deployment of renewable energy technologies and improvements in energy efficiency and to analyse their contribution in achieving two of the two SE4All objectives by 2030: doubling the share of renewables in the global energy mix in comparison to 2010 levels (hereafter “renewable energy objective”), and doubling the global rate of energy intensity improvement (hereafter “energy efficiency objective”). For this purpose, this working paper looks at three different analyses:

- 1) The potential of accelerated deployment of renewable energy technologies (“REmap Options”) to realise the renewable energy objective, without taking into account possible improvements in energy efficiency beyond business as usual. (Section 4.1)
- 2) The potential of accelerated deployment of energy efficiency measures, without taking into account the deployment of renewable energy technologies beyond business as usual. (Section 4.2)
- 3) The potential of accelerated deployment of renewable energy technologies and energy efficiency measures, and their synergies and trade-offs. (Section 4.3)

The first two analyses evaluate the extent to which renewable energy technologies and energy efficiency measures could contribute separately to meeting the

SE4All objectives by 2030, without taking into account the synergies between them; whereas the third analysis focuses on the importance of these synergies and trade-offs. This paper is not limited to examining these three analyses, but also answers several key policy questions (in section 5) that are relevant for policy makers, namely:

- What is the magnitude of synergies between energy efficiency and renewable energy? What are their roles in progressing towards the SE4All objectives? Which factors make it important to take into account these synergies (e.g., cost synergies, policy effectiveness/efficiency gains)? (Section 5.1)
- What is the magnitude of trade-offs between simultaneous deployment of renewable energy and energy efficiency? (Section 5.2)
- How much will the policies aiming for synergies cost, and will the combined policies be easier to implement? (Section 5.3)
- What alternative indicators can be used for measuring progress towards the SE4All objectives (particularly in relation to energy efficiency improvement), and what can their potential effects be? (Section 5.4)

The working paper has the following structure: Section 1 introduces the SE4All initiative and its objectives, and presents the aim and objectives of this paper. Section 2 provides background discussion on the interaction between the renewable energy and energy efficiency objectives. Section 3 presents the methodology used in this paper. Section 4 discusses the results of the analysis and is structured around three outlined research objectives. Section 5 discusses the results with the focus on answering policy-relevant questions presented above. Section 6 presents concluding remarks and summarises the key messages from the analysis.

2 BACKGROUND

Efforts to track progress are key to informing countries and providing guidance in view of the global commitments to the three SE4All objectives. Therefore, a framework for tracking the progress towards achieving these objectives has been defined under the SE4All initiative. This *Global Tracking Framework (GTF)* has been established through a collaborative effort of various organisations, and proposes a set of indicators that can be used to track the immediate and medium-term progress, both globally and at the country level, towards achieving the three objectives.

The first volume of the GTF was released in May 2013 (World Bank, 2013a), and the second volume was released in May 2015 (World Bank, 2015). Based on the GTF, this section provides the definition and indicators of renewable energy and energy efficiency that are used throughout this paper, and provides a brief overview of the status of progress in each area. A few examples of how renewable energy and energy efficiency can act in tandem also are presented.

2.1 Energy efficiency

Energy efficiency refers to using less energy input to deliver the same service (or, similarly, using the same amount of energy input to deliver more service). For example, energy input can be the use of electricity by a light bulb to deliver the service “light”. Service can be measured in physical terms (e.g., one passenger-kilometre) or in monetary terms (e.g., one US dollar (USD) of steel production). The use of physical instead of monetary terms is preferred since it provides a better understanding of technical efficiency.

Under the framework, the compound annual growth rate (CAGR) of energy intensity has been chosen as an immediate (but imperfect) proxy to measure the progress in energy efficiency improvements. Energy intensity is defined as the amount of energy required to produce a unit of economic activity¹. The immediate

advantage of using this indicator is the availability of data at an aggregate level, although it fails to account for the multi-dimensional nature of energy efficiency.

According to the GTF 2013, global energy intensity improved by 1.3% annually during the 20-year period from 1990 to 2010. The rate of improvement was slower during 2000-2010 (1% per year) than during 1990-2000 (1.6% per year). Developments in 2011-2012 provide some optimism that energy demand can be further decoupled from GDP growth. In the business-as-usual case, including policies under consideration today, the improvement rate in energy efficiency is projected to remain at 1.3% annually until 2030.

The adjusted rate of improvement in energy intensity² is estimated at 1.6% per year in the 1990-2010 period, which is higher than the unadjusted rate of 1.3% per year.

Different sectors, countries and regions have shown different rates of improvement in energy intensity. In the 1990-2010 period, the agriculture sector achieved the highest rate of improvement, at 2.2% per year, whereas industry and other sectors of the economy improved their energy intensity at a rate of only 1.4% per year (all referring to adjusted rates) (World Bank, 2013a). At a regional level, improvements during 1990-2010 ranged from as low as 0.1% per year in North Africa to as high as 3.2% per year in the Caucasus and Central Asia. In comparison, energy intensity in West Africa deteriorated by 0.8% per year over the same period (World Bank, 2013a).

The two main sources of energy efficiency improvements are: 1) greater technical efficiency from the implementation of energy efficiency technologies, and 2) structural economic changes that result in the production and consumption of goods with lower energy intensity.

Technologies that offer greater technical efficiency could include, for example, a condensing gas boiler

¹ Measured in primary energy terms (megajoules, MJ) per unit of gross domestic product (GDP) in real 2005 USD at purchasing power parity (PPP).

² According to the World Bank (2013a), adjusted energy intensity is “...a measure derived from the Divisia decomposition method that controls for shifts in the activity level and structure of the economy.”

(more than 100% efficiency) which offers energy savings in residential space heating compared to an older-type boiler. By using a catalyst with better selectivity³ or by injecting coal into a blast furnace, higher levels of energy efficiencies can be achieved in the production processes of chemicals and steel, respectively. Some renewable energy technologies also offer improvements in energy efficiency, such as a solar thermal water heater with 100%⁴ efficiency compared to a coal-fired water boiler that can reach efficiencies of around 85-90% (Einstein, Worrell and Khrushch, 2001).

Examples of structural changes that can improve energy efficiency are the use of electric bicycles instead of cars with internal combustion engines, or using a high-speed train instead of an airplane. In the context of the transport sector, this change is known as a “modal shift”. An example of structural change in the manufacturing sector is shifting from the production of primary steel (from iron ore) to secondary steel (from recycled steel), which results in energy-use reductions.

2.2 Renewable energy

Renewable energy is the use of solar, wind, geothermal, hydro, ocean and biomass energy sources to deliver power and heat (space, water and process heat) to end-users, as well as the use of biomass sources to provide fuels for transportation, cooking and other purposes.

In defining renewables, it is important to clarify whether traditional use of biomass is considered to be “modern renewables” or not. For example, when traditional biomass used for cooking is combusted inefficiently and/or unsustainably sourced, it may not be considered to be renewable energy. The International Energy Agency (IEA, 2012a) defines traditional use of biomass as: “The use of wood, charcoal, agricultural residues and animal dung for cooking and heating in the residential sector. It tends to have very low conversion efficiency (10% to 20%) and often relies on unsustainable biomass supply.” When data availability allows, “renewable energy share”

³ The selectivity of a catalyst is defined as the conversion of the reactant to the desirable product divided by the overall conversion of the reactant.

⁴ When estimating the primary energy equivalent for electricity or heat generation, 100% efficiency is assumed for solar PV, wind, hydro and solar thermal heat (IEA, 2014a).

is expressed by excluding the total amount of traditional use of biomass.

The indicator for measuring progress towards realising the renewable energy objective is the share of renewable energy in total final energy consumption (TFEC). TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for the industry and building sectors) as well as electricity and district heating/cooling systems (referred to as district heating throughout this paper). TFEC excludes non-energy use, or the use of energy carriers as feedstocks to produce chemicals and polymers (IRENA, 2014a).

Renewable energy share in TFEC is estimated as the sum of all renewable energy use from all renewable sources and the share of district heat and electricity consumption originating from renewable energy divided by TFEC. It can be estimated for the total of all end-use sectors of a country or for each sector separately.

In 2010, 18% of the world’s total energy demand came from renewable energy sources, with half (9%) coming from modern forms of renewables. The other half is traditional use of biomass, of which only part is sustainable. Global renewable energy use (including traditional uses of biomass) has grown by nearly 50% from about 40 exajoules (EJ) in 1990 to approximately 60 EJ in 2010. While the absolute growth is large, the change in the global share of renewable energy is marginal, from 16.6% to 17.8% over the same 20-year period. This small change in the share of renewables is explained by the fact that TFEC is also growing at a similar pace.

The share of renewable energy (including traditional uses of biomass) shows large differences across world regions. In regions where traditional use of biomass is common, such as Latin America, Asia and Africa, renewable energy shares reach as high as 30-40%. These shares would be much lower if modern forms of renewables provided the heat required for cooking and water heating. In comparison, in the EU or North America, the renewable energy share is about 10%.

2.3 Accounting of energy demand

The main difference between the renewable energy and energy efficiency indicators is the accounting of the

total energy use. Whereas TFEC is used to measure the renewable energy share, total primary energy supply (TPES) is used for measuring energy efficiency progress. Accounting methods differ, and using a different metric, such as primary energy, may yield different results. For example, when viewed as primary energy, a shift from coal and nuclear to solar, wind or hydro power generation results in a doubling or tripling of the efficiency gains.

There are three ways to estimate primary energy based on the methods used by different organisations:

- 1) In the Physical Energy Content method used by the IEA and EUROSTAT, renewable electricity (e.g., wind, solar photovoltaics (PV) and hydro power) and biofuels are counted in primary energy as they appear in the form of secondary energy (i.e., using a 100% efficiency to convert them into primary energy equivalents), whereas geothermal, concentrated solar power (CSP) and nuclear electricity are counted using average process efficiencies (e.g., 10-33%) to convert them into primary energy equivalents. Whereas for solar thermal heating 100% efficiency is applied, for geothermal heating 50% is used (IEA, 2014a).
- 2) In the Direct Equivalent method used by the IPCC and the UN, all non-combustible energy sources (e.g., renewables, nuclear) are converted into primary energy equivalents as they appear in TFEC (i.e., using a 100% efficiency to convert them into primary energy equivalents).
- 3) In the Substitution method used by the US Energy Information Administration (EIA) and BP, renewable electricity and heat are converted into primary energy using the average efficiency of the fossil fuel power and heat plants which otherwise would have been required to produce these quantities.

Final energy also can be defined in different ways. Gross final energy consumption (GFEC), used by EU countries, is defined as “the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission” (Renewable Energy

Directive 2009/28/EC) (EC, 2009). In comparison, total final consumption (TFC) excludes the losses of electricity and heat in distribution and transmission, and therefore its value is lower than GFEC for the same country. TFEC has the same system boundaries as TFC, but it excludes non-energy use.

2.4 Synergies between renewable energy and energy efficiency technologies

Although indicators and accounting methods for renewable energy and energy efficiency differ, from a technology point of view there are important overlaps between the two areas. A number of technologies both offer savings in primary energy demand and also increase the share of renewable energy in TFEC. Examples of such technologies include (see also table 1 and box 1):

- Efficient cook stoves: Today, the traditional use of biomass accounts for 9% of global TFEC and is an inefficient form of energy. Replacing this traditional use of biomass with modern and efficient forms of cooking and heating helps to raise the share of modern renewable energy, improves the energy efficiency of cooking and contributes to the delivery of modern energy access. However, if renewable energy share is expressed by including both modern and traditional forms of renewables, substituting inefficient cook stoves with efficient ones would reduce the total renewable energy share.
- Electric vehicles: Electric vehicles achieve about three times the efficiency compared to internal combustion engines. If the power required for electric motors is generated from renewable energy sources, they represent an important enabling technology option for a transition to renewable electricity and contribute to a reduction in energy consumed for an equivalent level of energy services.
- Heat pumps: Heating accounts for around 25% of global TFEC. Air-to-air heat pumps are about three times as efficient as conventional boilers. Geothermal heat pumps are even more efficient than air-to-air heat pumps. The main energy input to heat pumps is electricity. If this power required by heat pumps is supplied by renewables, it is an

Table 1: Efficiency gains from renewable energy technologies

Renewable energy technology	Conversion efficiency		Efficiency gain to deliver the same energy service
	Renewable energy technology	Conventional technology	
End-use sector technologies			
Efficient cook stove	30-50%	10%	66-80%
Electric vehicle	0.7-1 MJ/p-km	1.7 MJ/p-km	40-60%
Heat pumps	350-450%	80-90%	75-85%
Variable renewable energy technologies			
Solar PV / wind	100%	30-55%	45-70%

Source: IRENA, 2014a

Modern cook stoves, electricity-based heating and transport technologies and most types of renewable energy power plants offer the potential to both improve energy efficiency and increase renewable energy share.

enabling technology option for a transition to renewable electricity.

- Variable renewable energy technologies: Most forms of renewable power generation (e.g., wind, solar PV with 100% efficiency) offer efficiency gains which are superior to those from fossil fuel and nuclear power generation technologies (e.g., nuclear with 33% efficiency).
- Local district thermal networks: The cost-effectiveness and efficiency of local district thermal (heating and cooling) networks are higher compared to individual thermal units.

Use of these types of technologies results in improvements of technical efficiency. The *REmap 2030* analysis shows that this gain in efficiency from higher deployment of some of these technologies in the REmap Options would reduce global TFEC by about 5%, or from 470 EJ to 445 EJ per year in 2030. A somewhat higher saving potential was estimated for TPES. The reductions in TFEC differ greatly by country, ranging from no savings in Germany to as high as 13% savings in Nigeria.

The savings also varies by individual end-use sector. For example, Denmark's manufacturing sector realises energy savings of 18% compared to business as usual when the potential of all renewable energy technologies is implemented, largely because renewably sourced electricity, instead of boiler technologies, is used to generate process heat. The energy savings achieved in the building sectors of France and South Korea is as high

as 19%, explained by the increased use of heat pumps and non-biomass renewable energy technologies for heating (i.e., solar thermal, geothermal).

Improving energy efficiency and renewable energy technologies also will depend on the structure of the country and its growth expectations. Economies that grow rapidly have more opportunity to improve efficiency than those that are stagnant. Economies with ageing capital stock that needs replacement also have more opportunity to improve efficiency than those with young capital stock. In high-income and industrialised countries, energy intensity has dropped by 1% per year; in China, it has dropped by 4% per year over the last two decades.

Several other technologies and approaches also provide synergies, for example decentralised energy systems and (typically) mini-grids. Decentralised renewables and energy efficiency can be combined through various demand-response, smart-grid and intermediate energy storage systems. A decentralised renewable energy system also can contribute to behavioural changes, by making consumers more aware of the importance of not wasting energy and hence more sensitive to the notion of energy efficiency. Electric vehicles and heat pumps can also serve as energy storage systems, which is key for a large-scale integration of renewable energy. And if energy-efficient smart appliances (e.g., washing machines, air conditioners, electric water heaters, freezers) can be programmed to run only when renewable electricity is supplied, this can provide further synergies.

Box 1: Examples of synergies between renewable energy and energy efficiency

Buildings

A net zero-energy building (NZEB) is usually defined as a building in which energy demand is greatly reduced through efficiency gains, and the remaining energy needs are satisfied using renewable energy (Torcellini, Pless and Deru, 2006). Therefore, the amount of renewable energy needed to satisfy a building's energy demand depends directly on its level of energy efficiency. The higher the efficiency of a building's systems, the lower its energy demand, and the less renewable energy is needed to achieve net zero-energy balance. This increases the cost-effectiveness of such buildings by reducing the size and capacity of the renewable energy systems required to satisfy energy needs.

Energy efficiency measures commonly used in NZEBs include advanced insulation, reduced thermal bridging, air tightness, use of the thermal mass, daylighting and ventilation strategies, and energy-efficient lighting and appliances. Renewable energy for NZEBs can be generated both on- and off-site of the building. The former usually involves building-integrated solar systems (e.g., thermal collectors, PV), while the latter may include export of renewable energy to the building from, for example, solar power plants or wind farms.

A positive trend observed in the European Union is to set targets for the number of NZEBs to be achieved within certain period. For example, the Netherlands was planning to construct 60 000 new NZEBs by 2015. In Malta, a minimum of 5% of the new buildings occupied and owned by the public authorities are expected to be built in accordance with the NZEB definition (Groezinger *et al.*, 2014).

Transport

Use of electricity as the main energy source for mobility increases the efficiency of transportation and lowers accompanying emissions, if the electricity is generated from low-carbon energy sources. In developed countries, sales of electric and hybrid vehicles are growing rapidly: in the United States, these sales increased by 229% in 2013 compared to the previous year (Shahan, 2014). At the same, battery costs are decreasing, making electric vehicles more competitive; the battery cost in the United States dropped from USD 1 000 per kilowatt-hour (kWh) in 2008 to USD 485 per kWh at the end of 2012 (Trigg and Telleen, 2013).

Although the market penetration of electric vehicles remains small – in 2013, it reached 6.6% in Norway, 5.6% in the Netherlands, 4% in California and 1.3% in the United States overall (Mock and Yang, 2014) – the vehicles present a good example of potential synergies between energy efficiency and renewable energy, provided that the electricity for charging the vehicles comes from renewable energy sources (hydro, wind and solar).

A study conducted at the University of Minnesota shows that electric vehicles powered by low-emitting electricity from natural gas, wind, water or solar power have the lowest environmental health impacts from a life-cycle perspective, whereas vehicles that use corn ethanol or “grid average” electricity have a higher impact on air quality than conventional gasoline cars do. The impact of gasoline vehicles can be reduced greatly with the improvement of their efficiency (Tessum, Hill and Marshall, 2014). The study demonstrates the importance of fuel efficiency and decarbonisation of the electricity supply. Despite sustainability benefits, the competitiveness of electric vehicles may be worsened by decreasing oil prices (Bloomberg, 2014).

District energy systems

Renewable energy sources can be used to power district energy systems that can efficiently supply heating, cooling and in some cases electricity to a network of buildings. District energy systems are most effective when they are supplying services to efficient buildings that require less heating and cooling. Modern district energy systems are applying technologies to co-ordinate the supply of thermal energy and power to improve

energy efficiency and integrate locally available renewable energy sources and waste heat. District energy systems have been used for many years in cities throughout Europe, the United States and Canada and will continue to be an important part of city planning and development given that heating and cooling account for about half of the energy consumed in cities (IPCC, 2014).

Today, district heating meets almost all of the heating needs in cities such as Helsinki, Finland and Copenhagen, Denmark. District energy systems continue to deliver multiple benefits such as an increased share of renewables in the energy mix, lower energy costs, increased energy security, improved air quality and reduced emissions. District heating systems cover about 13% of the current European heat market for buildings in the residential and service sectors (Euroheat & Power, 2013).

2.5 Total investment needs

A significant gap exists in the field of tracking energy efficiency investments, especially at a global level. This can be explained by the numerous actors and sources of funding involved in undertaking energy efficiency investments, as well as by the lack of a unified definition for the scope of such investments and methodologies to estimate them (IEA, 2012b). The IEA made the first attempt to bridge this gap, using a top-down approach and a country-by-country survey of energy efficiency investments. Data were derived from national sources and estimates, as well as from multilateral development banks and other sources on public expenditures channelled to energy efficiency projects. Using this methodology, the IEA estimated that global investments in energy efficiency improvements amounted to USD 180 billion in 2011 (IEA, 2012b). More than 60% of the investments were made by OECD regions, with the EU alone responsible for more than 40% of the global total.

A more recent bottom-up assessment estimated global investments in energy efficiency to be USD 130 billion in 2013 (IEA, 2014b). This estimation was made using detailed technological data from the IEA World Energy

Model through the analysis of the technological investment cost, stock turnover and return across different sectors and end-uses. Investments in energy efficiency improvements are estimated as additional investment required to achieved a higher level of efficiency of a product or service and cover various measures, excluding the ones in the field of fuel supply, transformation sector, fuel switching, behavioural changes, research and development, etc. Depending on the methodology of the assessment and accompanying assumptions, the estimated levels of global investments into energy efficiency can vary significantly.

Investments in renewable energy increased from less than USD 50 billion in 2004 to USD 214 billion in 2013. Investments declined in 2012 and 2013, but the pace of new capacity development was maintained, since a large drop in solar PV costs meant that the same growth in capacity could be accomplished with less money. Investments grew again by 21% in 2014 to USD 270 billion (FS-UNEP Centre/BNEF, 2015).

Based on above data, in 2014, total investments in energy efficiency and renewables were approximately USD 400 billion worldwide.

3 METHODOLOGY

This section provides details on the methodology used in this paper and presents the key assumptions and input data.

3.1 Overview

This section presents the analytical methods performed for this working paper. The study consists of three key analyses, each of which corresponds to a specific SE4All objective. The methodological framework used in this paper and its alignment with the SE4All objectives is presented in table 2.

Analysis 1 evaluates how much of the SE4All renewable energy objective can be achieved if various renewable energy options (REmap Options) are deployed globally without taking into account energy efficiency improvements beyond business as usual.

This analysis relies on the work previously carried out by IRENA within its *REmap 2030* project (IRENA, 2014a). Through country dialogue, IRENA collected the current and projected TFEC for the 26 most important energy users in the world, which account for three-quarters of global energy demand⁵. With these data, business as usual (referred to henceforth as the “Reference Case”) was determined for each country for the period 2010-2030. The Reference Case includes developments in TFEC by sector and by energy carrier. In addition, IRENA collected technology cost and performance data for renewable energy technologies, including various applications of hydro, wind, solar, bioenergy, geothermal and ocean for heating, cooling and power generation, as well as the use of biofuels in the transport sector.

In *REmap 2030*, IRENA also estimates the country-level “realisable” potentials of each renewable energy technology beyond the Reference Case in 2030 – the

so-called REmap Options. The Reference Case and the REmap Options combined yield “REmap 2030”, which IRENA considers to be how the share of renewables in the global energy mix can be doubled (see box 2). In 2014 and 2015, the country scope is being expanded from 26 countries to include at least another 10 countries.

C2E2 is collaborating with a number of organisations and regional centres to promote energy efficiency globally. C2E2 also is playing a key role in the Global Energy Efficiency Accelerator Platform, which is an “umbrella” for a number of sector- or technology-oriented accelerators (e.g., vehicles, district energy, buildings, appliances and lighting). This platform is a public-private partnership that was established to help double energy efficiency improvement globally. C2E2 will mobilise their and other stakeholders’ capacity to contribute to the data collection and review efforts to support and track the pathway to improved energy efficiency.

Given that C2E2 began its analysis activities only in early 2015, the availability of findings regarding energy efficiency is as yet limited. For this reason, the energy efficiency analysis (potential and costs) presented in this working paper relies on the work carried out by the IEA in its *World Energy Outlook 2012* (IEA, 2012b). Potential differences in methodology between the IEA and IRENA have not been considered in making comparisons of the findings, but the potential implications on results are discussed when necessary.

Analysis 1 estimates the contribution of REmap Options to increasing renewable energy deployment at the country and sector levels (for the renewable energy objective of SE4All). For this purpose, renewable energy use in the TFEC of each end-use sector was compared for the Reference Case and the REmap 2030 case at the country level. Since for each sector numerous technologies are being deployed and contribute to the changes in TFEC, the analysis provides results to the extent possible at the disaggregated level of technologies that show similarity in their applications (e.g., heating) and/or operation (e.g., electrification).

⁵ Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom (UK) and the United States. Analysis of Tonga is excluded from this study given its small share in the global TFEC (<1%).

Table 2: Snapshot of the methodological framework

Analysis	Objective	RE options	EE options	Contribution to SE4All objectives	Outputs/ indicators
1	Potential of REmap Options with business-as-usual energy efficiency improvements (section 4.1)	Yes	No	RE objective	RE share TFEC
2	Potential of energy efficiency improvement with business-as-usual renewable energy deployment (section 4.2)	No	Yes	EE objective	Energy intensity TPES
3	Potentials of REmap Options and energy efficiency improvements, and their synergies and trade-offs (section 4.3)	Yes	Yes	RE and EE objectives	RE share TFEC & Energy intensity TPES

RE: renewable energy; EE: energy efficiency; TFEC: total final energy consumption; TPES: total primary energy supply

For example, for the building sector, efficiency gains from modern cook stoves (*i.e.*, substitution of traditional use of biomass), from heating/cooling with heat pumps, and from heating/cooling with solar thermal technologies are estimated separately. In the transport sector, gains from electric vehicles are estimated. The contributions of technologies are estimated in incremental steps by the comparison of TFEC when all variables are kept identical and once the REmap Options related to each technology group are deployed. During its work on the *REmap 2030* report, IRENA developed an analytical tool – the REmap tool – which enables the estimation of TFEC, TPES, energy intensity and renewable energy share (see box 2).

The analysis also looks at the investment needs for renewables that would be required between 2010 and 2030, in both the Reference Case and REmap 2030.

Analysis 2 estimates the portion of the energy efficiency objective of the SE4All which can be achieved through ambitious energy efficiency improvements across different sectors, without taking into account the contribution of renewable energy options beyond the Reference Case (hereafter the “Efficiency Case”).

Because C2E2 began its modelling activities only in early 2015, information from IRENA for comparing energy efficiency measures to renewable energy will be available later. For this reason, the energy-savings potentials and related costs rely on earlier work in the IEA’s *World Energy Outlook* under its Efficient World Scenario (EWS), which prioritises the deployment of energy efficiency measures. Energy-saving potential

is estimated based on the EWS scenario in relation to the New Policy Scenario (NPS) for different sector and energy carriers. This potential served as a base for constructing the Efficiency Case for the selected countries (see box 3 for a brief description of scenarios). Because IRENA’s Reference Case follows to a large extent the idea and estimates of the IEA’s NPS (partly for the EU, China), the relative differences between the EWS and the NPS were considered as good indications of the additional economically realised energy-saving potential by 2030 (see box 3).

These potentials were applied to the Reference Case TFEC values for each region, sector and energy carrier in 2030 to derive estimates of TFEC for the Efficiency Case. Total primary energy supply (TPES) was estimated based on the result for TFEC across the sectors and energy for power and heat generation. The shares of fossil fuel energy use for each energy carrier were calculated based on the difference in the amount of power generated in 2030 under the Reference Case and REmap 2030. For this analysis, the amount of renewable energy in the power mix was assumed to be the same between the Reference and Efficiency cases.

Using the relation between the estimated TPES under the Efficiency Case and GDP (PPP) for each country, the overall energy intensity of the economy was calculated, providing the opportunity to estimate and compare the annual rates of energy intensity reduction in 2010 and 2030 for the Reference and Efficiency cases.

In order to draw conclusions on the contribution of energy efficiency improvements towards doubling the

Box 2: REmap terminologies and the REmap tool

REmap terminologies

There are five key data points in REmap which also represent the terminologies used across the analysis. A 2010 national energy balance of countries is the starting point of the analysis and is considered the base year (data point 1). National energy balances show the TFEC by sector and by energy carrier (e.g., coal, hydro, electricity).

The *Reference Case* is the business-as-usual case representing policies in place or under consideration, including energy efficiency improvements if contained in national plans (data point 2). The Reference Case includes the TFEC of each end-use sector and the total generation of power and district heat sectors, with a breakdown by energy carrier for the period 2010–2030.

As a next step, the additional technology options are investigated. These additional technologies are defined as *REmap Options*, essentially illustrating what the gap towards the doubling of the share of renewables would look like (data point 3).

The total of the Reference Case and REmap Options for each country results in the *REmap 2030* case of each country (data point 4). Each REmap Option is categorised by its substitution costs, which is the incremental cost per unit of final renewable energy relative to a conventional energy technology. Substitution costs of each REmap Option and its potential are plotted on country cost-supply curves (data point 5).

The REmap tool

IRENA has developed a tool that allows national experts to evaluate the analysis and create their country's cost-supply curve. The tool provides a simplified but dynamic accounting framework to evaluate and verify the Reference Case developments and REmap Options within the countries.

The tool consists of two parts. In the first part, national experts can evaluate and adjust the country's Reference Case for REmap Options between 2010 and 2030. In the second part, they can substitute conventional technologies assumed to be in place in 2020 and 2030 with REmap Options based on the Reference Case. For ease of use, the experts have a range of technology options to choose from in the transport, building, industry, and power and district heat sectors.

The tool allows experts to choose REmap Options, assess their impacts on the country's renewable energy share and evaluate their position within the country's cost-supply curve. At any time, the experts can increase or decrease the size of REmap Options and choose a different substitute. When a single button is clicked, the tool automatically adjusts the cost-supply curve. Furthermore, the tool allows for a consistent analysis and comparison of results among countries.

share of renewable energy in the 2030 energy mix, the share of renewable energy for the Efficiency Case was calculated as the relation between TFEC from renewables by TFEC across all energy carriers and sectors, allowing for comparison between the renewable energy shares in 2010 and 2030 for the Reference and Efficiency cases.

The investment needs for energy efficiency measures that would be required between 2010 and 2030 were

also estimated, based on the estimates of the IEA's EWS scenario.

Given that most of the energy efficiency analysis presented in this paper relies on the findings from an external IEA analysis, more work will be required to ensure their comparability with the IRENA analysis in *REmap 2030*. For the purpose of this working paper, the potential uncertainties arising from these differences were not considered.

Box 3: Description of IEA's New Policy and Efficient World Scenarios

New Policies Scenario (NPS)

The New Policies Scenario includes the policy commitments and plans that countries or local authorities took into account in order to achieve their energy challenges, despite the fact that some of those commitments are planned to be implemented but have not yet been introduced. The new commitments include renewable energy and energy efficiency targets, programmes relating to nuclear phase-outs or additions, national targets to reduce greenhouse gas emissions communicated under the 2010 Cancun Agreements, and the initiatives taken by G-20 and Asia-Pacific Economic Cooperation (APEC) economies to phase out inefficient fossil fuel subsidies. The NPS considers only implementation of current commitments and plans. In countries for which climate policy is uncertain, the policies are assumed to be inadequate to successfully meet their declared goals.

Efficient World Scenario (EWS)

The Efficient World Scenario helps in measuring the results of an extensive change in energy efficiency in the economy, the environment and energy security. The basic assumption is that all investments that are capable of improving energy efficiency are made if they are economically viable and while market barriers, which obstruct and prevent the achievement of this scenario, are removed. The rate of implementation is established, by sector and region, based on systematic review of the technical potential in raising energy efficiency and also from the payback periods that investors will need to commit funds to energy efficiency projects.

Source: IEA, 2012a

Analysis 3 estimates the potential to achieve both the SE4All renewable energy and energy efficiency objectives if both REmap Options and the 'realisable' energy efficiency improvements are implemented (hereafter the "REmap 2030 + EE" case).

For these two analyses, the energy intensity levels in 2030 are estimated taking into account the REmap Options (Analysis 1) in combination with the energy efficiency potential estimated in Analysis 2. The reduction in the gap towards each objective (if any) calculated in the previous analysis gives an idea of how additional renewable energy options can, on the one hand, contribute to achieving the energy efficiency objective. On the other hand, the impact of higher energy efficiency on the total renewable energy share in the global energy mix is also estimated. For that, the TFECs of sectors and countries are re-estimated taking into account energy efficiency improvement, and the renewable energy share is subsequently calculated.

Analysis 3 begins with estimating the TFEC by sector based on the Reference Case. The energy efficiency

gains then are estimated relative to each sector's TFEC. These gains are distributed across the various energy carriers of each sector. When doing so, renewable energy demand of sectors is assumed not to change, whereas fossil fuels, electricity and district heat do change. As a sensitivity analysis, the case when energy efficiency measures affect renewable energy demand is also investigated. This may result, for example, in less need for new power capacity, thereby affecting the renewable energy shares.

Several indicators are developed to estimate the synergy and trade-offs between energy efficiency and renewable energy. These indicators include the following:

- Annual rate of change in energy intensity between 2010 and 2030
- Renewable energy share in TFEC
- Renewable energy share in power generation
- Total power generation capacity
- Total renewable power generation capacity
- Incremental investments in energy efficiency options and REmap Options beyond the Reference Case.

Table 3: Input data on GDP growth, renewable energy share and energy intensity for the countries selected for the analysis

Analysed countries	Growth between 2010 and 2030		Renewable energy share in TFEC ²		Energy intensity ³		References for population and GDP growth
	Population	GDP ¹	2010	2030 Reference Case	2010	2030 Reference Case	
	(% per year)	(% per year)	(%)	(%)	(MJ/USD)	(MJ/USD)	
China	0.1	5.7	13	17	9.3 (11.8)	5.3	IEA (2012b)
India	0.9	8.7	39	22	7.0 (7.5)	3.2	PC (2014)
United States	0.9	2.4	8	10	7.0 (7.1)	4.6	US EIA (2013)
EU-5 countries:							
Denmark	N/A	N/A	22	39	4.3 (4.5)	2.8	DEA (2011)
France	0.3	1.4	13	26	5.3 (5.7)	3.2	DGEC (2011)
Germany	-0.2	1.1	10	23	4.7 (5.0)	2.7	DLR/Fraunhofer-IWES/IFNE (2012)
Italy	N/A	N/A	10	17	3.8 (4.4)	3.2	MSE (2013)
UK	0.6	1.7	3	13	3.6 (4.2)	2.5	DECC (2011a;b); DECC (2012)

N/A: Not available

1 GDP for the base year was expressed in 2005 USD per capita based on purchasing power parity (PPP) (World Bank, 2013b).

2 Includes both traditional and modern forms of renewables.

3 Data in brackets show the estimates according to the World Bank (2013a) in 2010.

The eight countries analysed in this study account for half of total global energy use.

Investment needs have been estimated via two separate approaches for renewables and energy efficiency. For renewables, the assessment is bottom-up for all country and technologies. The capital investment cost (in USD per kW of installed capacity) in each year is multiplied with the deployment in that year to arrive at total annual investment costs. The capital investment costs of each year are then summed over the period 2012-2030. This total is then turned into an annual average for the period.

For energy efficiency, the analysis relies on the assessment of the IEA (2012b) based on its NPS and EWS scenarios. For each region analysed, the assessment provides the total investment needs that would be required to reach improvements in a business-as-usual scenario (NPS) and an accelerated energy efficiency improvement scenario (EWS).

For the purpose of this analysis, four industrialised (or near industrialisation – India) regions that also represent the largest energy use worldwide have been chosen because of their rich data availability. These

countries/regions are China, the EU (based on the analysis of five countries covered in *REmap 2030* that account for 60% of the region's TFEC), India and the United States. The total primary energy supply of these eight countries in 2010 (269 EJ per year) covered exactly half of the global total in 2010 (540 EJ per year) (IEA, 2013)⁶. Where relevant, findings from other countries also are presented.

3.2 Input data and assumptions

This section provides key input data and assumptions used in the three analyses described above.

Table 3 provides the data basis used for the analysis of the eight countries separately for the year 2010 and the Reference Case.

⁶ REmap analysis of Denmark, France, Italy and the UK dates back to June 2014. REmap China analysis has been released in November 2014. REmap US analysis was released in June 2015. REmap Germany and REmap India analyses are as of July 2015, and still under discussion with the countries.

Table 4 presents the data on TFEC for 2010 and 2030 separately for the IEA's NPS and EWS scenarios for four

analysed regions. These data are used to estimate TFEC in 2030 for the Efficiency Case.

Table 4: Input data for TFEC in selected regions in 2010 and 2030

TFEC		2010 (EJ/year)	2030	
			NPS (EJ/year)	EWS (EJ/year)
China	Industry	30.1	44.9	38.3
	Transport	7.4	20.0	15.9
	Buildings	14.4	24.3	20.0
	Total	51.8	89.2	74.2
India	Industry	6.4	13.5	12.1
	Transport	7.4	6.8	6.8
	Buildings	14.4	10.8	9.5
	Total	28.1	31.3	28.4
United States	Industry	16.2	11.8	10.8
	Transport	27.3	21.1	19.5
	Buildings	20.3	22.9	19.3
	Total	63.7	55.8	49.6
EU-28	Industry	6.3	12.1	11.6
	Transport	8.0	11.6	6.8
	Buildings	11.8	22.1	18.5
	Total	26.0	45.8	36.9

Sources: Reference Case – IRENA, 2014a; NPS and EWS – IEA, 2012a

4 RESULTS

This section presents the results of Analyses 1-3 described in section 3.1 and discusses the potential to achieve the SE4All objectives for energy efficiency and renewable energy. It also demonstrates the importance of synergies between them.

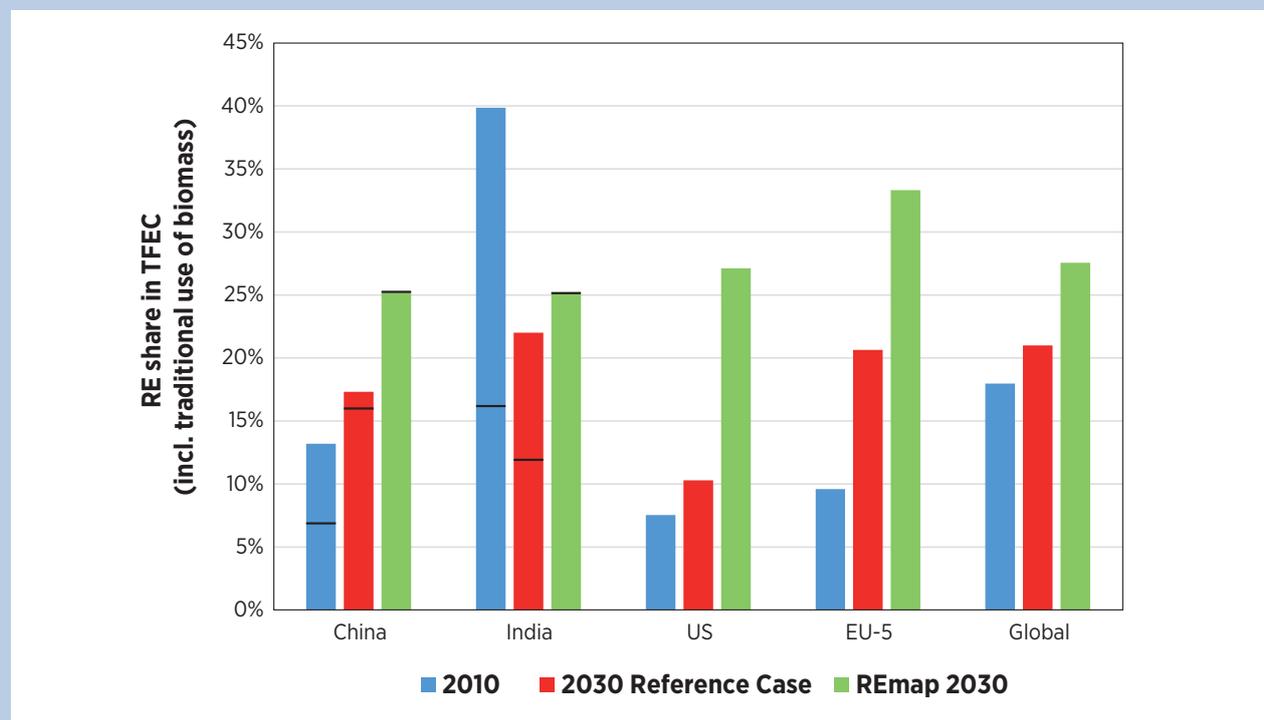
4.1 Potential of accelerated renewable energy deployment with business-as-usual energy efficiency improvements

Figure 1 shows the changes in renewable energy shares in the selected REmap countries between 2010 and

2030. If all REmap Options are implemented, the renewable energy share in TFEC (including traditional use of biomass) increases by a factor of two to four between 2010 and 2030 for all countries with the exception of China and India. China and India are exceptions because REmap Options replace traditional use of biomass with more modern forms, reducing overall consumption of biomass. When the related amounts are excluded, the modern renewable energy share increases by a factor of three to four in China.

In India, the modern renewable energy share develops differently. In the Reference Case, it decreases from 17% to 12% because the growth in TFEC is faster than the deployment of renewables. There is significant

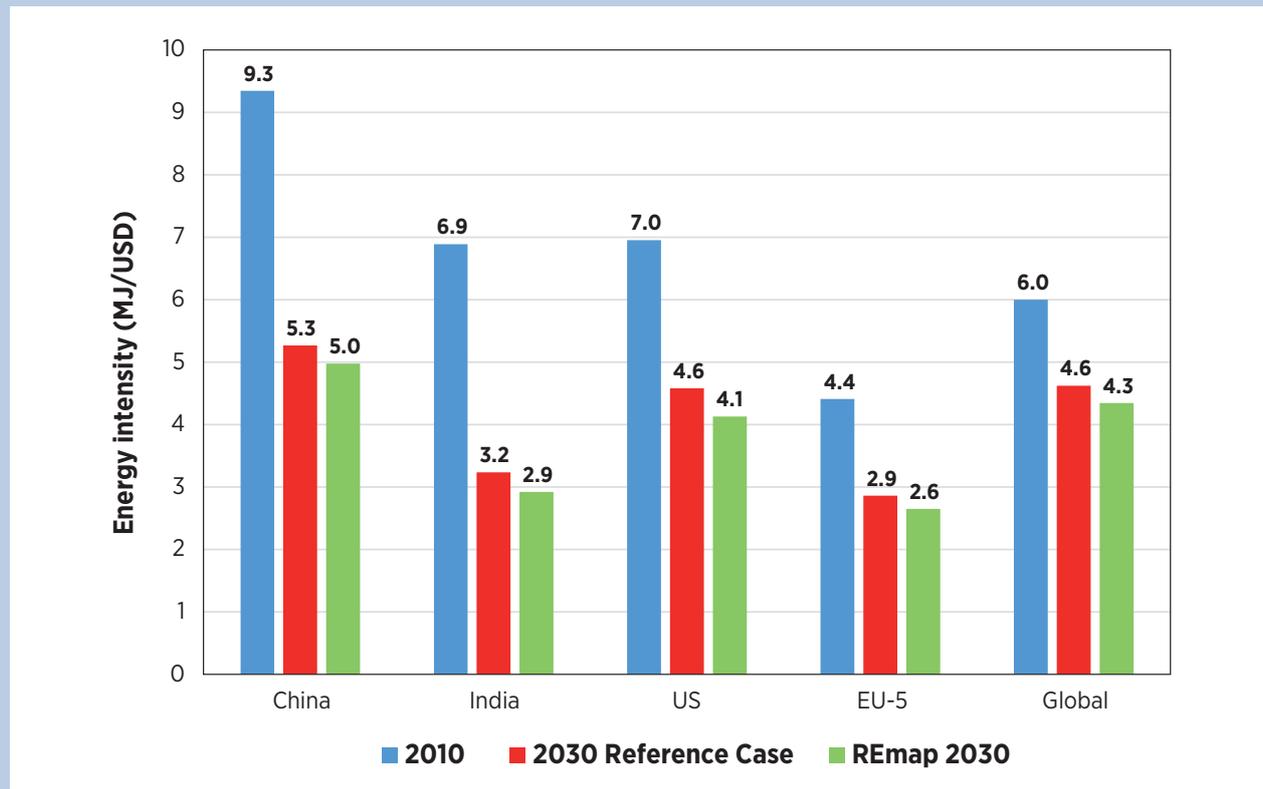
Figure 1: Renewable energy share in 2010, the 2030 Reference Case and REmap 2030 for selected countries and the world



Note: Black lines indicate the renewable energy share excluding traditional use of biomass. "Global" is based on IRENA's REmap 2030 analysis of 26 countries that cover three-quarters of the total global energy demand.

Between 2010 and 2030, there is potential to increase the share of renewable energy from 18% to 27% worldwide. The modern renewable share increases by a factor of two to four in the selected countries.

Figure 2: Energy intensity in 2010, the 2030 Reference Case and REmap 2030 for selected countries



Note: It was assumed that 2030 GDP does not change between the 2030 Reference Case and REmap 2030.

Renewables can reduce energy intensity by 5-10% compared to the Reference Case in 2030.

growth in fossil fuels in end-use, specifically natural gas in industry and oil in transport. However, with the increased use of modern renewables to substitute both traditional uses of biomass and conventional fuels, this situation reverses in REmap 2030, and the share of renewables in India grows to 25% by 2030. In comparison, the renewable energy share less than doubles in most countries under the Reference Case.

The change in the energy intensity of selected countries between 2010 and 2030 is shown in Figure 2. Under the Reference Case, the potential reduction in energy intensity over this period ranges from 34% (in the EU, from 4.4 MJ per USD to 2.9 MJ per USD) to 43% (in China, from 9.3 MJ per USD to 5.3 MJ per USD). These potentials translate into annual energy intensity improvement of 2-3% per year in the same period.

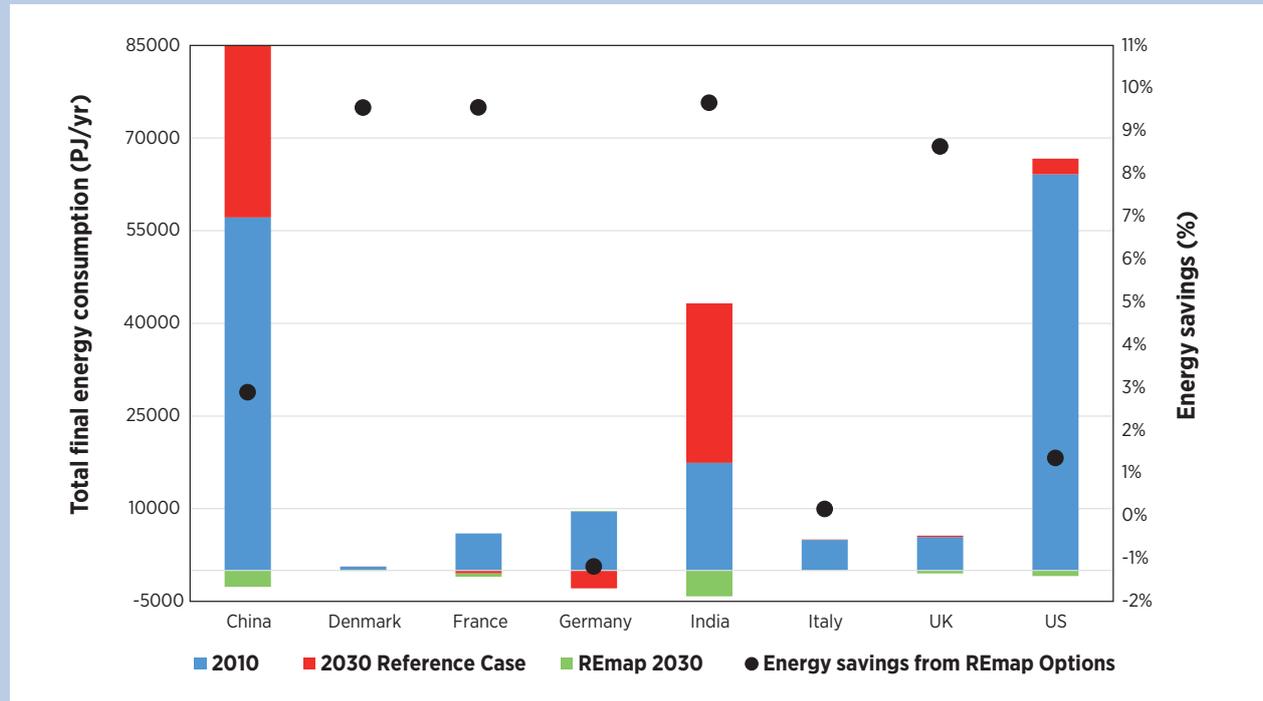
Implementing REmap Options contribute to further improvements in energy intensity. In India and the

United States, there is a potential to improve energy intensity by 10% in primary energy terms compared to the Reference Case, from 3.2 MJ per USD to 2.9 MJ per USD (India) and from 4.6 MJ per USD to 4.1 MJ per USD (the United States). These savings are possible with the implementation of renewable energy technologies that are more energy-efficient compared to their conventional alternatives.

Figure 3 shows the growth in TFEC in the period 2010-2030 based on the Reference Case (blue and red bars) for selected countries. The figure also shows the change in TFEC when REmap Options are implemented (green bars). With the implementation of all REmap Options, energy savings (in final energy terms) can be as high 10% in Denmark, France, India and the United Kingdom⁷.

⁷ Compared to final energy, energy savings are much higher when expressed in terms of primary energy.

Figure 3: Change in TFEC between 2010 and 2030 and related energy savings from the implementation of REmap Options for selected countries



Note: Energy savings from REmap Options (indicated with black dots in the figure) are estimated in comparison to the Reference Case in 2030, and are referred to on the right-hand side of the y-axis. REmap 2030 TFEC is estimated by adding blue and red bars and subtracting the savings according to the green bars.

India sees the highest level of energy savings due to the electrification of transport and to the substitution of traditional uses of biomass with modern cook stoves.

Two main factors explain the improvement in energy intensity across countries. The first is the type of renewable energy technologies being deployed and the magnitude of efficiency gains relative to their conventional counterparts. The second is the sectors in which the deployment happens.

Figure 4 shows the energy savings from REmap Options at the sector level for the analysed countries. Table 5 shows a more detailed breakdown of developments at the sector level.

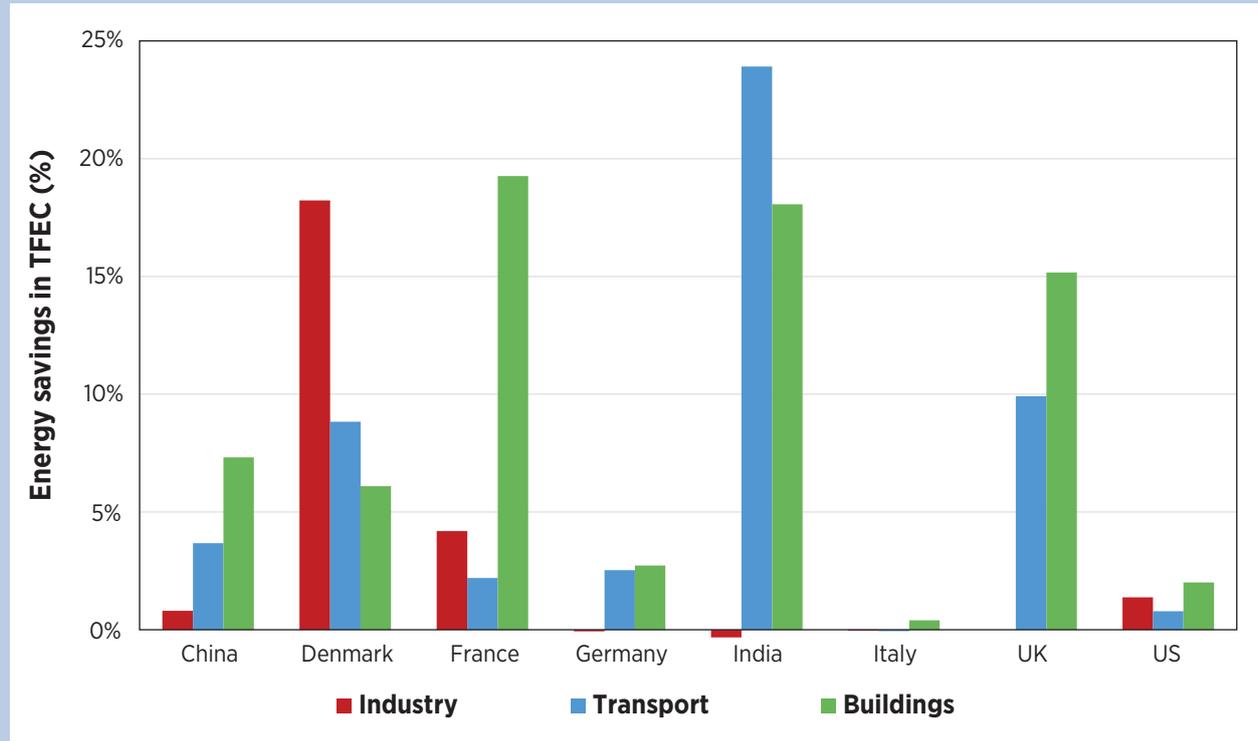
The comparison shows that the largest energy-saving potentials from renewable energy technologies are in the building and transport sectors, explained by the large potential for electrification in transport and for heating, and by the substitution of traditional uses of biomass for cooking. Table 6 shows which technologies contribute to the savings.

The industry sector, on the other hand, has a lower potential, as electrification technologies are only at the beginning of their innovation cycle and there are no

Table 5: Energy savings at the sector level in REmap 2030 compared to the Reference Case, 2030

	China	India	United States	EU
TFEC	3%	10%	1%	4%
Industry	1%	0%	1%	1%
Transport	4%	24%	1%	4%
Buildings	7%	18%	2%	9%

Figure 4: Energy savings from REmap Options by sector for selected countries



Note: Energy savings from REmap Options are estimated in comparison to the Reference Case in 2030.

Electricity-based heating and transport result in savings of nearly 20% in the end-use sectors of Denmark and France.

or minor efficiency gains from biomass-based process heat generation compared to fossil fuels. Energy savings in the industry sector from REmap Options are lowest

among the analysed sectors. Energy savings for all countries are in the range of -1% (in the UK, indicating an increase, not a saving) and +4% (in France).

Table 6: Change in the use of technologies that results in energy savings in REmap 2030

	China	India	United States	EU-5
Increase in the share of electricity use (in p.p., compared to 2010)				
TFEC	11%	15%	4%	7%
Industry	11%	6%	1%	5%
Transport	7%	9%	2%	9%
Buildings	19%	29%	6%	8%
Increase in the share of 100% efficient heating/cooling systems (solar thermal & geothermal) in buildings and manufacturing sectors (in p.p., compared to 2010)				
Industry	3%	1%	2%	0%
Buildings	20%	5%	7%	6%
Share of traditional use of biomass				
2010	29%	62%	N/A	N/A
REmap 2030	0%	0%		

p.p.: percentage points

Denmark is an exception in the EU and demonstrates a saving potential of up to 18%. This is due to the significant increase in the share of electricity use in the Danish manufacturing industry (to 50%) in REmap 2030, compared to 25% in the Reference Case. Electricity-based process heating technologies are more energy-efficient than conventional fossil fuel-fired steam boilers to deliver the same amount of process heat.

In the transport sector, several countries show the potential to realise savings of more than 10%, such as the UK and India. This can be explained by the substitution of internal combustion engines with electric vehicles (including two- and three-wheelers, as in India) or by modal shifts (such as towards electric trains in the UK).

Across the sectors, the building sector has the highest energy savings in REmap 2030 compared to the Reference Case. Savings can be as high as 20% in France, where heat pump and solar thermal potentials are high. The decrease in the share of traditional use of biomass from the implementation of REmap Options in the building sector also has a significant impact on the energy savings of some countries. In India, for example, the share of traditional use of biomass decreases from 40% in the Reference Case to no use in REmap 2030, resulting in 18% energy savings in the country's building sector TFEC. Similarly, the share of traditional use of biomass in Nigeria (a country that is excluded from this study, but which shows the largest saving among the 26 REmap countries) decreases to 24% compared to 66% in the Reference Case. The share of solar water heaters and geothermal systems in France's building sector as well as increased use of heat pumps (the electricity share increases from 44% to 56%) result in energy savings of 19%.

4.2 Potential of energy efficiency improvements with business-as-usual renewable energy deployment

Total primary energy supply under the Reference Case increases by 2030 in all selected regions, except for the EU (see figure 5). Due to significant economic and population growth foreseen in the next two decades, TPES is estimated to increase substantially in India and China by 2030: in India, it is expected to more

than double relative to the 2010 level, and in China it is expected to grow by more than 70%. TPES in the United States increases by 6% by 2030, whereas in the EU it decreases by 11%.

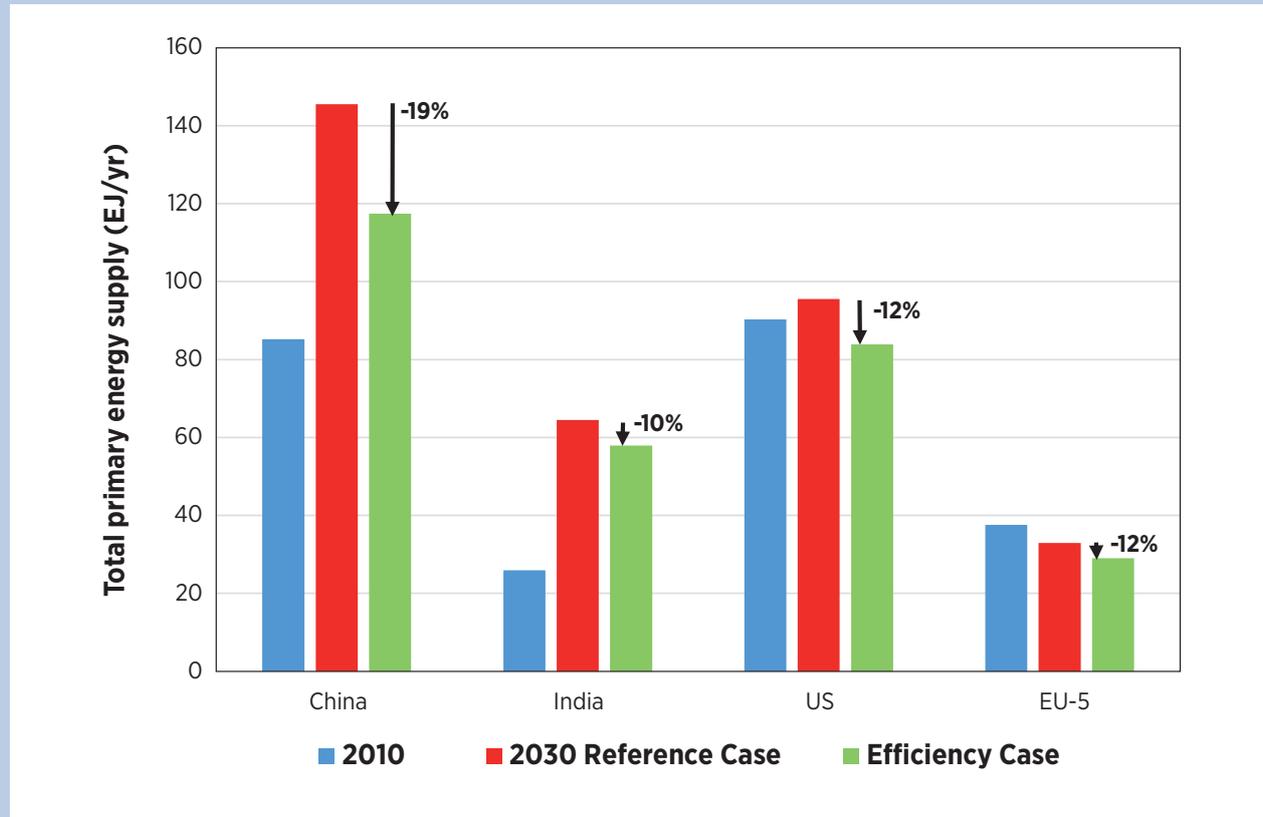
The accelerated deployment of energy efficiency through realisation of its economically feasible potential by 2030 across different sectors reduces the TPES in selected countries (see Figure 5). China demonstrates the largest potential energy savings by 2030 among the analysed countries, with a 19% reduction in TPES for all sectors in the Efficiency Case relative to the Reference Case, compared with India with a 10% reduction, and the United States and EU with 12% reductions each.

Potential savings in TFEC from energy efficiency improvements by 2030 in relation to the Reference Case (see table 7) show that most of the energy use can be reduced across the sectors through decrease in consumption of coal and utilisation of more efficient alternatives. The building sector in the selected countries demonstrates the largest potential for reducing coal consumption in comparison with other sectors. This sector also shows significant savings from other fossil fuels, such as oil and natural gas, in most of the countries. Only in India is consumption of natural gas assumed to increase significantly by 2030.

Reductions in energy use

In China, most of the primary energy savings from the accelerated deployment of energy efficiency measures are expected to result from cutting demand for coal and oil and increasing the availability of natural gas. Coal use will decrease as a result of reduced demand for electricity and therefore for new power plant capacity, as well as improved efficiency of the plants and industrial processes. The assessment of energy-saving potential assumes that China achieves its overall goal of improving the energy efficiency of its economy across different sectors and reduces its energy intensity by 16% by 2015 in comparison to 2011. The assessment also assumes that China fully implements existing and planned policies, including mandatory building codes for new residential buildings with large floor areas, mandatory labelling for large commercial buildings, product labelling, full implementation and further extensions of fuel economy standards for passenger light duty vehicles (PLDVs) and trucks, and energy savings targets by 2015 for the largest 10 000 industrial energy consumers (IEA, 2012b).

Figure 5: TPES in 2010 and 2030 for selected regions in the Reference and Efficiency cases for selected countries



Energy efficiency measures can reduce primary energy demand from 10% in India to as high as 20% in China by 2030 compared to the Reference Case.

Through similar measures as in China, India is also expected to achieve significant primary energy savings from reducing the demand and import of coal. Improvements in energy efficiency in transport and industry are important for realisation of the country’s potential. India already has introduced an energy efficiency mechanism targeting large energy-intensive industries (Perform, Achieve and Trade), which in the analysed scenario is expected to deliver substantial energy savings. The country’s building sector is also considered to offer significant savings, which are assumed to be achieved by 2030 through wide-scale adoption and enforcement of building energy codes, the use of more-efficient cooking stoves and lighting systems, as well as stringent minimum energy performance standards for a wide variety of products (IEA, 2012b).

In the United States, a large share of the reduction in TPES is due to the country’s reduced demand for coal, including through the replacement of old, inefficient

coal plants with more-efficient coal and natural gas alternatives. Demand for oil and natural gas also decrease by 2030, mainly through increased efficiency in the transport sector and in buildings. The United States already has in place electricity efficiency programmes, minimum energy performance standards (MEPS) and energy-saving targets in a number of states. These policies are assumed to be effective, well-enforced and further tightened under the Efficiency Case, increasing potential energy savings in relation to the Reference Case (IEA, 2012b). Further savings can come from the refurbishment of existing buildings, improvements in the efficiency of heating and cooling systems, achieving fuel economy targets and complying with more-stringent standards for passenger cars and heavy trucks, as well as increasing the proliferation of hybrid cars.

The EU countries demonstrate the lowest energy savings among the analysed countries under the Efficiency Case in relation to the Reference Case, as the region

Table 7: Realisable energy-saving potential in TFEC in 2030 under the Efficiency Case in relation to the Reference Case by region, sector and energy carrier

Sector	Energy carrier	United States	EU-5	China	India
Industry	Coal	-8%	-6%	-11%	-12%
	Oil	-3%	-7%	-11%	-10%
	Gas	-8%	-2%	-17%	-10%
	Electricity	-9%	-6%	-18%	-13%
	Heat	-15%	-5%	-15%	0%
	Renewables	-8%	-5%	0%	-3%
Transport	Coal	-9%	-10%	-21%	1%
	Oil	13%	2%	0%	-10%
	Gas	0%	-17%	-9%	7%
	Electricity	-3%	-10%	-23%	-16%
	Heat	-8%	0%	-20%	0%
	Renewables	0%	0%	0%	0%
Buildings	Coal	-60%	-17%	-34%	-28%
	Oil	-39%	-22%	-27%	-21%
	Gas	-21%	-18%	-13%	60%
	Electricity	-14%	-15%	-24%	-14%
	Heat	-20%	-18%	-14%	0%
	Renewables	33%	-9%	-5%	-9%

Source: Authors' calculations based on the data from IEA, 2012b; US EIA, 2013

Energy efficiency results in significant reduction in fossil fuel use, particularly coal, across all countries and sectors. The building sector demonstrates the largest energy savings potential.

already has established an ambitious energy efficiency policy framework, which is expected to result in substantial energy savings even under the Reference Case. These policies include, for example, the EU “20% by 2020” targets⁸ and the EU Energy Efficiency Directive, which requires that Member States set national energy efficiency targets, invest in zero-energy buildings, and engage large enterprises and the public sector in energy-saving actions. By realising energy efficiency measures, the EU can reduce greatly its primary energy demand for fossil fuels (natural gas, oil, coal), limit the use of nuclear energy and accelerate the use of hydro, biomass and other renewables (IEA, 2012b). Similar to the United States, the EU demonstrates significant energy-saving potential through accelerated energy efficiency action in transport (e.g., increasing the uptake of highly energy-efficient vehicles, making fuel economy standards more stringent, etc.) and buildings (e.g., deep retrofits, improved building envelopes and

more-efficient technologies for space heating, cooling, water heating and lighting).

The described changes in TPES are also reflected in the results for energy intensity, the reduction in which, in this paper, is assumed to indicate energy efficiency improvement. Figure 6 shows that energy efficiency measures allow for accelerating the decrease in the overall energy intensities of all analysed economies.

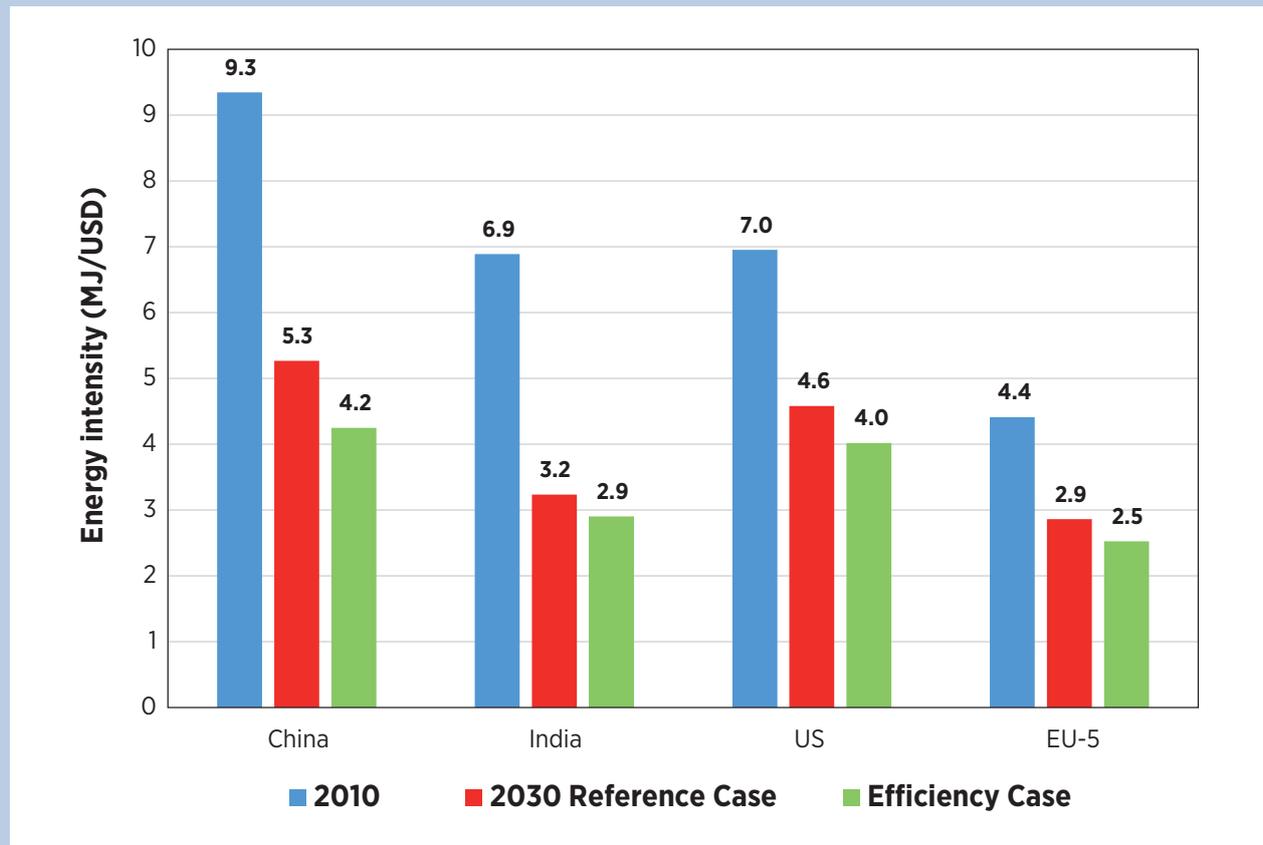
Changes in the rate of energy intensity

The overall SE4All objective for energy efficiency is to double the global rate of energy intensity improvement between 2010 and 2030 in relation to the rates achieved between 1990 and 2010. It is therefore important to analyse the results on energy intensity for selected countries with respect to this objective.

Figure 7 demonstrates annual rates of energy intensity reduction in selected countries and for different periods: 1990-2010 and 2010-2030 separately for the Reference

⁸ 20% increase in energy efficiency, 20% of energy from renewables and 20% reduction in greenhouse gas emissions (EC, 2011).

Figure 6: Energy intensities in 2010 and 2030 in the Reference and Efficiency cases for selected countries



Energy efficiency measures can accelerate annual energy intensity improvement rates, resulting in a more than 50% decrease in intensity between 2010 and 2030 in China and India and in a roughly 40% decrease in intensity in the United States and the EU, compared to business as usual.

Full substitution of traditional uses of biomass in China and India results in significant energy savings in the building sector compared to the Reference Case in 2030.

and Efficiency cases. The results show that, in all countries, energy efficiency measures are accelerating the reduction in energy intensity beyond the Reference Case and 1990-2010 business as usual (Only in China is the rate in 1990-2010 higher than under the Efficiency Case, due mainly to structural changes in the country's economy during that period). However, only the EU demonstrates the possibility of reaching the objective of doubling the historical rate of energy intensity reduction by 2030 solely through efforts related to energy efficiency. India has the potential to get very close to this targeted level, whereas China and the United States demonstrate a more significant gap to achieve this goal.

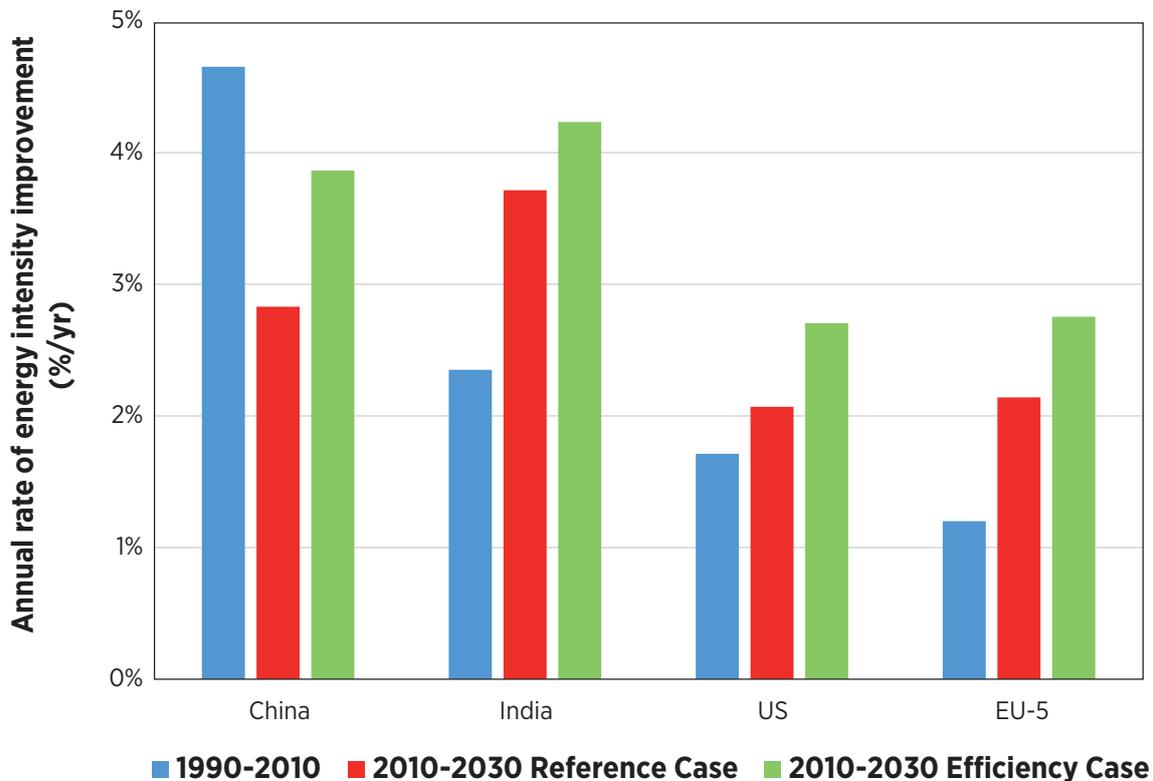
Country-based results show that in order to minimise this gap at a global level, it will be important to combine

energy efficiency actions with deployment of renewable energy technologies. Substituting some of the fossil fuel use with renewable energy will make it possible to reduce the overall TPES of an economy and, consequently, decrease energy intensity. Section 4.3 further discusses the synergy effects between energy efficiency and renewable energy.

Figure 8 shows how improvements in energy efficiency affect the share of renewable energy in TFEC in the analysed countries. With less energy consumption, the same amount of renewables accounts for a larger share of TFEC⁹. This is the case in all countries analysed, with

⁹ Here we assume that efficiency measures apply to reduce the demand of conventional fuels only.

Figure 7: Annual rate of energy intensity improvements for selected countries



The EU and India show the potential to double annual energy intensity improvement rates between 2010 and 2030 compared to 1990-2010 through energy efficiency actions only, whereas in China and the United States additional efforts would be required to reach this level.

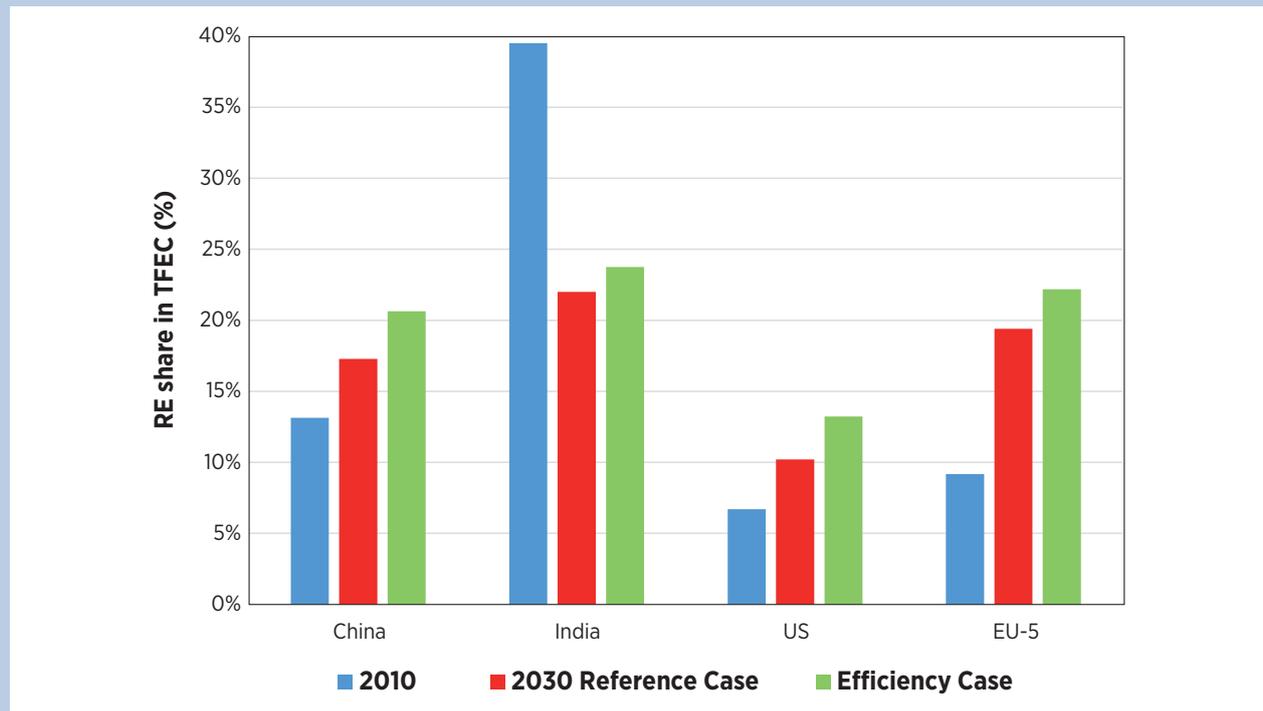
varying magnitudes. The most significant increase is in the EU countries, where the renewable energy share nearly triples in the Efficiency Case by 2030 relative to 2010, although the region is able to more than double this share already under Reference Case. This large growth in the renewable energy share is explained by the stagnant TFEC of the EU between 2010 and 2030, compared to the case where renewable energy use grows.

Results for the United States show that the country has a potential to increase its share of renewable energy in TFEC from 7% in 2010 to 13% by 2030 solely through energy efficiency improvements. In China and India,

energy efficiency measures increase the share of renewables; however, the impact of efficiency on raising the renewable energy share is lower in countries where TFEC is projected to grow rapidly.

The results discussed above demonstrate that in order to achieve SE4All objectives related to energy efficiency and renewable energy in different countries, it is necessary to explore the synergies between the actions in these two fields. The following section discusses potential effects of the interactions between energy efficiency measures and the deployment of renewable energy options in the selected countries and across sectors.

Figure 8: Renewable energy shares in 2010 and 2030 in the Reference and Efficiency cases in selected regions



In countries where there is low growth in total energy demand, higher levels of energy efficiency improvement help to raise the renewable energy share in the countries' energy mix.

4.3 Potential of accelerated renewables deployment and energy efficiency improvements, and their synergies and trade-offs

Combining the potential of accelerated deployment of renewable energy technologies and energy efficiency measures would contribute further to raising renewable energy shares and accelerating energy intensity improvements.

According to the Reference Case, TPES would increase by 70% in China and would more than double in India (see figure 9). Assuming that of all the identified potential of efficiency measures and REmap Options is implemented (here, the “REmap 2030 + EE” case), there is a potential to reduce TPES by 20% in India and 25% in China by 2030, compared to the Reference Case.

The growth in TPES in the United States by 2030 according to the Reference Case is estimated to be

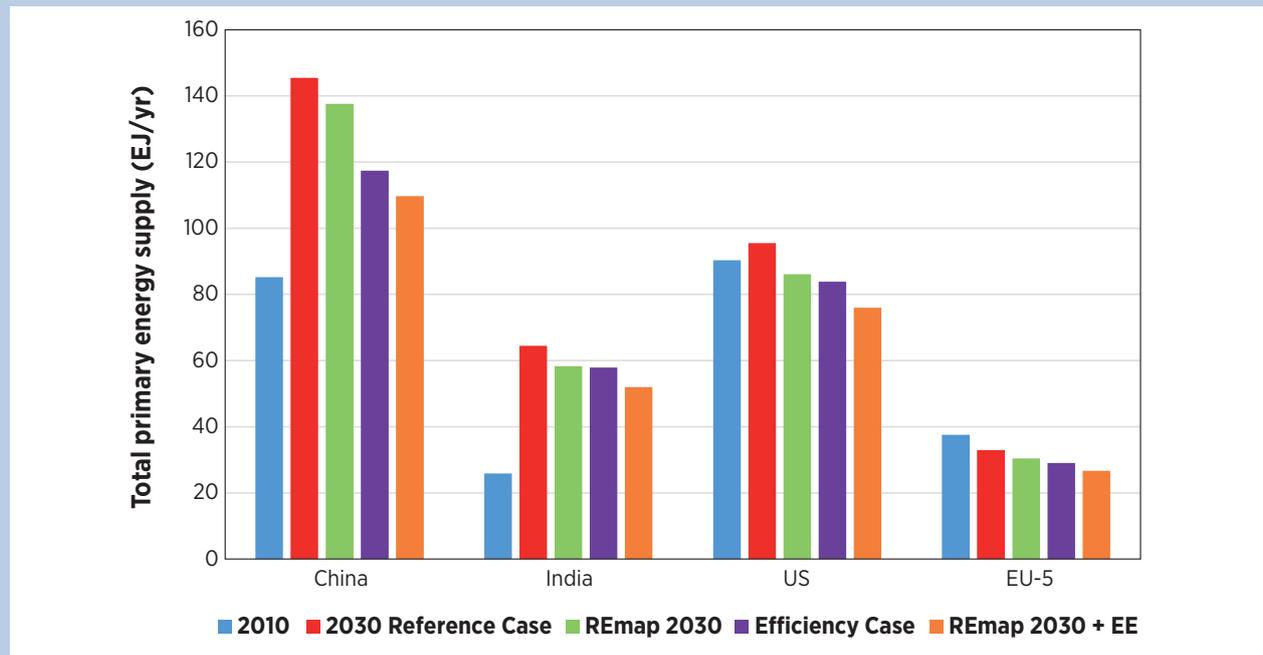
lower than global levels – only 6% compared to the 2010 level. The efficiency gains from the deployment of REmap Options would keep the 2030 TPES 5% below the 2010 level. With additional energy efficiency measures implemented, there is a potential to reduce TPES further, by 16% compared to 2010 levels or 21% compared to the Reference Case in 2030.

The savings in the EU's TPES under the Reference Case is estimated to be approximately 12% compared to the 2010 level. Under the REmap 2030 + EE case, the TPES of the selected EU countries can be reduced by 29% compared to the 2010 level.

These developments have a significant impact on the countries' energy intensities and on the annual rate of their improvements (see figure 10). The annual rate of improvements can be accelerated by 40-50% in the REmap 2030 + EE case when compared to improvements under the Reference Case by 2030.

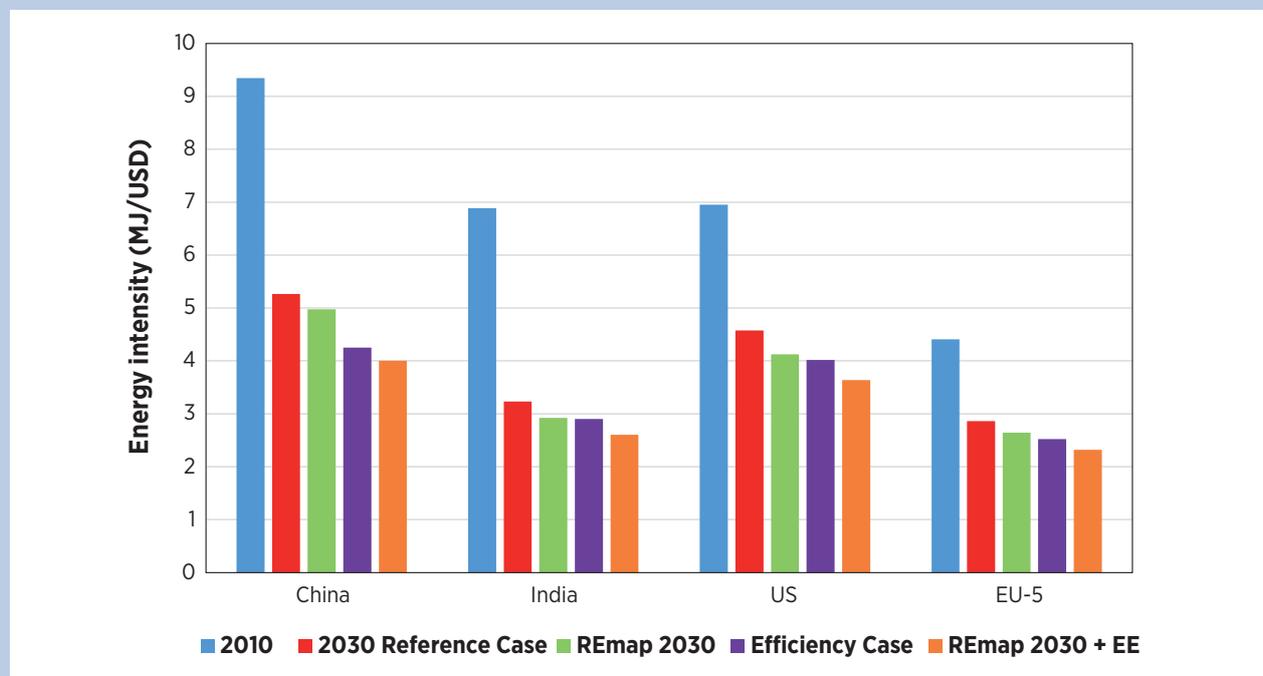
Implementing the economically feasible energy efficiency measures would contribute 50-75% of the

Figure 9: TPES in selected countries, 2010-2030



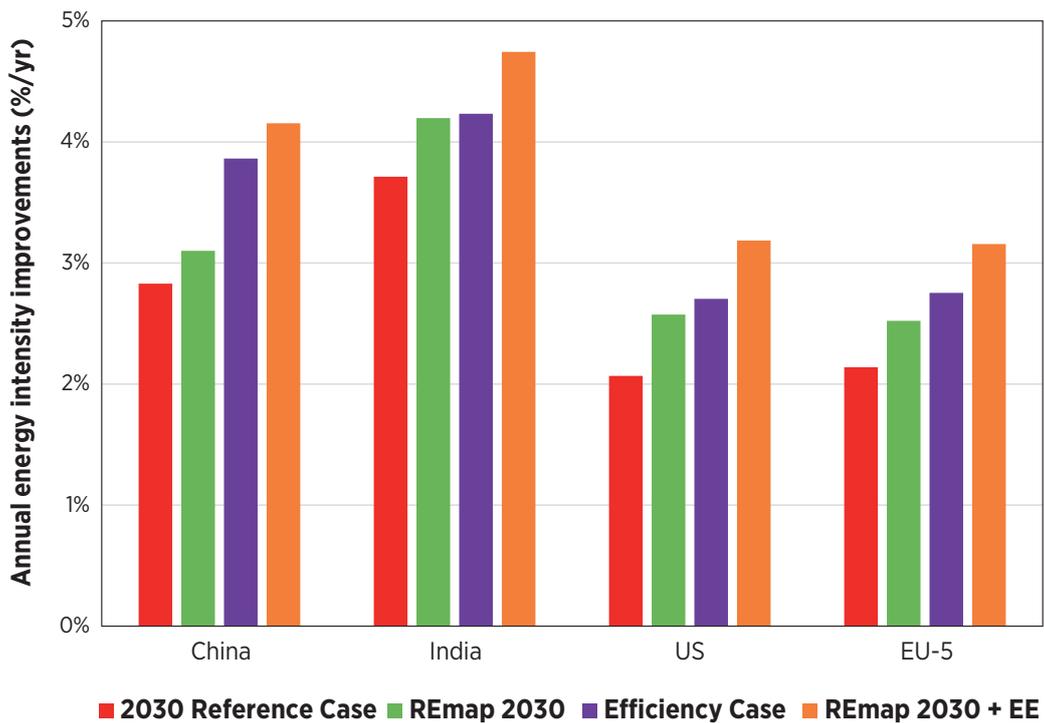
When the potentials of higher energy efficiency and renewable energy deployment are combined, the growth in total primary energy supply can be reduced by up to 25% by 2030 compared to the Reference Case.

Figure 10: Energy intensities of selected countries, 2010-2030



In the case where the potentials of higher energy efficiency and renewable energy deployment are combined, energy efficiency measures would account for 50-75% of the total potential to improve energy intensity.

Figure 11: Annual energy intensity improvements of selected countries, 2010-2030



total savings. The contribution of efficiency measures to the total savings is higher in China compared to other countries, given the large energy-saving potential that exists across the country's different sectors. This is because the energy-saving potential in the Efficiency Case compared to the Reference Case is high in China – up to 20% – compared with about half of that in other countries analysed.

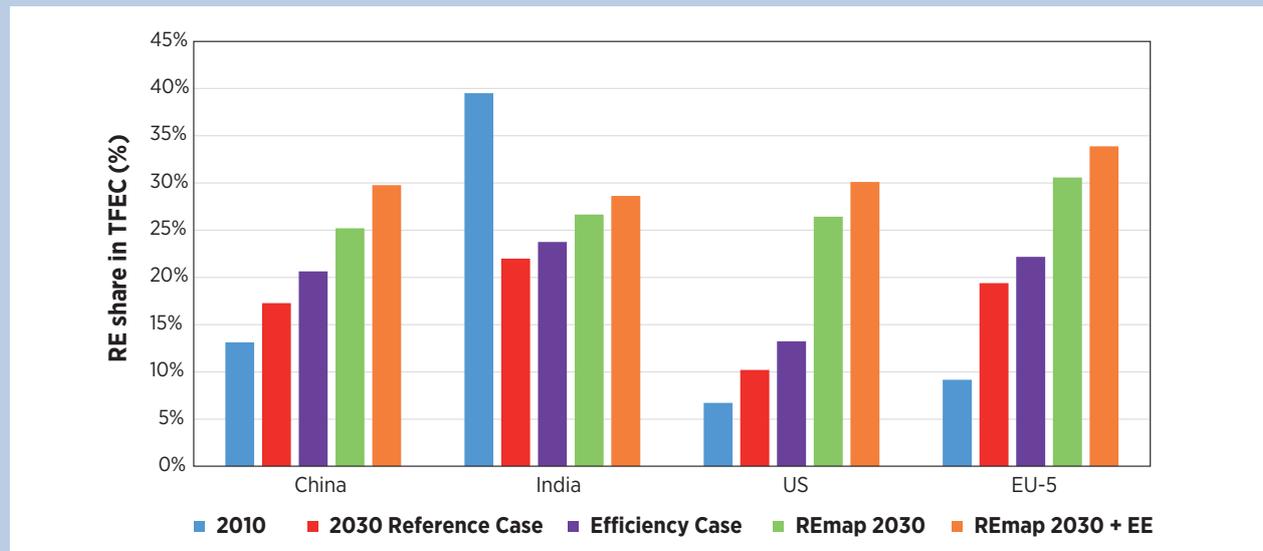
Figure 11 shows the average annual energy intensity improvements between 2010 and 2030 across different cases. Both renewables and energy efficiency measures contribute to reducing the annual energy intensity improvement rates of the selected countries. Energy efficiency measures have a higher impact compared to renewables. In the United States and the EU, energy efficiency measures increase annual improvement rates slightly more than the accelerated deployment of renewables does. This is mainly an outcome of low energy demand growth between 2010 and 2030 in these countries, where higher shares of renewables easily accelerate energy intensity improvements. In India, renewables and energy efficiency measures increase energy intensity rates at a similar magnitude.

Combining REmap Options and energy efficiency measures has a pronounced effect on the shares of renewable energy in TFEC. Although energy intensity decreases mainly through implementation of energy efficiency measures, the renewable energy share in TFEC changes with a similar magnitude both with efficiency measures and REmap Options (see figure 12).

In the REmap 2030 + EE case, China reaches a renewable energy share of 29%, compared to 13% in 2010. This is also higher than China's renewable energy share in REmap 2030 of 25%. In the REmap 2030 + EE case, the renewable energy shares of the United States and EU increase fourfold compared to their 2010 levels, indicating impressive growth. In all regions, the combination of REmap Options and efficiency measures increases the overall renewable energy share in TFEC by 1-4% in comparison to REmap 2030, clearly highlighting the synergies between improving energy efficiency and deploying renewable technologies for realising the SE4All renewable energy objective.

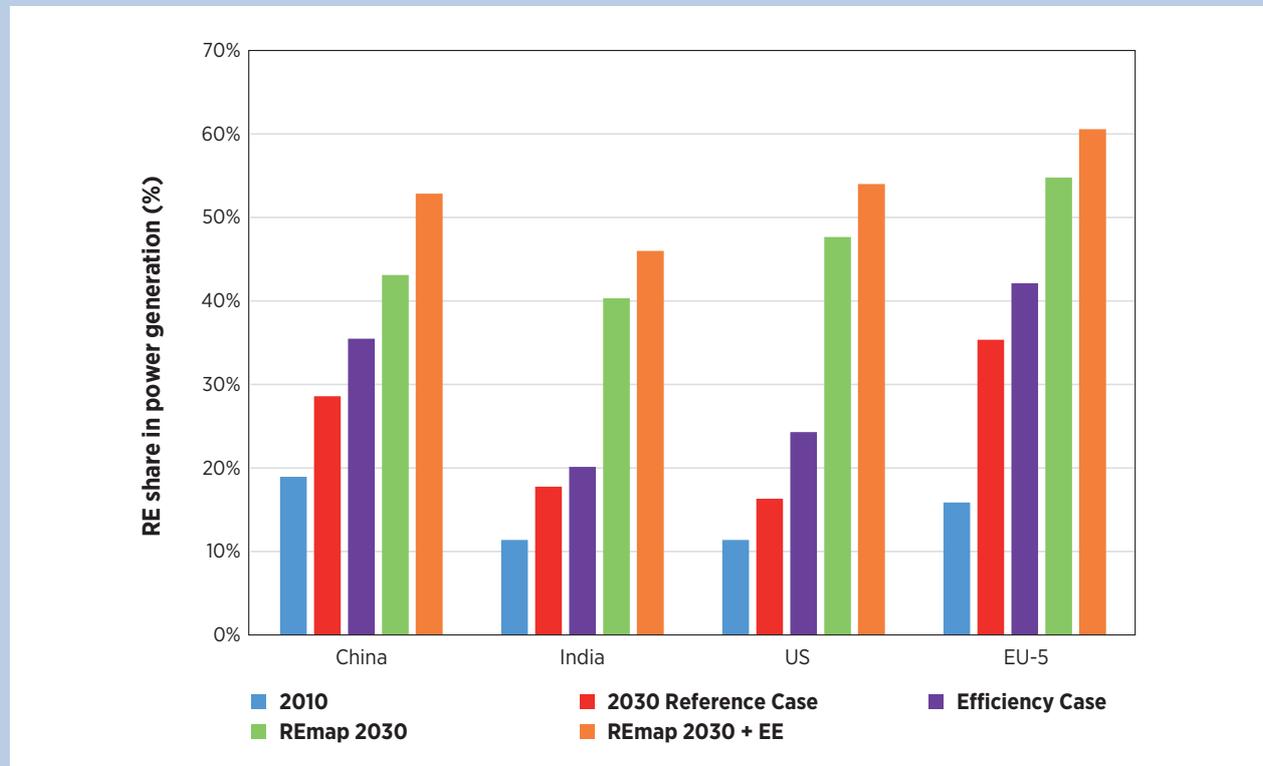
There is an equally high effect on the share of renewable energy in power generation (see figure 13) when

Figure 12: Renewable energy share in TFECE for various cases analysed in selected countries



Energy efficiency improvements and renewable energy deployment combined increase the share of renewable energy by 2030 in all analysed countries to a higher level compared to a case where only increased renewable energy deployment is achieved.

Figure 13: Renewable share in power generation in selected regions, 2010-2030



Combined efforts to realise high rates of energy efficiency improvement and renewable energy deployment also result in higher renewable energy shares in power generation across all analysed countries.

efficiency measures are implemented on top of REmap Options. Assuming that the same amount of renewables capacity remains in REmap 2030 (*i.e.*, that it is not reduced due to energy efficiency improvements), the renewable energy share in power generation in the EU has the potential to reach 60% in the REmap 2030 + EE case. In China and India, this share under the REmap 2030 + EE case can reach 43% and 52%, respectively, of the power generation mix in 2030. Similarly, the renewable energy share in the United States is estimated to achieve 54% of power generation by 2030.

These estimates assume that all renewable energy capacity in the Reference Case and REmap 2030 remain unchanged in the Efficiency Case and in REmap 2030 +

EE; hence efficiency measures reduce demand related to conventional energy only. This stems from the idea that the most cost-effective way to achieve energy savings is to implement energy efficiency first and then to deploy the additional potential of renewables to reduce conventional energy sources. On the other hand, it can be argued that this approach is biased towards raising the renewable energy share in TFEC, and that, in reality, lower demand for energy will reduce the capacity of both conventional and renewable energy technologies. When energy efficiency improvements reduce the demand for both conventional energy carriers and renewables, the renewable energy shares in power generation and in TFEC are estimated to be identical to the case in REmap 2030 (see table 8).

Table 8: Effects of energy efficiency measures on renewable energy shares

	REmap 2030	REmap 2030 + EE (efficiency improvements apply to fossil fuels only)	REmap 2030 + EE (efficiency improvements apply to all energy carriers)
RE share in power generation (%)			
China	42%	52%	42%
India	38%	43%	38%
United States	48%	54%	48%
EU-5	55%	60%	55%
RE share in TFEC (%)			
China	25%	29%	26%
India	27%	28%	26%
United States	26%	30%	28%
EU-5	31%	34%	31%
Energy intensity in 2030 (MJ/USD)			
China	5.0	4.0	4.1
India	2.9	2.6	2.6
United States	4.1	3.6	3.7
EU-5	1.6	1.4	1.4

5 ANSWERS TO POLICY-RELEVANT QUESTIONS

This section aims to answer a number of policy-relevant questions in light of the results of the analysis presented above.

5.1 What are the synergies between energy efficiency and renewable energy?

Overall energy system

The analysis presented in section 4 explored a number of indicators to quantify the synergies between energy efficiency and renewable energy. These indicators include TPES, renewable energy shares in TFEC and in power generation, and energy intensity.

The results showed that implementing energy efficiency measures and renewable energy options at the same time contributes significantly to increasing the renewable energy share in TFEC and accelerating the rate of annual energy intensity improvements.

Implementing REmap Options alone are not sufficient to greatly reduce energy intensity compared to the Reference Case in 2030. Energy savings from REmap Options are estimated in the range of 5-10% depending on the country. In comparison, measures that focus specifically on improving energy efficiency can reduce energy intensity by between 10% and 19% compared to the Reference Case.

The combined energy-saving potential from renewables and energy efficiency ranges from 19% to 25% in the analysed countries. As a result, 50-75% of the total primary energy savings results from energy efficiency measures, with the remaining 25-50% related to renewables. However, these estimates look at the entire change in primary energy use, thereby taking into account changes from both renewable energy and conventional energy (fossil fuel, nuclear and traditional use of biomass). When primary energy savings are assumed to reduce demand for fossil fuels, the contribution of renewables to the energy mix increases (see table 9) to between 55% (7 EJ per year in India) and 65% (22 EJ per year in the United States).

Table 9: Total avoided primary energy supply and CO₂ emissions resulted from energy efficiency and renewable energy potential, 2030

	China	India	United States	EU	Total of selected regions
Primary energy reduced (EJ per year)					
Efficiency Case (from additional EE measures)	28	7	12	4	50
REmap 2030 (from REmap Options)	17	8	22	5	53
REmap 2030 + EE (total of Reference Case and additional)	45	15	33	9	102
CO₂ emissions avoided (million tonnes per year)					
Energy efficiency	2 231	596	773	208	3 809
Renewable energy	1 571	751	1 639	296	4 257
Total (EE and RE)	3 802	1 347	2 412	504	8 065

Note: All data are compared to the Reference Case in 2030.

In the analysed countries, CO₂ emissions could be reduced by almost 8.1 gigatonnes per year by 2030 if both higher rates of energy efficiency improvement and renewable energy deployment were achieved.

Among the analysed countries, energy efficiency measures have the highest energy-saving contribution in China, accounting for 60% of the estimated absolute reductions in total primary energy in 2030 (28 EJ out of the total 45 EJ per year). In the other analysed countries, this contribution ranges between 36% (12 EJ per year in the United States) and 43% (4 EJ per year in the EU countries).

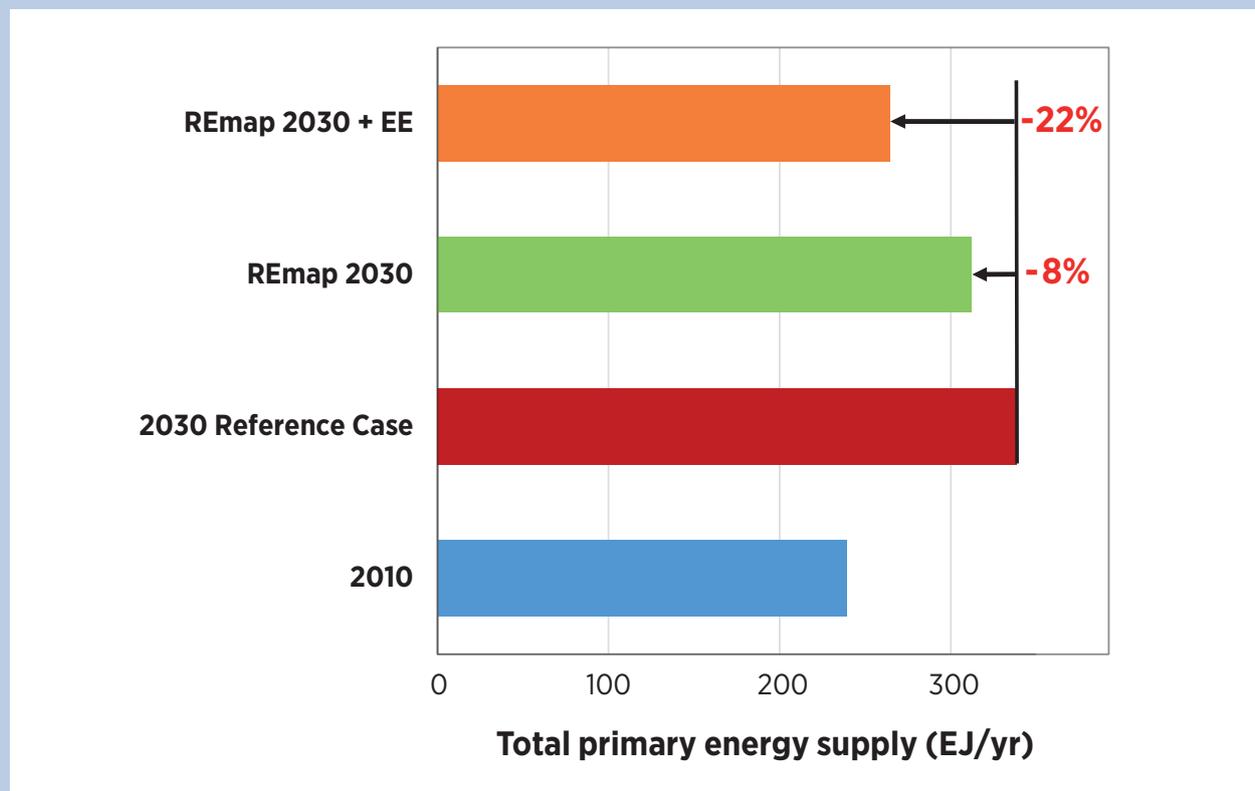
In terms of carbon dioxide (CO₂) emissions, the share of avoided emissions resulting from lower fossil fuel use due to REmap Options accounts for about 40% in China (1 571 million tonnes per year) and about 70% in the United States (1 639 million tonnes per year) compared to the Reference Case in 2030 (see table 9). This variability is because energy efficiency measures substitute a mix of fuels in the entire energy system that includes both natural gas with low emission intensity and coal with high emission intensity. In comparison,

renewables to a large extent substitute carbon-intensive coal in the analysed countries (mainly for power generation). In the case of the EU countries, since both energy efficiency measures and renewables substitute natural gas, their contributions to primary energy and CO₂ emission reductions are similar.

The change in energy intensity is determined mainly by the extent to which efficiency measures are applied. As shown earlier in figure 12, however, the renewable energy share in TFEC increases at a similar order of magnitude with both efficiency measures and REmap Options implemented one after another on top of the Reference Case.

Synergies between energy efficiency and renewables are more pronounced when the efficiency measures reduce the demand from conventional energy and where renewable energy capacity remains the same.

Figure 14: TPES in the selected countries, 2010 and 2030



The combined implementation of energy efficiency measures and renewable energy technologies can reduce the growth in total primary energy supply from 40% to 10% in the 2010-2030 period, with two-thirds of that potential originating from improving energy efficiency.

Technology breakdown

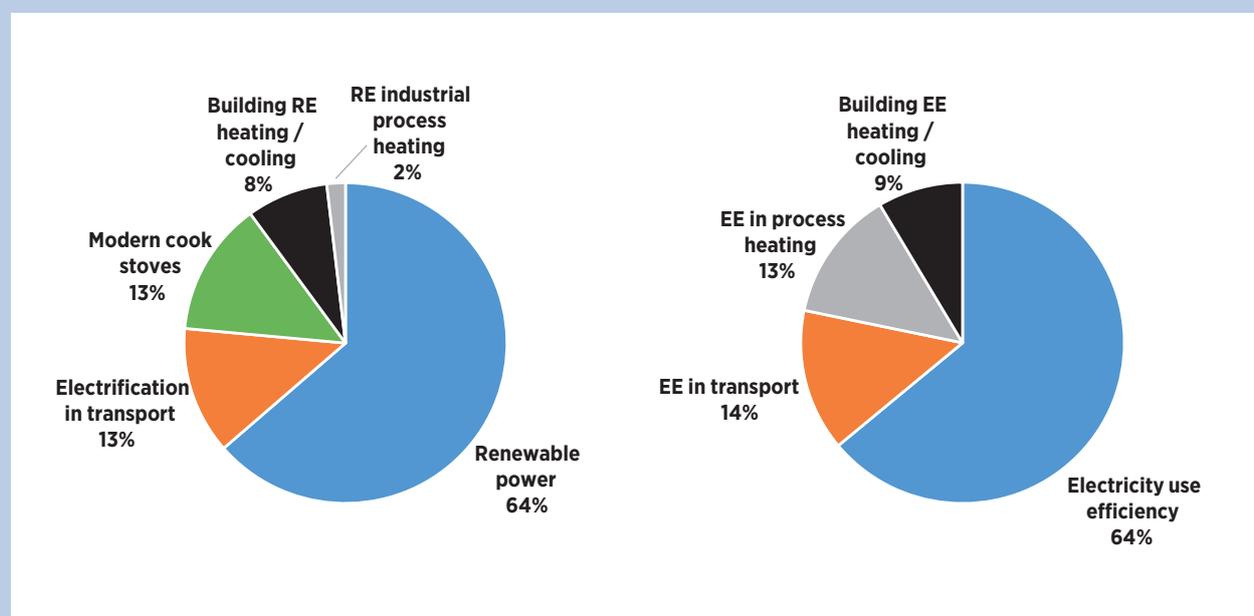
Total primary energy supply of the countries analysed increases by 40% between 2010 and 2030 according to the Reference Case, from 240 EJ to 340 EJ (see figure 14). This can be reduced by 8% if all of the REmap Options identified are implemented. An additional potential 14% reduction exists through the implementation of energy efficiency measures. This results in a combined potential of a 22% reduction in TPES compared to the Reference Case in 2030. This would reduce the total growth in TPES from 40% to 10% in the 2010-2030 period.

Figure 15 provides a breakdown of the total primary energy savings by implementing renewable energy technologies (left pie chart) and energy efficiency measures (right pie chart). In both cases, electricity-related technologies account for two-thirds of the total savings. This is explained by the fact that savings related to the electricity sector are estimated in terms of primary energy instead of final energy.

Renewable energy technologies in the building sector follow renewable power generation technologies, with a total potential of 21%. Much of that potential is related to the substitution of traditional uses of biomass for cooking with modern cook stoves. The potential in the building sector is followed by the potentials in the transport sector. REmap Options in the industry sector have a small contribution to overall primary energy savings related to renewables. In comparison, energy efficiency measures in end-use sectors have a similar contribution to primary energy savings.

Figure 16 shows developments in the share of modern renewable energy between 2010 and 2030. The Reference Case increases the renewable energy share of the analysed countries from 8% in 2010 to 14% in 2030. Implementing renewable energy (under REmap 2030) has the potential to raise this share to 26% by 2030. When energy efficiency measures are also implemented (REmap 2030 + EE), the renewable energy share reaches 30%, since the demand is less and the same amount of renewables covers a large share of TFEC.

Figure 15: Technology breakdown of primary energy savings between the 2030 Reference Case and the REmap 2030 + EE case



Note: The left pie chart refers to the contribution of renewable energy technologies, whereas the right pie chart refers to the breakdown of energy efficiency measures.

Renewable power generation technologies and energy efficiency measures account for approximately two-thirds of the total primary energy savings in 2030 compared to the Reference Case.

Figure 16: Modern renewable energy share in the selected countries, 2010 and 2030

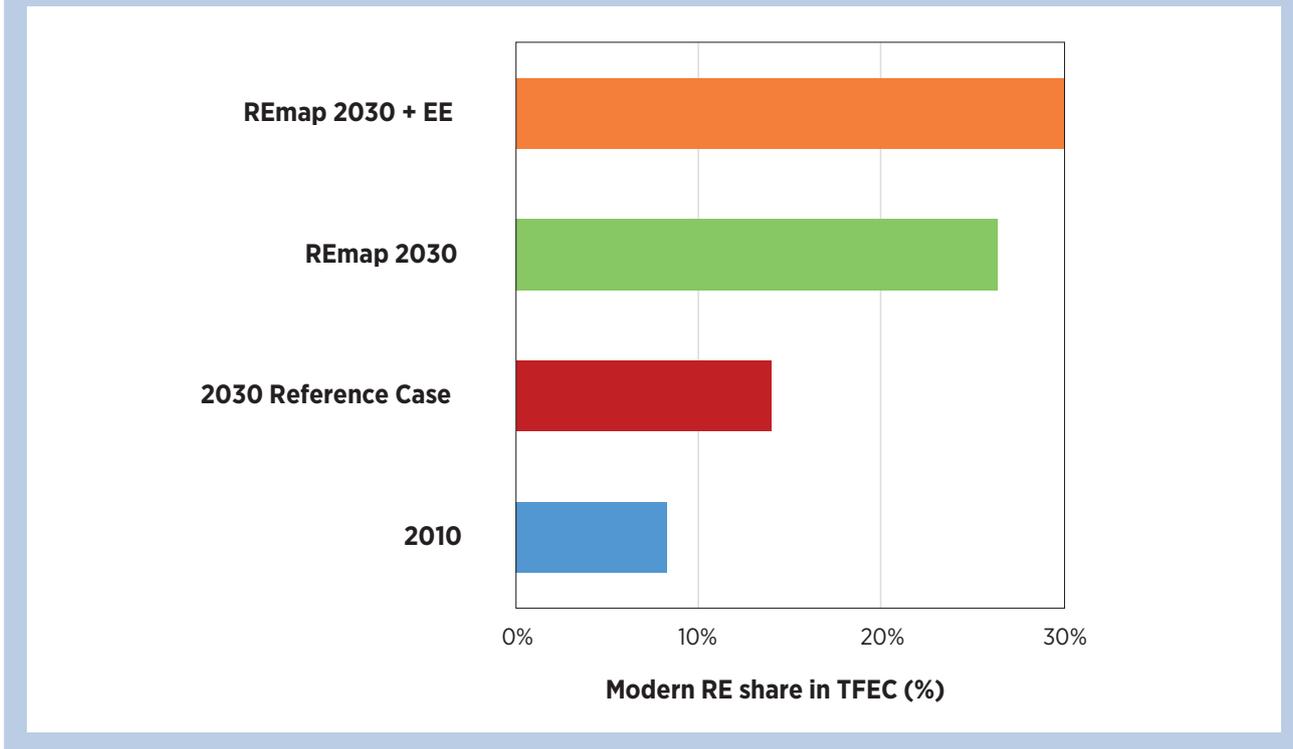


Figure 17 shows the contribution of renewable energy technologies and energy efficiency measures to the renewable energy share in TFEC between the 2030 Reference Case and the REmap 2030 + EE case. This breakdown is expressed in terms of final energy, not primary energy. This is an important difference compared to figure 15.

The contribution of renewable power to the renewable energy share covers half of the total potential of all renewable energy technologies. If the renewable energy share were to be expressed in primary energy terms, the share of renewable power would be much higher. Renewable energy in the industry sector is the second largest contributor. (Although technologies have little impact in terms of energy savings, they play a key role in raising the renewable share.) The remainder is related to the potential in the building (20%) and transport (9%) sectors.

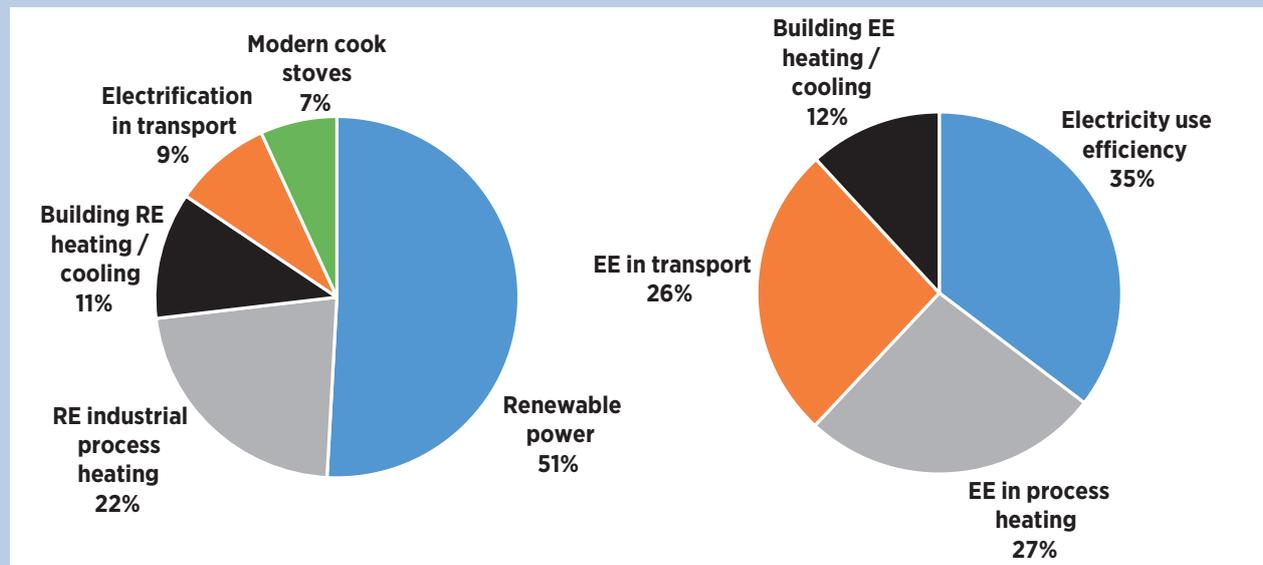
Energy efficiency measures have a more-or-less similar contribution to the overall increase in the modern renewable energy share. Improving the efficiency of electricity-based technologies accounts for one-third. The potentials of measures in the industry and transport sectors account for more than half of the total potential.

The comparison shows that technologies related to electricity use account for the largest share of the total potential, but with a lower magnitude compared to their role in primary energy savings. Furthermore, both renewables and energy efficiency measures in manufacturing industry have an important role in raising the modern renewable energy share compared to the Reference Case in 2030.

5.2 Are there trade-offs between renewable energy and energy efficiency?

As discussed earlier, it could be the case that efficiency measures would reduce demand not only for conventional energy sources, but also for renewable energy sources. Hence, improving energy efficiency could reduce the demand for new renewable energy capacity, thereby limiting the increase in the renewable energy share of TFEC. When this is the case, the renewable energy shares of TFEC in the REmap 2030 + EE case remain identical to those in REmap 2030. In contrast, energy intensity improves further, but by about 20% less than it otherwise would have improved if renewable energy capacities were not influenced.

Figure 17: Technology breakdown of modern renewable energy share between the 2030 Reference Case and the REmap 2030 + EE case



Note: The left pie chart refers to the contribution of renewable energy technologies, whereas the right pie chart refers to the breakdown of energy efficiency measures.

Renewable power generation technologies and energy efficiency measures account for a large share of the increase in the share of modern renewables in 2030 compared to the Reference Case, followed by the potential in the manufacturing industry.

5.3 How much will the policies aiming for these synergies cost, and will the combined policies be easier to implement?

Table 10 shows the costs of implementing energy efficiency measures and renewables under business as usual as well as with the accelerated deployment of energy efficiency measures and renewable energy technologies.

In view of the relatively modest growth in energy efficiency improvements in China and India, investment in modern renewable energy capacity in the Reference Case to 2030 is two to five times higher than for energy efficiency measures. This difference is because a large share of the growing energy demand is met by renewable energy capacity. In comparison, investments in energy efficiency play a more important role in the United States and the EU due to their ageing capital stock and its inefficiency, thereby resulting in a significant saving potential. Where one would expect

a similarly high level of investments for renewables, the ambition level of renewables deployment in these countries' Reference Cases to 2030 is low.

The investment in renewables in REmap 2030 for the United States is estimated to increase by a factor of 9 compared to the Reference Case, and it can double in the EU. The increase in investments required for energy efficiency measures in the Efficiency Case is estimated to be as high as in the Reference Case in the EU and only 50% higher in the United States.

The opposite estimates are observed for the two growing energy users: China and India. Both countries have substantial potential to improve their energy efficiency, and thereby show a significant volume of required investments in the Efficiency Case compared to the Reference Case. Investments in additional renewable energy technologies (REmap Options) are lower in REmap 2030 compared to the Reference Case. This is because investments for heating (with a lower total capital cost per unit of capacity compared to power sector technologies) account for a larger share of the

Table 10: Comparison of investments for energy efficiency and REmap Options

	China	India	United States	EU
	Investment needs (in billion USD per year, average between 2012 and 2030)			
Reference Case ¹	139	23	58	61
Energy efficiency	51	6	49	47
Renewables	88	18	9	14
Efficiency Case ² (from additional EE measures)	97	17	74	51
REmap 2030 ² (from additional REmap Options)	54	27	77	29
REmap 2030 + EE ³ (total of Reference Case and additional)	290	67	209	141
Energy efficiency	148	22	123	98
Renewables	142	45	86	43

Note: See IRENA (2014a) for methodology to estimate the externalities.

1 These represent the energy efficiency measures and renewable energy technologies that would be deployed between 2010 and 2030.

2 These represent the additional energy efficiency measures and renewable energy technologies that are deployed on top of the Reference Case.

3 This is the total of the Reference Case and the additional deployment of technologies beyond the Reference Case.

total REmap Options, and power sector investments that already have been deployed to a large extent in the Reference Case account for a lower share of the total REmap Options.

The REmap 2030 + EE case would in total require up to USD 290 billion in annual investments in China between 2012 and 2030, with investments shared almost equally between efficiency measures and REmap Options. In the United States and the EU, energy efficiency investments account for 60-70% of the total investment needs.

Total investment needs in these four regions that account for about half of the global use of renewable energy today are estimated to be USD 700 billion per year on average between 2012 and 2030, with 55% of the total investments related to energy efficiency measures (USD 390 billion) and 45% related to renewables (USD 310 billion). At a global level, this would translate to approximately USD 650 billion for energy efficiency and USD 650 billion for renewables, if the same coverage for energy use of the regions applied to total investments as well. Compared to current levels, this implies a need to grow energy efficiency investments by five times and renewables investments by about 2.5 times in the 2012-2030 period. Total investment for both energy efficiency and renewable energy technologies (USD

1 300 billion) would need to grow by a factor of 3.5 in the 2012-2030 period compared to the current level of about USD 400 billion.

As an indication of monetary benefits, table 11 shows the total avoided energy costs from energy efficiency measures and REmap Options (compared to the Reference Case). In 2030, these savings are higher than the average investment needs, demonstrating that both additional energy efficiency measures and REmap Options can be implemented in a cost-effective way.

When the avoided costs related to CO₂ emissions and human health (air pollution¹⁰) are factored in, the benefits of energy efficiency improvements and REmap Options would increase further. This is shown by the total avoided externalities.

The reductions in human health externalities of renewables are higher than those achieved by energy efficiency improvements. There are several reasons for

¹⁰ The external costs related to outdoor and indoor air pollution are evaluated from the following sources: 1) outdoor emission of sulphur dioxide (SO₂), mono-nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres (PM_{2.5}) from fossil fuel-based power plant operation, 2) outdoor emissions of NO_x and PM_{2.5} from road vehicles and 3) indoor emissions of particulates from biomass and coal combustion in the residential sector.

Table 11: Comparison of benefits for energy efficiency and REmap Options

	China	India	United States	EU
Total avoided energy costs (in USD billion per year in 2030, compared to business as usual)				
Energy efficiency	140	33	72	35
Renewables	86	42	133	48
Total	226	75	204	83
Total avoided externalities (in USD billion per year in 2030, compared to business as usual)				
Human health				
Energy efficiency	50-86	2-5	2-4	1-2
Renewables	79-136	66-137	12-31	2-4
Climate change				
Energy efficiency	45-179	12-48	15-62	4-17
Renewables	31-126	15-60	33-131	6-24
Total				
Energy efficiency	95-265	14-53	17-66	5-19
Renewables	110-262	81-198	45-162	8-28

If both higher rates of energy efficiency improvement and renewable energy deployment were achieved in the countries analysed, externalities related to human health and CO₂ could be reduced by between USD 375 and USD 1 055 billion annually by 2030.

this. Renewables have a large potential to substitute fossil fuel use for power generation, where the largest reductions in externalities happen. In comparison, efficiency measures reduce demand for power only, and therefore the effects on reducing fossil fuel demand and fuel substitution are limited. The magnitude of externalities related to fossil fuel use in the transport sector and for heating are rather small, although the absolute volumes of energy savings are high. This is explained by the lower unit external costs of these applications compared to those of power generation.

The difference between the externalities of renewables and energy efficiency is particularly high in the case of India, due to the substitution of large traditional uses of biomass with modern renewables. Such high reduction in traditional use of biomass does not happen with reductions in energy demand alone.

Similarly, in China, traditional uses of biomass are substituted with renewables, contributing greatly to the country's total avoided human health externalities of USD 79-136 billion in 2030. In the case of China, however, externalities from energy efficiency measures are also high. This is because coal use in the residential sector is valued with the same externality costs as the traditional use of biomass. This is an exception compared to the

analyses of other countries, since indoor combustion of coal for cooking is not common outside of China.

Climate change-related externalities (with CO₂ emissions valued at between USD 20 and USD 80 per tonne of CO₂) are much higher in the United States and the EU compared to their human health externalities for both energy efficiency and renewables.

Detailed accounting of the benefits from the avoided externalities from higher shares of renewables and improved energy efficiency is key to estimating the true costs of these efforts. However, in realising the energy, climate and sustainability goals of countries, there are clear synergies between energy efficiency and renewable energy to reduce their energy costs, improve human health and mitigate climate change.

5.4 What are the different indicators for measuring progress towards the SE4All objectives?

One of the most aggregated indicators that is commonly used as a proxy for energy efficiency is energy

intensity, typically represented by the ratio of the quantity of energy consumption in primary form per unit of economic output (Banerjee *et al.*, 2013). Energy intensity was adopted as the indicator to measure the rate of energy efficiency improvement under the SE4All initiative (Banerjee *et al.*, 2013) and is used in the analysis for this paper. However, the scientific community has recognised that the effectiveness of this indicator is limited, as energy intensity can in reality be driven by factors which are not directly linked to energy efficiency, such as structural changes in the economy (Trudeau and Murray, 2011). This makes it necessary to explore alternative indicators to measure the changes in energy efficiency. This section focuses on different approaches to develop indicators for energy efficiency which are available in the recent literature and beyond, namely:

- Enerdata energy efficiency index
- IEA energy efficiency indicators
- RISE energy efficiency indicator
- ACEEE Energy Efficiency Scorecard
- Improving Policies through Energy Efficiency Indicators (IPEEI)

The last section discusses alternative indicators for measuring the renewable energy share.

Enerdata energy efficiency index

The energy efficiency index developed by Enerdata aims to analyse energy efficiency trends at the aggregate level by sector (industry, transport, buildings) or for the overall economy (Enerdata, 2010). The advantage of this approach is elimination of the effects of structural changes and other factors not related to energy efficiency (Doucet, 2008). In comparison to energy intensity, this index requires more complex calculation (a weighted average of sub-sectoral indices of energy efficiency progress (Enerdata, 2012)) and demands the input of more-detailed data. The energy efficiency index is used less often than energy intensity, but it reflects more accurately changes in the efficiency of technologies (Bashmakov and Myshak, 2014). The index aggregates changes in unit consumption at a disaggregated level (sub-sector or end use) for a given period of time. Unit consumption can be expressed in various units depending on its application (toe/m², kWh/appliance, etc.) and can be calculated separately for the building, industry and transport sectors (Enerdata, 2012).

When calculating the index for the building sector, the residential and service sub-sectors are considered separately (IEA, 2012a). For the residential sub-sector, the index aggregates the tendencies in different end-uses based on their weight in total consumption. For each end-use, in order to measure the efficiency progress, the following indicators are used: heating/cooling (unit consumption per m²), lighting (unit consumption per dwelling), appliances (kWh/year/appliance) and cooking (unit consumption per dwelling). For the service sub-sector, unit consumption is measured as the ratio between the final energy or electricity consumption and the number of employees (Enerdata, 2012).

Unit energy consumption (UEC) for industry is expressed in terms of the energy used per unit of physical output (tonnes produced for paper, glass, cement and steel, and production index for other industry branches) (Enerdata, 2012). At the moment, UEC cannot serve as the ultimate indicator for energy efficiency of the overall industry, as the quality and comparability of the data, and the boundaries of each industry, still need to be validated (Trudeau and Murray, 2011). At the disaggregated level, however, this indicator can reflect improvements in the technical efficiency of separate production processes (Trudeau and Murray, 2011).

The energy efficiency index for transportation aggregates the trends from each transport mode into a single indicator for the whole sector. For the transport of goods (e.g., by light vehicles and trucks) the unit consumption per tonne of transported goods is used to illustrate the energy required to deliver one unit of output. For cars, energy efficiency is expressed in litres/100 km, and for other modes of transport, the following indicators are used: air transport (tonnes of oil equivalent per passenger-km), passenger rail (grams of oil equivalent per passenger-km), transport of goods by rail and water (grams of oil equivalent per tonne-km), and motorcycles and buses (toe/vehicle) (Enerdata, 2010).

IEA energy efficiency indicators

In its recently developed framework, the IEA uses the concept of a pyramid to document three main groups of indicators for measuring energy efficiency. The pyramid demonstrates a hierarchy of energy indicators from the most detailed (at the bottom) to the most aggregated (at the top) (see figure 18). The top level of indicators reflects trends in energy consumption in each sector in a

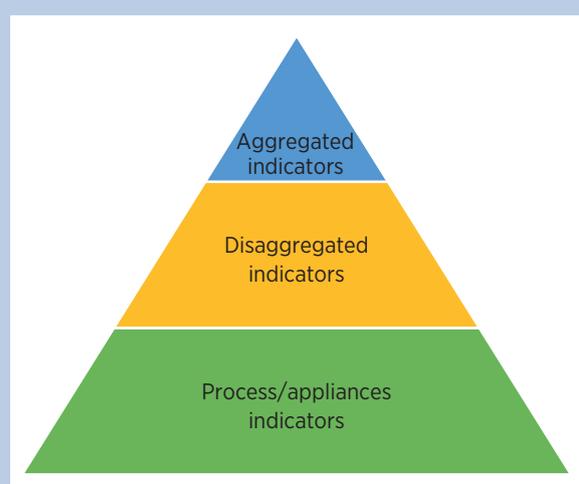
very broad way. The middle level contains indicators for energy consumption per unit of activity in each sector, and the bottom level comprises the most disaggregated indicators for separate sub-sectors or end-uses (see table 12) (IEA, 2014c).

According to the IEA, the information that energy indicators provide can be crucial when evaluating and monitoring existing policies and designing future actions (Phylipsen, 2010). The IEA acknowledges that further improvement is necessary for detailed analyses in order to avoid issues with data quality and comparability.

RISE energy efficiency indicator

Another framework to measure energy efficiency has been developed by the World Bank and is presented in the 2014 report *Readiness for Investment in Sustainable Energy* (RISE), which describes a set of indicators that assess the legal and regulatory environment for investment in energy access, renewable energy and energy efficiency. The RISE framework was developed to capture the multidimensional aspects of policy actions in a country that promotes a friendly environment for

Figure 18: IEA indicators pyramid



Source: IEA, 2014c

sustainable energy (World Bank, 2014). The framework aims to indicate the level of a country's ambition in adopting a set of widely recognised energy efficiency best practices, and consists of three categories: 1) planning, 2) policies and regulations and 3) pricing and

Table 12: Overview of intensity indicators at the sector and sub-sector levels

Sector	Sub-sector	Intensity indicator
Residential	Space heating	Heat/floor area
	Water heating	Energy/capita
	Cooking	Energy/capita
	Lighting	Electricity/floor area
	Appliances	Energy/appliance
Passenger transport	Cars	Energy/pass-km or Energy/vehicle-km
	Bus	Energy/pass-km
	Rail	Energy/pass-km
	Domestic air	Energy/pass-km
Freight transport	Trucks	Energy/t-km or Energy/Value added
	Rail	Energy/t-km
	Domestic shipping	Energy/t-km
	Other modes	Energy/Value added
Services	Total services	Energy/GDP
	Total services	Energy/floor area
Manufacturing	Paper and pulp	Energy/Value added
	Chemicals	Energy/Value added
	Non-metallic minerals	Energy/Value added
	Iron and steel	Energy/Value added
	Non-ferrous metals	Energy/Value added
	Food and beverages	Energy/Value added
	Other	Energy/Value added

subsidies. Each category includes various indicators (see table 13). These indicators were established based on a pilot survey conducted in 17 developed and developing countries, and the scope of analysed policies was limited to some extent (World Bank, 2014).

ACEEE Energy Efficiency Scorecard

The Energy Efficiency Scorecard was developed by the American Council for an Energy-Efficient Economy (ACEEE) as a way to examine the best policies and practices across different countries and to compose a benchmark for comparing countries on their efforts to improve energy efficiency. ACEEE established a list of indicators (metrics), the aggregation of which reflects the level of commitment of a country to energy efficiency improvement.

The indicators are divided into four thematic sections: national efforts, buildings, industry and transportation. Within each section, the indicators are split into policy metrics and performance metrics. Depending on the country's efforts and achievements in each category and metric, the country can receive a certain number of points (or score) for each indicator. The maximum possible score is 100, with 50 points allocated for policy metrics and another 50 for performance metrics (Young *et al.*, 2014). The main disadvantage of the Energy Efficiency Scorecard is that there are many complications and country differences (e.g., population, predominant industries, climate and geography) that

may boost or weaken the overall score but which are not yet captured in the scoring methodology (Young *et al.*, 2014).

Improving Policies through Energy Efficiency Indicators (IPEEI)

The IPEEI, developed by the International Partnership for Energy Efficiency Cooperation, uses a different approach to monitor changes in energy efficiency, taking into consideration three types of indicators: energy intensity, specific energy consumption and indicators of diffusion. The indicators decompose and monitor five main sectors: power, industry, transport, buildings and the sectors overall (IPEEC and ADEME, 2015).

Renewable energy indicators

In this analysis, renewable energy share has been expressed with respect to TFEC. As explained earlier, accounting methods for total energy use differ, and using a different metric, such as primary energy, may yield different results. Moreover, renewable energy can be expressed in units other than "shares". This is particularly important where the overall effect of a specific technology or sector on TFEC is small; for example, small-scale solar PV systems will have marginal impact on TFEC, but they would be able to provide electricity to numerous households. Hence, renewables can be measured by accounting for the number of units, capacity or the services they provide.

Table 13: Indicators under the RISE framework

Categories	Indicators
Planning	<ul style="list-style-type: none"> ● National plan for increasing energy efficiency ● Entities for energy efficiency policies, regulations and implementation
Policies and regulations	<ul style="list-style-type: none"> ● Quality of information provided to consumers ● Incentives or mandates for energy supply utilities ● Incentives or mandates for public entities ● Incentives or mandates for large-scale users ● Minimum energy efficiency performance standards ● Energy labelling system ● Building energy codes
Pricing and subsidies	<ul style="list-style-type: none"> ● Incentives from electricity pricing ● Fossil fuel subsidy ● Carbon pricing mechanism

6 CONCLUSION AND RECOMMENDATIONS

The United Nations' SE4All initiative is grounded on three interlinked global objectives: 1) ensuring universal access to modern energy services, 2) doubling the global rate of improvement in energy efficiency and 3) doubling the share of renewables in the global energy mix.

This working paper explores the synergies and trade-offs between the energy efficiency and renewable energy objectives of the SE4All, which is a field of research that so far has not been explored. The analysis was carried out through co-operation between the C2E2 – the energy efficiency hub of the SE4All initiative – and the IRENA, the renewable energy hub of the initiative.

Accelerating the deployment of renewable energy technologies in line with the SE4All objective increases the share of modern renewables from 18% to 27% worldwide beyond a business-as-usual case where both energy efficiency improvements and renewables deployment follow current policies. Across the eight regions that were selected for the purpose of this analysis the renewable energy share increases by a factor of two to four between 2010 and 2030. Deployment of renewable energy technologies would reduce the energy intensity of countries by 5-10% by 2030 in comparison to business as usual. These savings are achieved by implementation of electrification technologies or modern cook stoves that are more efficient than the conventional alternatives while they increase the share of renewables.

Accelerating the deployment of energy efficiency measures can double the energy intensity improvement rates of the selected EU countries and India compared to business as usual. Lower energy demand from measures to accelerate energy efficiency contributes to increasing the renewable energy share of all countries, assuming

that renewable energy use will grow following business as usual. This is particularly the case for countries where low demand growth is projected to 2030, such as Germany and the United States.

Realisation of the accelerated renewable energy potential alone, or of energy efficiency measures alone, is not sufficient to achieve both SE4All objectives. However, this working paper shows that there is an important synergy from the accelerated deployment of energy efficiency measures and renewable energy technologies for both higher renewable energy shares and annual improvements in energy intensity. The combined potential of technologies reduces the total primary energy demand by up to 25% compared to business as usual in 2030. Energy efficiency measures account for 50-75% of the total primary energy savings.

On the other hand, as the improvement in energy efficiency reduces the overall energy demand, there is a potential trade-off, since it potentially can reduce the demand for new renewable energy capacity as well, and thereby limit the increase in the share of renewable energy in total final energy consumption.

Renewable power sector technologies and efficiency measures to reduce power demand will play the key role in both total primary energy savings and realising higher shares of renewables in the analysed countries. There is also an important role for renewables and energy efficiency in raising the renewable energy share in the manufacturing industry.

To arrive at more robust conclusions for the global situation, the analysis will need to be expanded to include other countries as well as technology-by-technology analysis of the energy efficiency potential, which in this paper relies on estimates from other sources.

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LIST OF ABBREVIATIONS

ACEEE	American Council for an Energy Efficiency Economy	MJ	Megajoules
APEC	Asia-Pacific Economic Cooperation	NOx	Nitrogen Oxides
C2E2	Copenhagen Centre on Energy Efficiency	NPS	New Policy Scenario
CAGR	Compound Annual Growth Rate	NZEB	Net Zero-Energy Building
CO ₂	Carbon Dioxide	OECD	Organisation for Economic Co-operation and Development
CSP	Concentrated Solar Power	p-km	Passenger Kilometre
EE	Energy Efficiency	PLDV	Passenger Light Duty Vehicle
EIA	U.S. Energy Information Administration	PM	Particulate Matter
EJ	Exajoules	PPP	Purchasing Power Parity
EU	European Union	PV	Photovoltaics
EWS	Efficient World Scenario	RE	Renewable Energy
GDP	Gross Domestic Product	RISE	Readiness for Investment in Sustainable Energy
GFEC	Gross Final Energy Consumption	SE4All	Sustainable Energy For All
GOE	Gram Oil Equivalent	SO ₂	Sulphur Dioxide
GTF	Global Tracking Framework	TFC	Total Final Consumption
IEA	International Energy Agency	TFEC	Total Final Energy Consumption
IPCC	Intergovernmental Panel on Climate Change	TOE	Tonnes of Oil Equivalent
IPEEC	International Partnership for Energy Efficiency Cooperation	TPES	Total Primary Energy Supply
IPEEI	Improving Policies through Energy Efficiency Indicators	UAE	United Arab Emirates
IRENA	International Renewable Energy Agency	UEC	Unit Energy Consumption
kW	Kilowatt	UK	United Kingdom
MEPS	Minimum Energy Performance Standards	UN	United Nations
		USD	United States Dollar



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