



**RENEWABLE  
ENERGY  
BENEFITS:  
MEASURING THE  
ECONOMICS**



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### **ABOUT IRENA**

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.

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### **AUTHORS**

Rabia Ferroukhi, Alvaro Lopez-Peña, Ghislaine Kieffer, Divyam Nagpal, Diala Hawila, Arslan Khalid, Laura El-Katiri, Salvatore Vinci and Andres Fernandez (IRENA).

For further information or to provide feedback, please contact  
IRENA, P.O. Box 236, Abu Dhabi, United Arab Emirates; Email: [info@irena.org](mailto:info@irena.org)

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Accelerating the transition to a renewables-based energy system represents a unique opportunity to meet climate goals while fueling economic growth, creating new employment opportunities and enhancing human welfare. The world is united in the commitment to realise this opportunity, attested by the inclusion of renewable energy targets both in the energy plans of 164 countries as well as in the Nationally Determined Contributions (NDC) that will drive the implementation of the Paris Agreement on climate. Decisions on energy sector investments made today will influence economic growth and development for the coming decades. They will also define our ability to decarbonise energy, an essential element of action on climate change. The transition to a renewables-based system can help meet this objective, while generating new sources of growth, increasing incomes, creating jobs and improving the health and wellbeing of millions.

The need for scaling up renewables is now undisputed, and the full range of benefits they can bring has come to the fore in global discussions. As countries consider options at their disposal, understanding the socio-economic benefits of the transition to a renewable energy future is of vital importance. *Renewable Energy Benefits: Measuring the Economics* provides the first global quantification of the macroeconomic impacts of renewable energy deployment. It finds that doubling the share of renewables by 2030 would bring a range of positive impacts including an increase in global gross domestic product (GDP) up to 1.1 percent, improvement of global welfare by 3.7 percent and over 24 million people working in the renewable energy sector.

This report provides the latest evidence that mitigating climate change through the deployment of renewable energy and achieving other socio-economic objectives are mutually beneficial. Thanks to the growing business case for renewable energy, an investment in one is an investment in both. A full understanding of these benefits can tip the balance towards low-carbon investments and future-proof our energy system.



**Adnan Z. Amin**  
*Director-General*  
 International Renewable  
 Energy Agency



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# ABBREVIATIONS

<b>CEM</b>	Clean Energy Ministerial
<b>CGE</b>	Computable general equilibrium
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>COP</b>	Conference of the Parties
<b>EU</b>	European Union
<b>GDP</b>	Gross domestic product
<b>GHG</b>	Greenhouse gas
<b>GJ</b>	Gigajoules
<b>GW</b>	Gigawatt
<b>HDI</b>	Human Development Index
<b>IMF</b>	International Monetary Fund
<b>IEA</b>	International Energy Agency
<b>IRENA</b>	International Renewable Energy Agency
<b>LCOE</b>	Levelised Cost of Electricity
<b>MW</b>	Megawatt
<b>O&amp;M</b>	Operations and maintenance
<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>PV</b>	Photovoltaic
<b>R&amp;D</b>	Research and development
<b>RE</b>	Renewable energy
<b>SE4ALL</b>	United Nations Sustainable Energy for All initiative
<b>UN</b>	United Nations
<b>UNDP</b>	United Nations Development Programme
<b>UNEP</b>	United Nations Environment Programme
<b>USD</b>	U.S. dollar
<b>WEO</b>	World Energy Outlook

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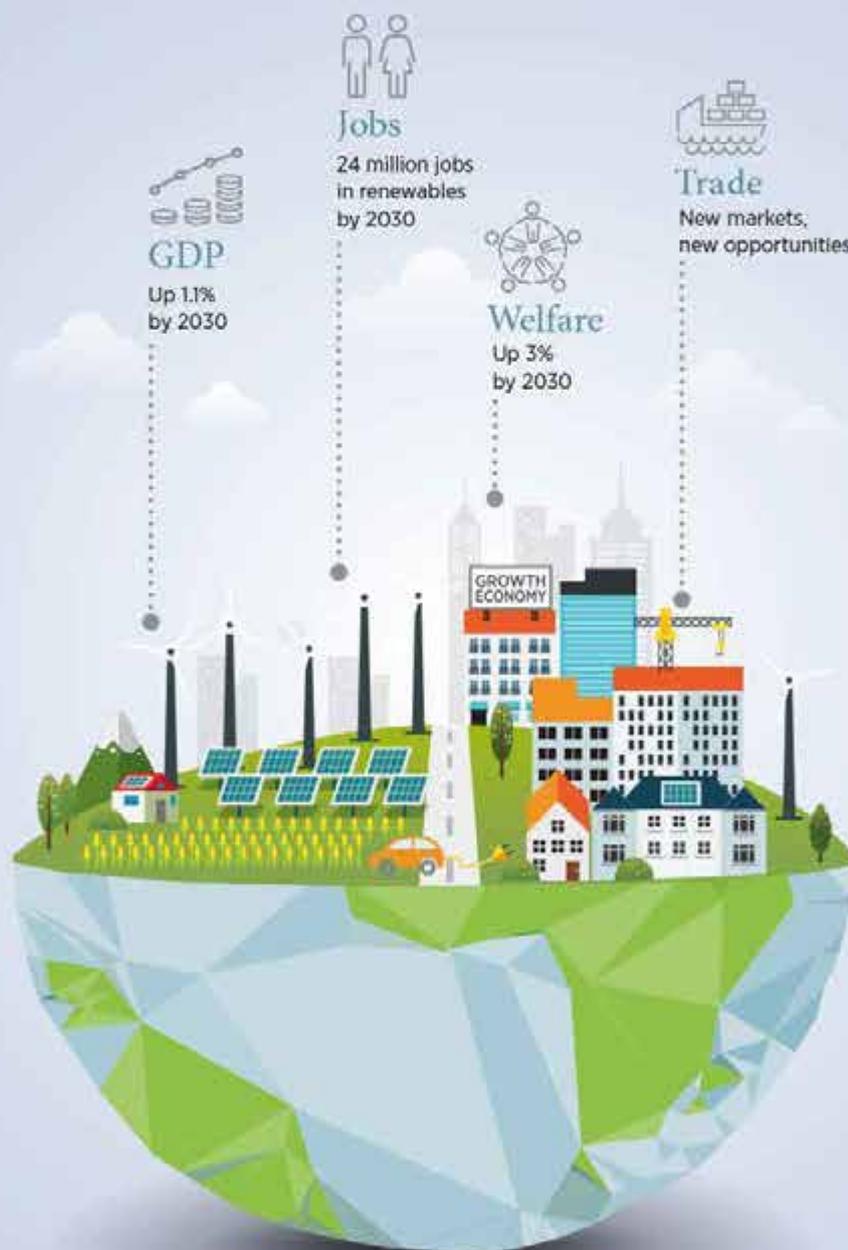
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# RENEWABLE ENERGY BENEFITS: MEASURING THE ECONOMICS



# EXECUTIVE SUMMARY

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***Renewable Energy Benefits: Measuring the Economics* provides the first quantification of the macroeconomic impact of doubling the global share of renewables in the energy mix by 2030.**

The adoption of the Sustainable Development Goals and the Paris Agreement sent a clear message that the transition to sustainable energy is central to meeting development and climate objectives. As policy makers consider options at their disposal, understanding the socio-economic benefits of this transition is of vital importance. To inform international debate and facilitate sound decision-making, *Renewable Energy Benefits: Measuring the Economics* provides the first global analysis of the impact of renewable energy deployment on the economy and the interdependencies between sectors and markets.

The study analyses the linkages between the energy system and the world's economies within a single quantitative framework. It builds on IRENA's previous work on the socio-economic benefits of renewable energy and IRENA's roadmap for doubling the global share of renewables, *REmap 2030*. It finds that, within the timeline of the Sustainable Development

Goals, renewable energy can offer solutions for the dual objective of ensuring economic growth and the imperative to decarbonise economies across the globe.

**Accelerating the deployment of renewable energy will fuel economic growth, create new employment opportunities, enhance human welfare, and contribute to a climate-safe future.**

Advances in renewable energy technologies and growing cost-competitiveness have strengthened the business case of renewables and opened new opportunities for countries to transform their energy systems. This study demonstrates that the benefits of scaling up renewable energy surpass cost competitiveness. Increased deployment can meet the energy needs of a growing population, drive development and improve well-being, while reducing greenhouse gas emissions and increasing natural resource productivity. It provides empirical evidence that economic growth and environmental conservation are fully compatible, and that the conventional consideration of trade-offs between the two is outdated and erroneous.



## GDP

*Doubling the share of renewables in the global energy mix increases global GDP in 2030 by up to 1.1%, equivalent to USD 1.3 trillion.*

● **Doubling the share of renewables in the global energy mix by 2030 would increase global GDP by up to 1.1% or USD 1.3 trillion.** The report shows that such a transition increases global GDP in 2030 between 0.6% and 1.1%, or between around USD 700 billion and USD 1.3 trillion compared to business as usual. Most of these positive impacts on GDP are driven by the increased investment in renewable energy deployment, which triggers ripple effects throughout the economy. If the doubling of the renewable share is achieved through a higher rate of electrification of final energy uses, the increase in global GDP is even higher, amounting to some 1.1%, or USD 1.3 trillion globally.



## Welfare

*Renewable energy improves human well-being and overall welfare well beyond GDP.*

● **Improvements in human well-being and welfare would go far beyond gains in GDP.** The benefits of renewables reach well beyond the traditional and limited measurements of economic performance. Doubling the share of renewables by 2030 has a positive impact on global welfare, which increases by 2.7% compared to a 0.6% GDP improvement. If achieved through higher electrification of heat and transport, global welfare would further rise by 3.7%. A combined indicator for welfare considers a number of factors including:

- Economic impacts based on consumption and investment;
- Social impacts based on expenditure on health and education; and
- Environmental impacts, measured as greenhouse gas emissions and materials consumption.



## Jobs

*Given the distributed and labour-intensive nature of renewable energy, direct and indirect employment in the renewable energy sector could reach 24.4 million people in 2030.*

● **Doubling the share of renewables increases direct and indirect employment in the sector to 24.4 million by 2030.** Renewable energy jobs will grow across all technologies, with a high concentration in the same technologies that account for a majority of the employment today, namely bioenergy, hydropower and solar. Along the renewable energy value chain, most renewable energy jobs will come from fuel supply (bioenergy feedstocks), installations and equipment manufacturing.



## Trade

*The transformation of the energy system will impact fuel importers and exporters, and new markets will be created.*

● **Renewable energy deployment affects trade of energy-related equipment and services as well as of fossil fuels.** Trade in renewable energy equipment and other investment goods and services will increase as a result of the scaled-up deployment in power and end-use sectors. At the same time, this will result in a decrease in trade of other energy sources, notably fossil fuels.

**The increase in the share of renewable energy in the global energy system will impact both fuel importers and exporters.** For fossil fuel importers, the switch to a greater share of renewables has potentially favourable trade implications stemming from the ripple effects on their economies, as well as improved energy security due to a greater reliance on indigenous sources. Fossil fuel exporters appear vulnerable to changes in trade patterns. Given the high contribution of fossil fuels to their GDP, the dependency on export revenues can have significant effects on their economies. This is not a foregone conclusion, however. Early renewable energy deployment in fossil fuel exporting countries could be seen as an opportunity for economic diversification, thereby positioning them in the new markets that will be created.

### **Policy makers can maximise the benefits of the transition to sustainable energy for their national economies.**

Doubling the share of renewables in the global energy mix pays back in terms of economic growth, social welfare, job creation and overall trade balances. The benefits depend on a set of enabling factors, which include a diversified economy and sufficient market capacity to absorb the opportunities for job creation, including training and education that help build a skilled and versatile workforce. Economic growth also depends critically on an increase in investments in renewable energy deployment without reducing investment in other economic sectors. This reinforces the study's central message that the many potential benefits from accelerated global renewable energy deployment depend on sufficient financial resources.

### **The macroeconomic impacts of renewable energy deployment presented in this study were obtained based on a macroeconomic analysis,**

using the E3ME tool. The main strengths of this approach are: its foundation on a solid empirical data set, its flexibility, and a proven track record of policy applications. Unlike other approaches, it allows the analysis of policies or regulations in situations where economic resources are idle, which is often observed in reality. Any macro-econometric approach has limitations that need to be taken into account. These include high data requirements and methodological limitations, such as assumptions on the availability of necessary resources for renewable energy deployment. Despite these limitations, this study – the first of its kind – provides a solid basis for future work to quantify the growth-enhancing potential of renewable energy in the global economy.



01

INTRODUCTION

# INTRODUCTION

Energy fuels global economic activity. As populations expand, living standards improve and consumption rises, total demand for energy is expected to increase by 21% by 2030 (IEA, 2015). At the same time, growing concerns over climate change are prompting governments worldwide to seek ways to supply energy while minimising greenhouse gas emissions and other environmental impacts. Decisions made today on energy sector investments and infrastructure lock in associated costs and benefits for at least a few decades. They also strongly influence how effectively the energy sector underpins growth across the economy.

The energy sector influences the vibrancy and sustainability of the entire economy – from job creation to resource efficiency and the environment. Major shifts in the sector can have a strong ripple effect throughout the economy as evidenced in Japan following the 2011 earthquake, or by the recent volatility in oil prices. Making the energy supply more cost-effective, reliable, secure and environmentally sustainable thus contributes to the long-term resilience of economic development.

The deployment of renewable energy technologies has seen remarkable growth in recent decades, supported by enabling policies and steep cost reductions. Improved energy security, fewer adverse climate change impacts and broader energy access are widely viewed as motivations for this increase. The business case for renewable energy is further strengthened by the socioeconomic benefits it can offer.

As many economies continue to struggle to regain momentum, policy makers are increasingly interested in the potential benefits of renewable energy deployment on

economic growth and job creation. However, further analysis and empirical evidence on this important subject is still needed. IRENA has been pioneering work in this field since 2011 (see Box 1). For example, it has recently

## Box 1: IRENA's work on Renewable Energy Benefits

The present report is part of a broader work stream within IRENA that started in 2011. It also includes the 2013 report *Renewable Energy and Jobs*, the 2014 study *The Socioeconomic Benefits of Solar and Wind Energy* and the 2015 report *Renewable Energy in the Water, Energy & Food Nexus*.

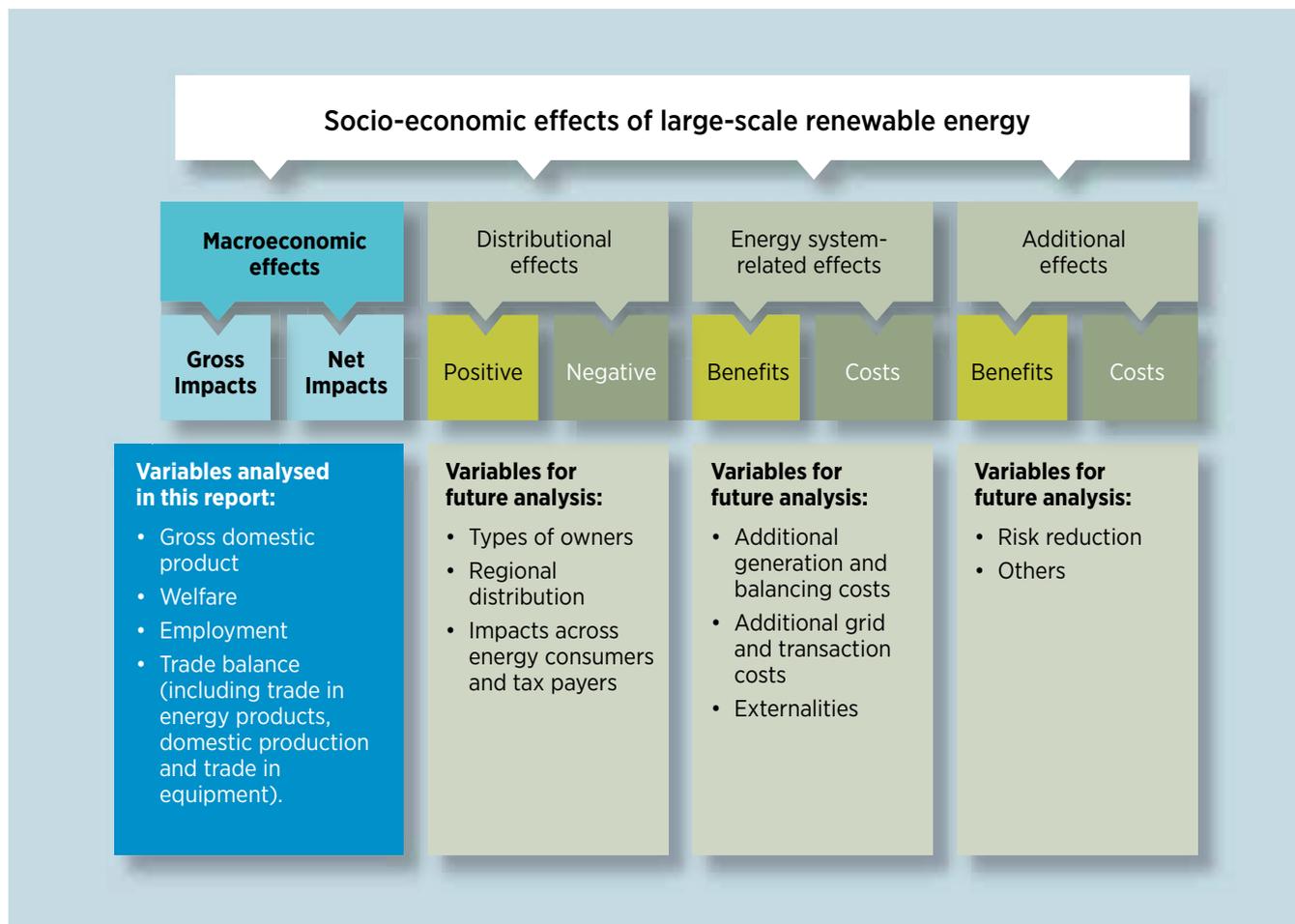


estimated that the global renewable energy sector employs as many as 9.2 million people (IRENA, 2015a).

Renewable energy benefits therefore play a critical role in informing policy decisions and tipping the balance in favour of low-carbon investments. With a view to contribute to this field of knowledge, IRENA developed a conceptual framework to analyse the environmental, social and economic value from large-scale solar and wind energy deployment<sup>1</sup> (IRENA and Clean Energy Ministerial, 2014). Its approach helps classify, quantify, aggregate

and compare socioeconomic effects in a holistic manner. As shown in Figure 1, the conceptual framework identifies four separate dimensions in which the effects can be categorised. The assessment of the macroeconomic effects as displayed in the left-hand column are the core of the present study. The study also includes the energy system-related effects, such as the cost of integrating variable renewables, which can have macroeconomic impacts.

**Figure 1:** Conceptual framework for analysing the socio-economic effects of large-scale renewable energy deployment.



Source: IRENA and CEM (2014), updated to reflect the scope of this report

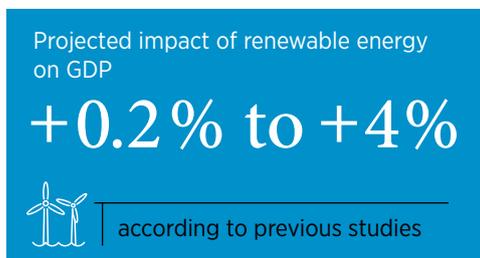
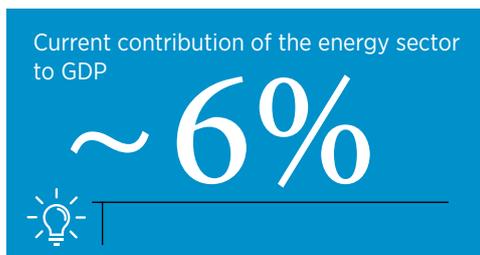
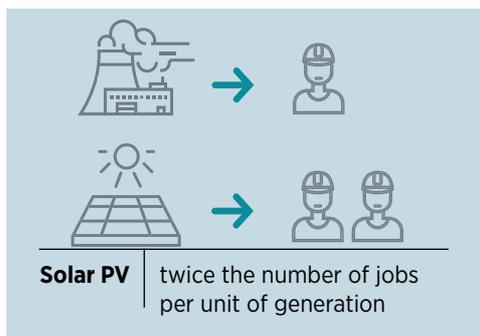
## 1.1 EXISTING KNOWLEDGE

Increasing the share of renewables can affect the world's economy through investment, trade and electricity prices, for example. A literature review was carried out to gather evidence on these effects. It set a benchmark to compare the results of the present analysis as well as guided the selection of the methodology, inputs and indicators.

The overview of country/region-specific studies (Box 2) shows that selected effects of renewable energy deployment at sectoral and national/regional level are predominantly positive. In fact, GDP growth in the forecast year can be between 0.2% and 4%.<sup>2</sup>

Among other factors, the magnitude of the impacts of renewable energy on GDP will depend on the economic structure of the country, the costs of alternative energy sources (e.g. fossil fuel prices, energy technology costs), and whether the equipment and required services are imported or sourced locally. Indeed, the literature available suggests that investment in renewable energy technologies (and any other technology) can have a more significant positive effect if the technology is produced locally under the right conditions (e.g. market, skills availability) (IRENA and CEM, 2014; Poyry and Cambridge Econometrics, 2014).

The existing studies also show that increased renewable energy deployment contributes to job creation. Depending on the policy intervention introduced in the countries under consideration, employment could increase anywhere from a few thousand to over a million in 2030 (see Box 2). The jobs created are likely to offset job losses in sectors such as fossil fuels because the sectors involved in the renewables supply



1. Off-grid and small applications were excluded from the analysis although the same report also proposed a conceptual framework for this context.  
 2. This increase is significant given that the share of the energy sector to GDP is only about 6% on average globally. This average hides large disparities at the country level, with a range of 3% in Germany to 57% in Kuwait (Statista, 2015, World Economic Forum, 2012).

**Box 2:** Previous studies on the projected economic impacts<sup>3</sup> of renewable energy deployment

Country/Region (Source)	Forecast year	Analysed policy intervention	Impact on GDP	Impact on employment
 <b>Chile</b> (NRDC and ACERA, 2013)	2028	20% renewables in electricity generation (excl. large hydro)	+0.63% (USD 2.24 billion)	7,800 direct and indirect jobs (+0.09%)
 <b>European Union</b> (European Commission, 2014)	2030	-40% greenhouse gas emissions in 2030 <sup>4</sup>	+ 0.46%	+1.25 million economy-wide jobs (+0.5%)
 <b>Germany</b> (Lehr <i>et al.</i> , 2012; Blazejczak <i>et al.</i> 2014; Bohringer <i>et al.</i> 2013)	2030	Different targets for renewable energy deployment	Up to + 3%	From negative* to + 1% on net employment
 <b>Ireland</b> (Pöyry Management Consulting and Cambridge Econometrics, 2014)	2020	Meeting the target for wind by 2020	+0.2% to + 1.3%	+1,150 to + 7,450 net jobs
 <b>Japan</b> (IRENA and CEM, 2014)	2030	Adding 23.3 gigawatts (GW) of solar PV	+0.9% (USD 47.5 billion)	N/A
 <b>Mexico</b> (own calculations based on PwC, 2015)	2030	21 GW of additional renewable power capacity	+0.2%	+134,000 in the sector
 <b>Saudi Arabia</b> (own calculations based on K.A.CARE, 2012)	2032	54 GW of renewable power capacity	+4% (USD 51 billion)	+137,000 in the sector <sup>5</sup>
 <b>United Kingdom</b> (Cambridge Econometrics, 2012)	2030	Larger role of off-shore wind instead of natural gas	+0.8%	+70,000 net employment
 <b>USA</b> (ICF International, 2015; Synapse Energy Economics <i>et al.</i> (2015))	2030	Decarbonisation driven by renewable energy	+0.6%,	+0.5 to +1 million net

Note (\*): if renewables are financed through a high labor tax or electricity surcharge

chain are usually more distributed and labour-intensive than the conventional energy sector. For instance, solar PV creates at least twice the number of jobs per unit of electricity generated compared with coal or natural gas<sup>6</sup>. As a result, substituting fossil fuels for renewables could lead to a higher number of jobs overall.

The literature review also found that many studies focus on the economics of climate change policy and green growth. However, little specific evidence exists of the economic impact of global renewable energy deployment. This study thus addresses a major knowledge gap on the impact of renewable energy deployment on key economic variables.

## 1.2 OBJECTIVES OF THIS STUDY

The objective of this study is to capture and measure the effects of renewable energy deployment on the basis of a holistic macroeconomic framework. More specifically, the study provides quantitative evidence of the macroeconomic impacts of renewable energy deployment at a global level. It also adds insights to the existing body of knowledge on the socio-economic effects of renewable energy deployment at the national level.

The report puts the conceptual framework presented in Figure 1 into use for the first time, concentrating on the four macroeconomic variables identified. These are **GDP**, **employment**, **welfare**<sup>7</sup> and **trade**. More specifically, this study provides a quantitative assessment of the



<p>Section 2.1</p> <h1>GDP</h1>  <p>page 24</p>	<p>Section 2.2</p> <h1>Welfare</h1>  <p>page 31</p>	<p>Section 2.3</p> <h1>Employment</h1>  <p>page 38</p>	<p>Section 2.4</p> <h1>Trade</h1>  <p>page 45</p>
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3. Most of these studies exclude externality costs.

4. The study considered efficiency and renewable energy options. The positive effects relate to both.

5. Both this figure on employment and the figure on GDP include the effects from other 'alternative energies' as per the original source.

6. The most conservative estimate for solar PV is at 0.4 jobs per gigawatt-hour, whereas the highest estimate for fossil fuels is at 0.2 jobs per gigawatt-hour (UK Energy Research Centre, 2014).

7. Understood as a broad measurement of human well-being, as explained in Chapter 2.

macroeconomic impacts of reaching the 2030 target of doubling the share of renewable energy<sup>8</sup> globally compared to 2010. This is in line with IRENA's previous work on the REmap analysis (see Box 3). The report analyses different cases of exogenously determined energy mixes obtained from the REmap analysis as of July 2015. They reflect varying degrees of renewable energy deployment and diverse technological focus for such deployment. Three main cases have been analysed:



- **The Reference case:** a business-as-usual case that reflects the most up-to-date official country plans under existing legislation. Where information from REmap is not available, the New Policies Scenario of the 2014 version of the International Energy Agency (IEA) World Energy Outlook (WEO) (IEA, 2014a) is used.

- **The REmap case:** the global share of renewables doubles by 2030 compared to 2010, reaching 36% in total final energy consumption. The global doubling does not imply a doubling for each country. Where information from REmap is not available, the IEA 450 parts per million (ppm) Scenario is used (IEA, 2014a).

- **The REmap Electrification case (REmapE):** the global share of renewables also doubles by 2030 but greater emphasis is placed on electrification of heating and transport, requiring a greater deployment of renewables for power generation<sup>9</sup>. For instance, electric mobility is more widely adopted instead of biofuels for cars. More power generation based on renewables is needed to meet the additional electricity demand while doubling the renewable energy share.

8. The share of renewable energy includes traditional biomass, most of which is considered to be substituted by 2030 in the REmap analysis.

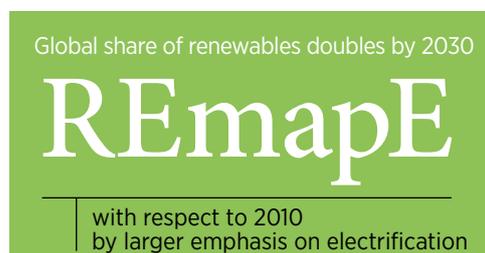
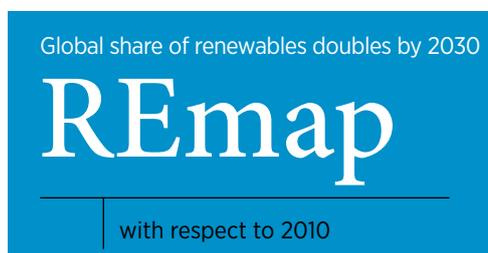
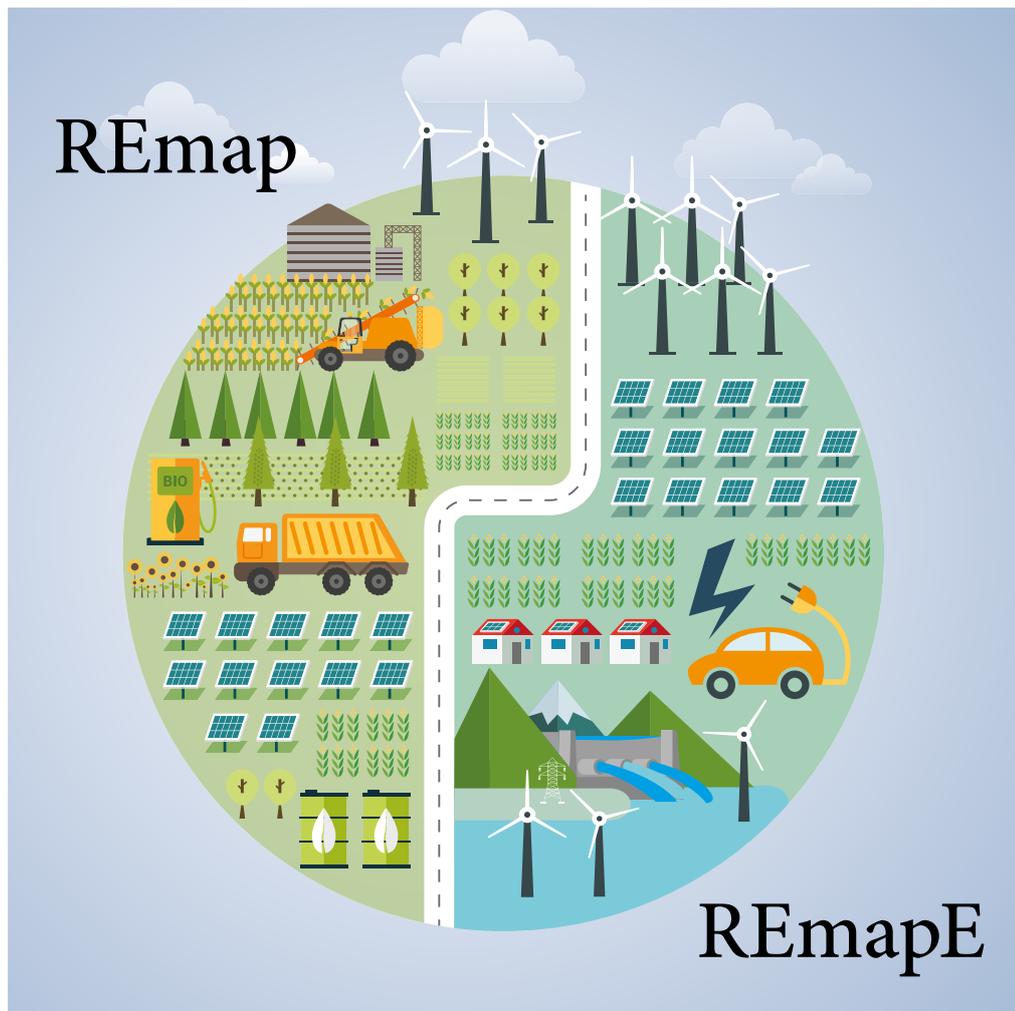
9. While this is not necessarily the case, it was assumed that more renewable power is required to achieve the overall doubling target (36% in total final energy consumption).

### Box 3: An overview of REmap 2030: A Renewable Energy Roadmap

REmap 2030 is a roadmap of technology options to escalate the share of renewables globally. It is based on official national sources of 40 countries, which account for 80% of the expected total global energy demand in 2030. This roadmap calculates the realistic potential for renewable energy deployment in these countries, taking into consideration existing technologies, their costs and the available timeframe.

(IRENA 2014, 2016 forthcoming).





This report consists of three main chapters. **Chapter 2** presents the main results of the econometric analysis of the macroeconomic impacts of renewable energy deployment at a global level. It shows the extent to which the impact of a transition to 36% renewables

would affect economic growth (GDP), welfare, employment and international trade. The approach is based on solid empirical evidence using a model employed for policy analysis in a wide range of circumstances. The analysis is based on a set of cases defined by energy

#### Box 4: E3ME, the tool used for this study

The tool used in this report is **E3ME**<sup>a</sup>, developed by Cambridge Econometrics. The main features are the following:

- It is a global simulation tool based on post-Keynesian principles, in which behavioural parameters are estimated from historical time-series data.
- It includes 24 different electricity generation technologies and 43 economic sectors. The model covers 59 countries/regions globally and allows the addition of new countries, which was necessary for the analysis.
- It enables the use of exogenous energy mixes, a key requirement to analyse the REmap cases.
- It is flexible and can be tailored to different technological, sectoral and geographical disaggregation.
- It integrates the energy system and the world's economies to provide estimates of the macroeconomic impacts of the different energy mixes.
- It has been applied extensively for policy analysis such as official assessments of the EU's 2030 climate and energy targets and the EU's long-term Energy Roadmap. In East Asia, it has recently been applied to work out possible future energy mixes and is also being used in Latin America.

To summarise, the model provides a highly suitable framework for the types of questions being addressed, and has already been validated.



*a More information can be found in [www.e3me.com](http://www.e3me.com)*

demand and supply mixes with different renewable shares. Although global in scope, the analysis also disaggregates the impacts by country or region.

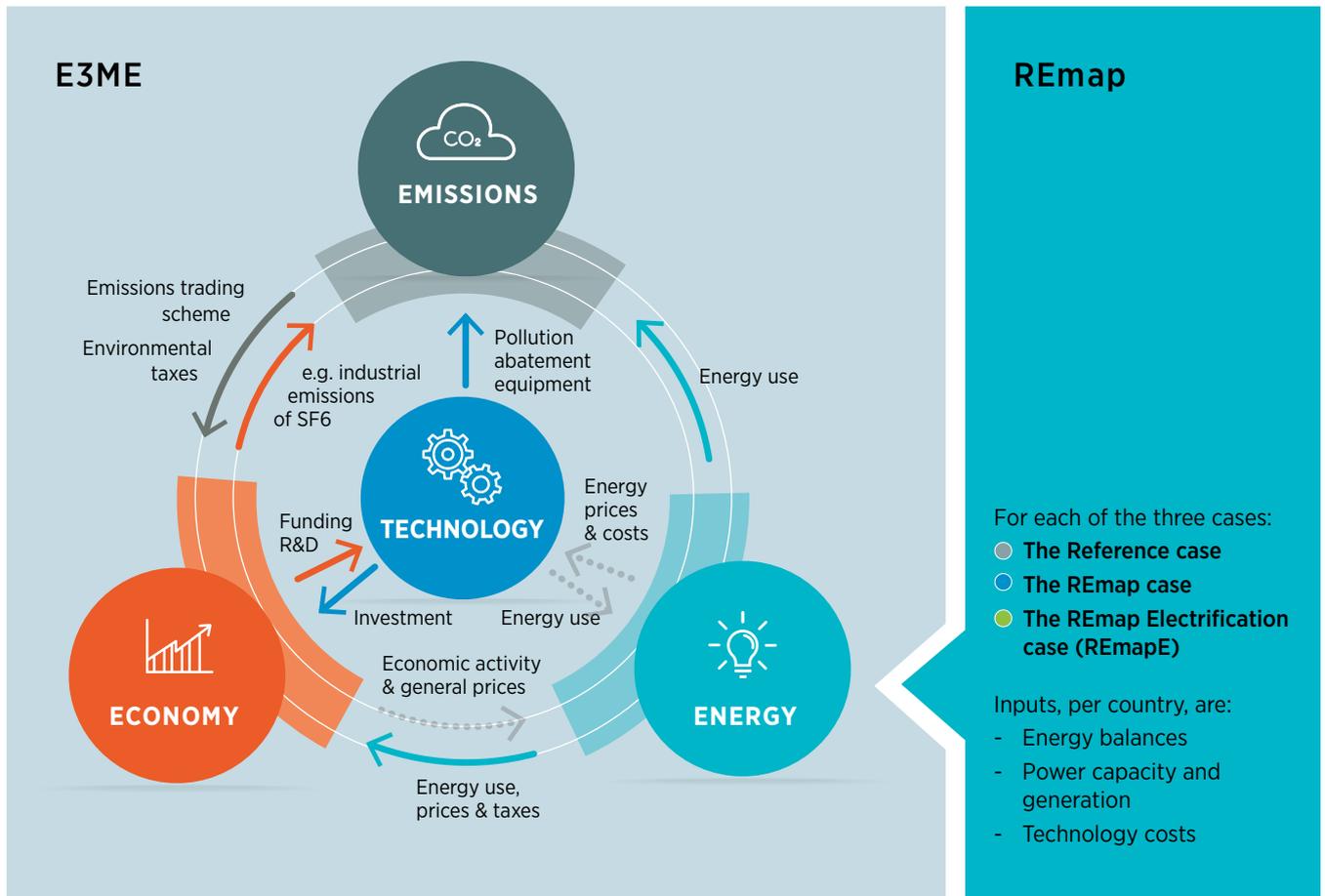
**Chapter 3** explains the approach taken to conduct the assessment. It provides details on the method used and the rationale behind the choice of the E3ME tool. It also explains the cases analysed, the sensitivity analysis<sup>10</sup> carried out and the limitations of the study.

Finally, **Chapter 4** outlines the conclusions and way forward.

### 1.3 APPROACH USED FOR THIS STUDY

This study relies on a macro-econometric approach and takes all relevant economic interactions into account within a single quantitative framework. The output results presented are thus 'net'. This means they cover impacts on all economic sectors and include both positive and negative impacts. The main strength of this approach is its foundation on a solid empirical data set; it has a proven track record of policy applications. Unlike other approaches, it allows the representation of additional policies or regulations drawing from idle economic resources, a situation often observed in reality. Furthermore, the approach takes unemployment into account, a key concern for policy makers.

This analysis uses the Cambridge Econometrics' **E3ME tool** (see Box 4) as illustrated in Figure 2. The tool connects the world's economies to estimate the macroeconomic impacts of changes to the global energy mix. It also connects the energy system with technological evolution and emissions. For the purpose of this analysis, the links feeding into the energy system, shown as dotted arrows, have been disabled to make the technology costs and energy balances<sup>11</sup> exogenous in order

**Figure 2:** Basic structure of the E3ME tool used for the analysis

to use the results from IRENA's REmap analysis.

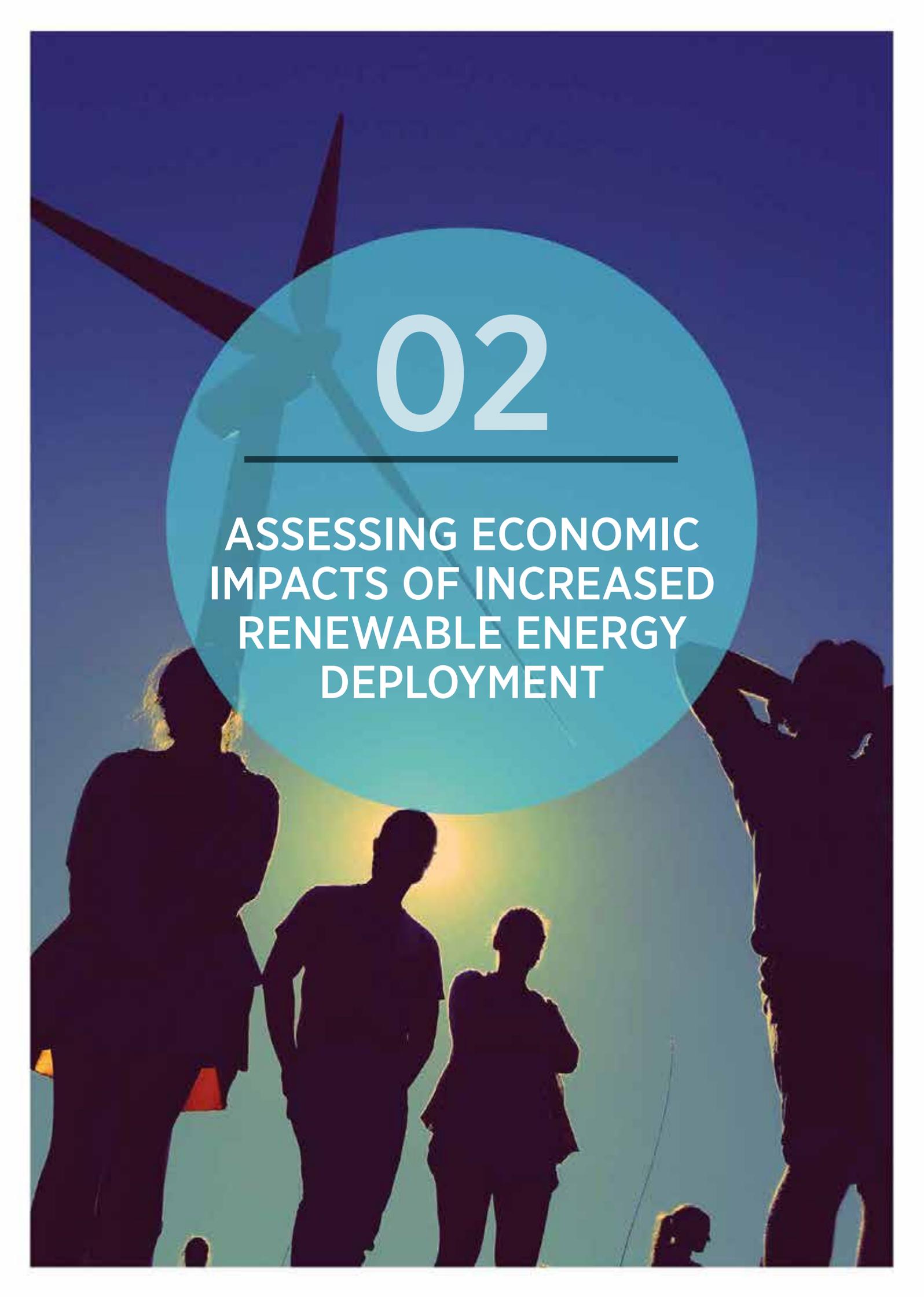
The E3ME tool is employed to estimate the macroeconomic impacts of the exogenous energy balances which are independent of technology costs and energy prices. The tool estimates electricity prices and the feedbacks to the wider economy including the price effects and changes in energy consumption. The final results obtained from the tool reflect these relationships but also take into account the main economic interactions (e.g.

employment affecting disposable income) as discussed in the chapters below.

The findings of this report will help policy makers gain a better view of the potential socio-economic benefits that can result from scaling up renewable energy deployment. Similarly, the analysis and insights presented are relevant to those in charge of informing investment decisions who also need a more complete analysis and evidence of the broad impacts of their projects.

10. A sensitivity analysis consists of repeating the same analysis while varying some of the key uncertain input assumptions. This tests whether the results and conclusions obtained hold under a range of uncertain situations. This is common practice in modelling exercises.

11. Energy balances provide a concise and sound overview of a country's complete energy sector for a specific year.



02

**ASSESSING ECONOMIC  
IMPACTS OF INCREASED  
RENEWABLE ENERGY  
DEPLOYMENT**

# ASSESSING ECONOMIC IMPACTS OF INCREASED RENEWABLE ENERGY DEPLOYMENT

The energy sector contributes to economic activity in two ways. Firstly, energy is an important economic sector that creates jobs and value by extracting, transforming and distributing energy goods and services throughout the economy (World Economic Forum, 2012). Secondly, the energy sector's impact ripples through the rest of the economy. Energy is an input to nearly every product and service in the economy and underpins the economic activity across each of its sectors.

Faced with the twin challenges of sluggish economic growth and the mounting imperative to decarbonise economies, countries are looking for solutions to improve their economic performance while minimising further greenhouse gas emissions. Given this context, renewable energy is emerging not only as a solution to meet growing energy demand while sharply reducing carbon emissions but also as a potential engine for economic growth and diversification.

This resonates strongly with the objective of green growth<sup>12</sup>, which is probably the only way to satisfy the needs of a growing population and drive development and well-being, while reducing greenhouse gas emissions and increasing natural resource productivity. Advancements in technology and growing cost-competitiveness has meant that renewables now offer governments the option to pursue such a vision for the energy sector and reduce the traditional trade-off between economic growth and environmental conservation

The transition to an energy system based on renewables is a unique opportunity. It could balance the demand for sufficient energy to power economic growth and development with the urgent need to sharply reduce carbon emissions. A global consensus is emerging on the need to realise this opportunity illustrated through the pledges submitted to the UN Conference of the Parties (COP21) in Paris as well as through national renewable energy targets that now exist in 164 countries (IRENA, 2015b). Indeed, the energy sector transformation is underway with renewable capacity additions in the power sector already exceeding those of conventional options since 2011.

The implicit relationship between the energy sector and the economy raises questions on the economy-wide impacts of the ongoing energy sector transformation. As discussed earlier, some national studies have quantified the impacts on GDP and employment, for instance, to inform the national dialogue. However, analytical work and empirical evidence on this important subject remains relatively limited, especially at the global level.

National renewable energy targets exist today in

164 countries

<sup>12</sup> The Organisation for Economic Co-operation and Development (OECD) (2011) defines green growth as: "fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies."

This study is the first to quantify the global macroeconomic impacts of renewable energy deployment targets. This chapter presents the main findings of the analysis, displaying impacts on economic growth (GDP), welfare, employment and international trade from doubling the share of renewables by 2030. The methodology behind the findings is presented in detail in Chapter 3.

## 2.1 RENEWABLES DEPLOYMENT INCREASES GLOBAL GDP

This section provides a framework for understanding the greater economic role of renewable energy through its impact on GDP<sup>13</sup>. As the most common measure of economic development and growth, IRENA estimated its impacts as part of the analysis.

The findings show that doubling the share

of renewables in the final global energy mix increases global GDP in 2030 between 0.6% and 1.1% compared to business as usual (Reference Case)<sup>14</sup>. The increase amounts to between USD 706 billion and USD 1.3 trillion<sup>15</sup>.

The magnitude of the impact is broadly consistent with the results obtained by national studies conducted to date (see Box 5). The subsequent sensitivity analysis to test the results is discussed in Chapter 3.

When renewable energy is doubled to 36% (REmap Case), global GDP increases by 0.6% in 2030, which equates USD 706 billion.<sup>16</sup> This is equivalent to the combined economies of the Colombia and Malaysia as of today. The scale of GDP impacts varies across countries (see Figure 3). In the first IRENA case for doubling the share of renewables – the REmap Case – Japan experiences the greatest positive impact (2.3%). This results from a large investment in solar PV and substantial reduction of fossil fuel imports. Australia, Brazil, Germany, South Korea, Mexico and South Africa also experience positive impacts amounting to more than 1% of GDP. Many other countries, including large economies such as China, France, India, the UK and US, also benefit from positive impacts, though with less than 1% (0.2% in China and around 0.9% for the others). Most of these positive impacts on GDP can be explained by the increased investment required by renewable energy deployment, which triggers ripple effects throughout the economy.

A few countries face a decline in GDP in line with their vulnerability to the dynamics of global fossil fuel markets. Oil and gas exporters such as Saudi Arabia, Russia, Nigeria and Venezuela



13. GDP measures supply and demand based on the value of goods and services produced and traded in a country during a given year. GDP is therefore the addition of a country's individual consumption expenditures (household payments for goods and services), governmental final demand (public expenditure on the supply of goods and services), net exports (exports minus imports) and investment (gross capital formation) (Mankiw, 2003).

14. This refers to a figure for GDP in 2030 that is 0.6% larger than in the Reference Case. It should not be confused with an addition of 0.6% to annual GDP growth between 2016 and 2030.

15. At 2015 prices.

16. At 2015 prices.

face reductions in their export volumes in the long term. Given the high share fossil fuels play in their GDP, the reduced trade in these fuels are expected to have effects on their economies. The global deployment of renewable energy affects fossil fuel exporters according to the degree of diversification in their economies.

In general, large oil and gas exporters rely on their energy sectors more than coal exporters rely on coal. The oil and gas sector, for example, represents around 25% of GDP in Saudi Arabia and Venezuela, and around 15% in Nigeria and Russia. By contrast, coal is around 8% of GDP in Australia and 5% in South Africa (World Bank, 2015a; Devaux 2013; Australian Bureau of Statistics, 2012; South Africa Embassy, 2013). As a result, coal exporters in general are less affected by an increase in renewables. Whereas oil and gas exporting countries Saudi Arabia and Russia face a GDP decline of 2% and 0.7% respectively, coal exporters Australia and South Africa experience a GDP improvement. Some of these countries could, however, become bioenergy exporters (e.g. Russia). In this case, the GDP impact could be better than seen here<sup>17</sup>.

The high dependency of oil and gas exporting countries on export revenues and the vulnerability to potential oil price reductions creates economic fragility. The present situation is a case in point: GDP growth in Saudi Arabia is expected to slow down from 4%-5% in 2013/14 to below 3% in 2015 and 2016, according to the International Monetary Fund (IMF, 2015). This is not a foregone conclusion. Countries exporting oil and gas could embrace renewable energy deployment as an opportunity for economic diversification and positioning in the new markets that will be created. In addition, renewable energy deployment could be an opportunity to reduce domestic fossil fuel consumption. This could be achieved by

#### **Box 5:** How do the study results compare with other studies?

This study is the first to concentrate exclusively on the macroeconomic impacts of increasing renewables deployment at the global level. However, many previous studies have either included renewables as part of a broader package of energy/climate policy or have assessed the impacts of additional renewables in a particular country. The results of this study are broadly in line with other studies looking at renewables impacts on GDP (see Box 2), notwithstanding methodological differences. For example, positive impacts on GDP in European countries are in line with a European Commission study conducted in 2014 that estimated impacts at around 0.5% (although the study includes the economic effects of energy efficiency as well). The results are also similar to the ones emerging from previous studies on other countries, such as Germany and the US.

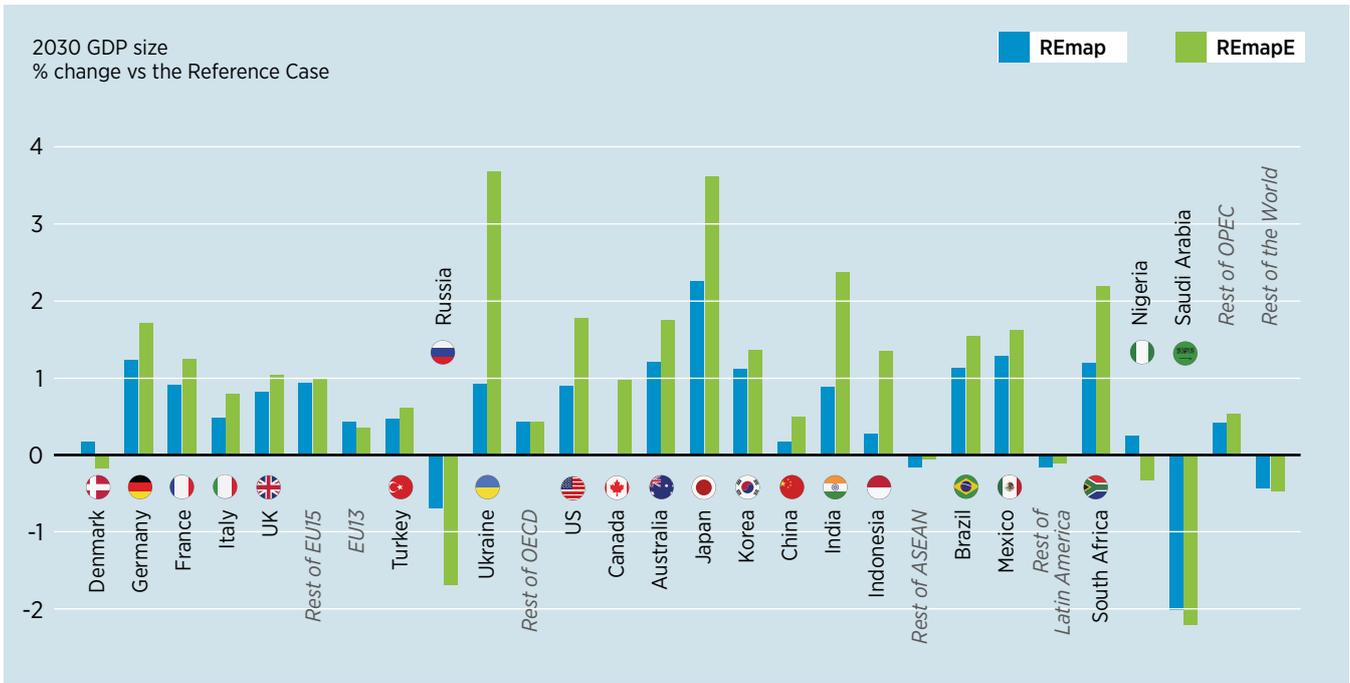
integrating renewable energy into an overall strategy which also includes the increase of energy efficiency. This is already in progress in some of the countries analysed in this report (IRENA, 2016a).

#### **Box 6:** Differences between GDP impacts in REmap and REmapE

The results show that the REmapE Case could provide a higher GDP improvement than REmap. This is mainly because the REmap analysis assumes that a large share of bioenergy comes from agricultural and forestry residues, thereby not creating additional output in the agriculture and forestry sectors. If the activities of producing, collecting, treating and transporting the different types of bioenergy are considered (as per IRENA, 2014c), GDP increase in the REmap Case would amount to 0.85% instead of 0.6% (the latter figure can therefore be considered a conservative estimate).

<sup>17</sup> Bioenergy trade is not represented in the analysis due to challenges highlighted in Chapter 3.

**Figure 3:** GDP impacts (2030 GDP size, % change vs the Reference Case)<sup>18</sup>



When renewable energy is doubled through a higher rate of electrification of final energy uses and lower reliance on bioenergy, the increase in global GDP is even higher (see Box 6).

It amounts to 1.1%, which equates to USD 1.3 trillion.<sup>19</sup> This is the second case analysed in this report i.e. REmapE. This increase is equivalent to the combined economies of South Africa, Chile and Switzerland today in the global economy. In most cases, the additional investment leads to higher levels of output and GDP. Several countries are notable for having a large positive impact on GDP due to higher investment, including Ukraine (3.7%), Japan (3.6%), India (2.4%), South Africa (2.2%), the US (1.8%) and Australia (1.7%) as shown in Figure 3. As in the REmap Case, oil and gas exporters also face a GDP decline which is slightly larger since global demand for oil is further reduced by the electrification of heat and transport.

In the electrification case, the positive impacts are generally greater and mainly reflect the higher amounts of investment required.

Scenario	% Change	Value	Equivalent to
REmap	+0.6%	+706 billion USD	= current GDP from Colombia + Malaysia
vs.			
REmapE	+1.1%	+1.3 trillion USD	= current GDP from Chile + South Africa + Switzerland

18. The country grouping presented in the results is determined by the geographical resolution and aggregations in the E3ME tool. These in turn depend on data availability. The order of the bars is, to the extent possible, geographical.

19. At 2015 prices

Renewable energy investments, however, could 'crowd out'<sup>20</sup> investment in other economic sectors, and in this case the GDP impacts could eventually turn slightly negative (see Box 7). In other words, the electrification case yields a higher but slightly riskier improvement in GDP depending on whether renewable energy crowds out investment in other economic sectors (see Chapter 3 for more detail).

### ENERGY SECTOR INVESTMENTS AS A KEY DRIVER OF GDP GROWTH

A number of factors influence the GDP growth estimated in this study, including investment in renewable energy deployment, fossil fuel production and trade, and electricity prices (see Box 8). Investments in particular influence GDP growth the most, triggered by the capital-intensive nature of renewable energy technologies compared to alternative options. Most of the total cost of renewable energy plants is used for the upfront investment on physical assets, as opposed to fuel expenditure throughout the lifecycle of the plant.

As the demand for energy grows, proportionate investments in energy infrastructure will be needed. To avoid lock-in with unsustainable energy systems, and realise the potential benefits on offer, energy sector investments will increasingly need to be directed towards renewable energy. Investment in renewable energy across all sectors needs to be scaled up substantially.

The power sector will continue to attract the majority of new investment. This report estimates the investments based on the installed capacities per year, technology and country for each of the three cases; as well as the capital costs, discount rates and other parameters required for each technology in each country and year.

#### Box 7: Financial crowding out can significantly affect GDP results

A large share of GDP growth is driven by the increased investments needed to deploy the high capital needs of renewables. Some of these investments are financed through bank lending, potentially competing with lending to other productive sectors (i.e. crowded out). A sensitivity analysis was conducted to examine this effect (see Chapter 3). The results show that in the case of a full crowding out, GDP impacts could become marginally negative (-0.02% in REmap and -0.06% in REmapE as opposed to +0.6% and +1.1%). In the case of partial crowding out, the results are positive. In conclusion, unless the financing of renewables competes 100% with investments in other productive sectors, GDP impacts are expected to be positive.

The results suggest that global annual investment in renewable power capacity in the REmap Case would need to be in the range of USD 500 billion to USD 750 billion between now and 2030. These results are broadly in line with earlier investment analysis presented in IRENA's *REthinking Energy: Renewable Energy and Climate Change*, which showed that annual investments in the power sector should reach at least USD 400 billion up to 2020 and USD 600 billion for the decade up to 2030. (see IRENA, 2015c for further details). The investment needs will be higher when the doubling is achieved through greater electrification of heat and transport.

The projected increase in investments in renewable power yields a global economy-wide rise in annual investment of 1.8% in the REmap Case and 3.1% in the REmapE Case by 2030 even when accounting for reduction in investments by the oil and gas sector. In other words, the increased investment in the power sector outweighs the reduced investment in

20. "Crowding out" of capital refers to the possibility that the investments needed for increased renewable energy deployment compete with and displace investments elsewhere in the economy (e.g. in the manufacturing sector). This can have a negative effect on GDP.

**Box 8:** Impact of fossil fuel production, trade and electricity prices on GDP growth

Reduced global demand for fossil fuels depresses the GDP of countries exporting and producing fossil fuel. This concerns oil and gas exporters more than coal exporters. This is because oil/gas production in countries rich in hydrocarbon generally accounts for a higher share of their GDP than is the case for coal in countries producing coal. In producing/exporting countries, activities related to the extraction and supply of fossil energy are expected to fall in line with exports, leading to reductions in GDP. On the other hand, fossil fuel importers, such as Japan, are likely to see an improvement in their trade balances. These impacts are discussed in detail in the trade section later in the chapter.

Electricity prices change in response to the different shares of technologies with different levelised costs in the power mix. By 2030, some renewable technologies are expected to have lower generation costs than conventional ones, contributing to a decrease in electricity prices as the share of renewable energy grows. Lower electricity prices can decrease inflation, increase real incomes and household consumption, and boost economic activity in electricity-intensive sectors.

the oil and gas sectors, raising overall economy-wide investment and having a positive impact on GDP. These effects are enough to create a positive GDP impact in some countries exporting fossil fuels, such as South Africa.

The positive impacts on GDP can be considered similar to a Keynesian stimulus, i.e. investment directed at any economic sector would boost GDP. Substantial investment in the energy sector will be needed in any case to meet

growing demand for energy. When the energy demand is met with renewables, the investment brings economic benefits as well as for the environment, energy security and energy access. A question that could arise is whether the investments in renewable energy would yield a better return to society if directed at other sectors, such as education. This comparative analysis is out of the scope of the present report, which focuses on assessing the macroeconomic effects of a doubling in the share of renewable energy by 2030.

Realising the observed positive macroeconomic effects requires bridging the investment gap. Even as the investment needs rise considerably to 2030, current trends indicate that investment in the sector is expected to remain at around the same level as today (around USD 280 billion in 2014). Public funding will continue to act as an important catalyst and will need to increase. It is expected that the share of public funding would remain at 15%, which still represents a substantial increase in absolute terms given the growth in investment needs in the renewable power sector.

The lion's share of new investment in renewables will have to come from the private sector. This is achievable if a strategy is pursued that focuses on risk mitigation instruments and other financing tools. These would stimulate a strong pipeline of projects and unlock private project financing and refinancing opportunities. The strategy needs to be adapted to each phase of renewable energy project cycle (planning, construction and operation) and include private

Increase in economy-wide investment for **REmap** and **REmapE Case**:

**+1.8 to +3.1%**



and public actors. Today's investment decisions could lock in power systems and associated emissions for decades. This means that in the short term, greater focus must be placed on the planning phase to guarantee attractive renewable energy projects are in the pipeline (see Box 9).

### CHANGES IN ECONOMIC STRUCTURE

The importance of the investment effect is felt not only in the overall GDP changes (global or by country) analysed above but also at the sectoral level. The general economic improvement caused by renewable energy deployment causes most economic sectors to increase their output but the benefits are greatest in sectors that produce investment goods and services. These are linked to renewable energy equipment manufacturing and installation.<sup>21</sup>

These sectors include companies predominantly in the construction, manufacturing and engineering sectors, in which output levels nowadays depend on volatile demand for investment goods and services. These sectors in many countries have still not fully recovered from the lasting effects of the financial crisis

#### Box 9: IRENA initiatives to improve renewable energy project planning

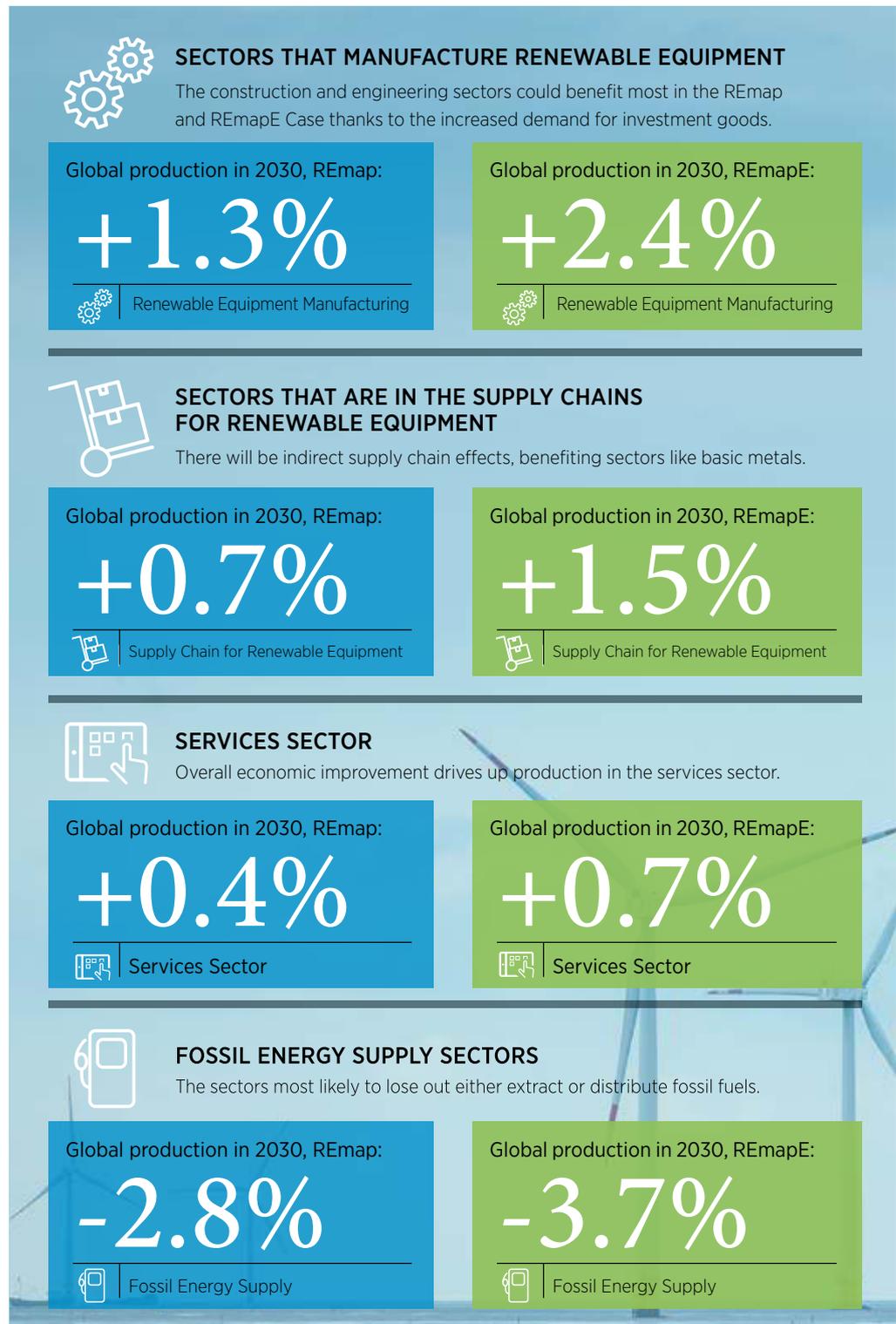
IRENA's Project Navigator and Sustainable Energy Marketplace tools, and the Regulatory Empowerment Project are designed to contribute to the objective of building a strong pipeline of projects. The Project Navigator provides project developers with knowledge, tools, case studies and best practices, while the Marketplace offers a virtual platform that brings together project developers and investors to facilitate exchange of investment opportunities. The Regulatory Empowerment Project provides targeted technical assistance to regulatory decision makers to help them overcome existing governance gaps to reduce investment risks (IRENA, 2015d).

and subsequent recession. They have also been negatively affected by the more recent slowdown in parts of the developing world. These sectors could therefore have spare capacity available to increase their output in the short term. Their economic output<sup>22</sup> is estimated to increase by 1.3% in the REmap Case and by 2.4% in the REmapE Case in 2030 (see Box 10).



21. The tool used for the analysis in this report includes a disaggregation of 43 sectors, which are linked both to each other (e.g. showing supply chain effects) and to the different power generation technologies. In this way, the results provide estimates of how each sector is affected on the basis of its interactions with the power sector and the wider economy.

22. Measured in constant 2015 USD

**Box 10:** Sectoral impacts in the two REmap Cases

Increased activity in these sectors has ripple effects on the rest of the economy because the construction, manufacturing and engineering sector supply chains are also likely to benefit. Notable examples include basic metals and non-metallic mineral products (e.g. silicon), which provide the materials used for manufacturing renewables equipment. Economic output increases by 0.7% in the REmap Case and by 1.5% in the REmapE Case by 2030 in these sectors. The supply chain effects can be traced further back to the primary (non-energy) extraction sector, although in macroeconomic terms this is a relatively small industry.

Output also increases by 2030 in the services sectors by 0.4% in the REmap Case and 0.7% in the REmapE Case. Some of the service sectors make up part of the supply chains for renewables (e.g. planning or transport). However, most of the impact on the services sectors are the result of induced effects, i.e. improvements in the wider economy. For example, if electricity prices fall there is an increase in real household income, which can stimulate activity in the retail or hospitality sectors. Changes in service sector activity can make a significant difference to the induced employment results because many of these sectors are relatively labour-intensive.

The main negative impacts occur in the fossil fuel industries, extraction, oil refineries and distribution chains. As overall demand for fossil fuels falls, these sectors are all affected. At a global level the value of their output in real terms declines by 2.8% and 3.7% in the REmap and REmapE Case respectively compared to the Reference Case.

## 2.2 RENEWABLE ENERGY IMPROVES WELFARE

In the current global economic scenario, policy options need to be designed to maximise social benefits in terms of incomes, health, education, employment and general human well-being. Welfare is an important alternative to GDP as a way of considering the effects of increased renewable energy deployment (see Box 11). Welfare measures can include sustainability as an additional dimension, particularly in view of an economy's ability to support chosen development paths with a finite natural resource base over the long term (Daly and Cobb, 1989). This resource sustainability component is important because conventional measures of welfare, including GDP, offer only a snapshot of some of the factors defined as socio-economic welfare. GDP is therefore unable to account





### Box 11: GDP and other measures of welfare

GDP provides a standard measure for comparing economic output levels in different countries. However, it is known that GDP and variants such as Gross National Product cannot be employed to infer estimates of broader economic welfare, as first observed by Simon Kuznets in the 1930s. Many activities add to welfare but are excluded from GDP (e.g. leisure time). Others add to GDP but not to welfare. For example, cleaning up after an oil spill increases economic activity and GDP but human welfare is not better off than before the spill. Another relevant example is the depletion of non-renewable natural resources. A country could increase its GDP by extracting more natural resources but this reduces the resources available for future generations (World Bank, 2011; UN University - International Human Dimensions Programme (UNU-IHDP) and United Nations Environment Programme (UNEP), 2014).

In the last few decades, significant work has been carried out within sustainable development discussions trying to propose better indicators of human welfare. In 1990, the United Nations Development Programme (UNDP) developed the Human Development Index (HDI). It expands the measurement of income to incorporate health and education.<sup>23</sup> For instance, its results show that a country such as Australia ranked 20th in the world today in terms of GDP per capita, but comes second in terms of HDI (UNDP, 2014). Countries like Rwanda have significantly improved their HDI not as a consequence of higher GDP but higher life expectancy and longer schooling periods (UNDP, 2013).

Other institutions, including the World Bank, the OECD and the EC, have also worked on broader welfare measurements. The EU 'Beyond GDP' initiative builds on the work led by Nobel laureate Joseph Stiglitz and carried out for the French government.<sup>24</sup> The World Bank adds the economic values of natural capital to the most commonly used value of produced capital.<sup>25</sup> This includes agricultural land, protected areas, forests, minerals and energy resources. Intangible capital, such as institutional, social and human capital, is another category added by the World Bank. Studies based on this measure find that intangible capital is the largest and fastest growing form of capital thanks largely to educational advances in large developing countries (World Bank, 2011).

The recent Inclusive Wealth Report 2014 by the UN confirms the importance of human capital improvements since 1990. It shows that inclusive wealth can be significantly greater than GDP (e.g. ten times larger in the USA). It also shows how the inclusive wealth of a few countries has been reduced despite GDP improvements, due to the exhaustion of non-renewable natural resources (UNU-IHDP and UNEP, 2014). The latest milestone in this field is the adoption in 2015 of the 17 UN Sustainable Development Goals, which outline targets far broader than GDP alone (UN, 2015).

The broad body of existing work does not, however, reach a consensus on how to measure human welfare. Recent academic studies have compared the various measures (Giannetti et al., 2014). Some have concluded that welfare indicators should not replace but should complement GDP (Chancel et al., 2014).

for factors such as natural resource depletion and additional costs caused by health and environmental damage related to an economy's chosen development path.

A review of the existing literature on welfare indicators has been used to identify three dimensions required for a comprehensive analysis. These are economic (consumption and investment in productive capital), social (including human capital improvements through health and education), and environmental (including the depletion of natural resources through consumption of materials). To explore the welfare impacts of increased renewable energy deployment, trying to go beyond the purely economic aspects captured by GDP, this report adopts a composite indicator of human wellbeing, comprising the three dimensions.

The proposed indicator includes, for the economic dimension, both consumption and investment, whereas other analyses base welfare only on consumption. This helps consider both

Doubling the share of renewables increases welfare

**+2.7 to +3.7%**



well beyond GDP growth

current consumption as a measure of present welfare and benefits resulting from a future more efficient and sustainable economy where investment is counted as future consumption. On the social dimension, the proposed indicator includes a measure of expenditure on health and education. Health impacts from local air pollution are subtracted from this value. Lastly, the environmental impacts are summarised through greenhouse gas emissions<sup>26</sup> and material consumption. In order to aggregate the components, the results for each are provided separately. Depending on the priorities, different weights can be attributed to derive

**Economic dimension**

- +  Consumption and Investment

**Social dimension**

- +  Employment
- +  Spending on health and education  
minus health impacts from local air pollution

**Environmental dimension**

-  Greenhouse gas emissions
-  Material consumption



**Welfare**



23. The latest methodology of the HDI (from 2010 onwards) is based on three sub-components: Gross National Income per capita (in USD purchasing power parity), life expectancy at birth and an education index composed of mean and expected years of schooling.

24. The English version can be found here: [http://www.insee.fr/fr/publications-et-services/dossiers\\_web/stiglitz/doc-commission/RAPPORT\\_anglais.pdf](http://www.insee.fr/fr/publications-et-services/dossiers_web/stiglitz/doc-commission/RAPPORT_anglais.pdf)

25. Comprising all human-made machinery, equipment and structures.

26. No climate feedbacks are included in the GDP estimates, as is standard in macroeconomic modelling exercises. There is therefore no double counting.

**Table 1:** Impact on welfare in main cases showing sensitivity with full crowding out (% from the Reference Case)<sup>27</sup>

	Weighting	REmap (main case)	REmap (with full crowding out)	REmapE (main case)	REmapE (with full crowding out)
<b>Economic dimension</b>					
 Consumption + Investment	1/3	0.7	0.0	1.2	-0.2
<b>Social dimension</b>					
 Employment	1/6	0.1	-0.1	0.2	-0.2
 Health and education	1/6	1.8	1.5	2.1	1.4
<b>Environmental dimension</b>					
 Greenhouse gas emissions <sup>28</sup>	(-) 1/6	-11.2	-11.2	-15.7	-15.7
 Material consumption	(-) 1/6	-1.6	-1.7	-1.9	-2.2
<b>Total welfare impact</b>		<b>2.7</b>	<b>2.4</b>	<b>3.7</b>	<b>3.1</b>

alternative values. In this report, equal weight is given to the economic, social and environmental dimensions (see Chapter 3).

The impact of renewable energy deployment on global welfare is positive, increasing by 2.7% (compared to 0.6% GDP improvement) if the share of renewables doubled. It would rise by 3.7% (compared to 1.1% GDP improvement) if achieved through the higher electrification of heat and transport. In other words, the benefits of renewable energy go beyond the traditional

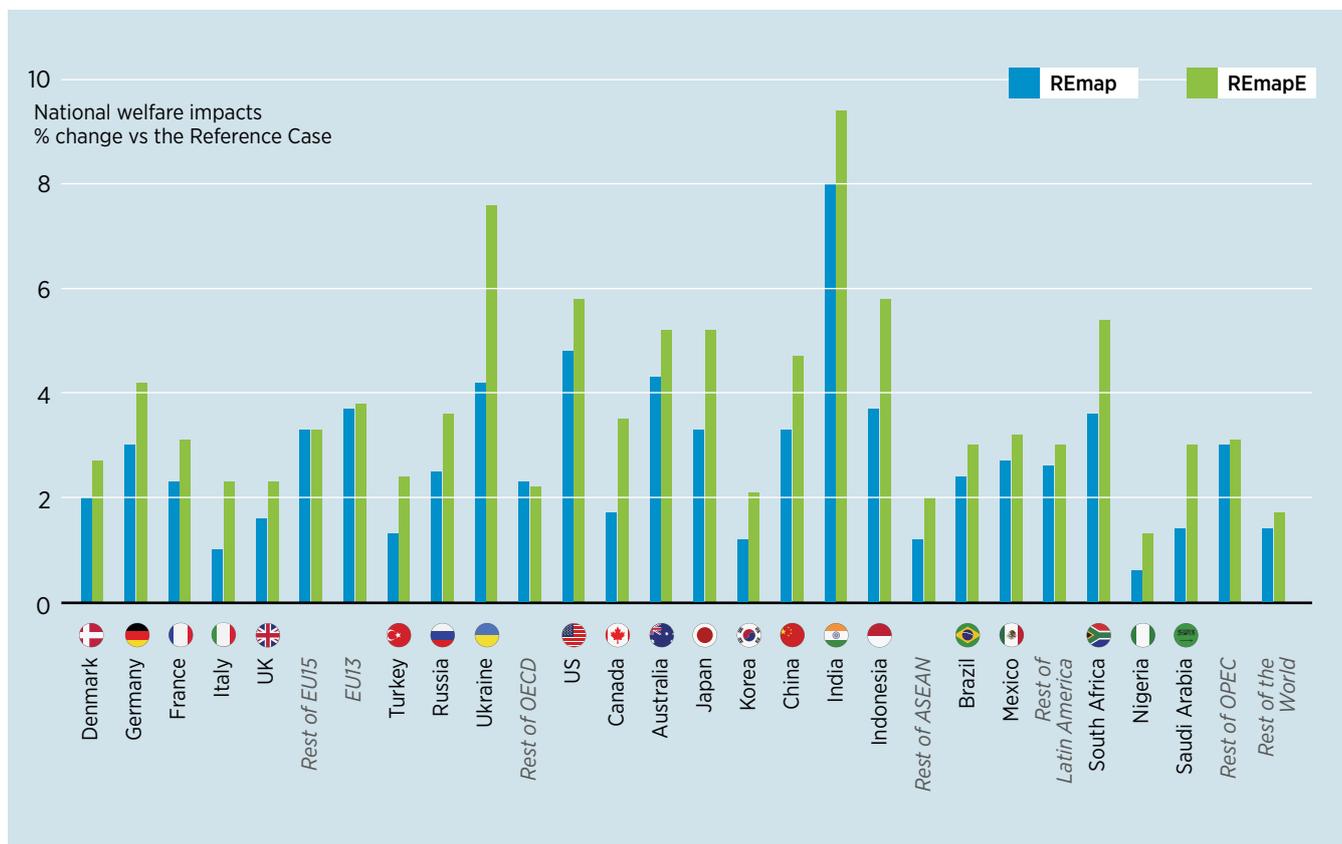
and limited measurements of economic performance. They improve human welfare in a much broader manner and in a way that allows for future long-term growth and positive socio-economic development (Table 1).

The largest contributor to growth in this measure of welfare is the significant reduction of greenhouse gas emissions by 2030 (11% and 16% in the REmap and REmapE Cases respectively), followed by improved health and education and a reduced material consumption.

27. All the figures are expressed as percentage difference from the Reference Case, and the weightings are applied to obtain the total welfare impact (bottom row). A negative weighting is applied to the environmental indicators, where lower results indicate increased welfare.

28. Includes all greenhouse gasses. There is no valuation involved since the proposed welfare indicator, as explained in Chapter 3, calculates percentage changes of each sub-indicator in its own units (tonnes of CO<sub>2</sub> equivalent in the case of greenhouse emissions).

**Figure 4:** National welfare impacts (% difference from the Reference Case)



Environmental effects, currently not priced into most global economic systems, hence play an overwhelming role in improving overall welfare. If the weighting across the different dimensions were changed (e.g. to put a higher weighting on economic outcomes), the estimated total welfare impacts would be lower overall but would remain higher than the GDP impacts.

Intuitively, these results are not surprising. Some of the highest costs incurred by our economies include implicit economic losses through natural disasters caused by climate change, for example, or political conflicts over access to scarce natural resources. An overall improvement in the economy including growth in GDP at an aggregate level and per capita, as well as job creation, also increases tax collection

and disposable income, with some of these additional resources being spent on health and education. Reinforced by the reduced negative health effects from air pollution, there are improvements on health and education components by around 2% in both cases.

Unlike when GDP is considered on its own, the welfare increase holds strong against the crowding out of capital, the most relevant sensitivity (see Chapter 3). This is primarily due to the continuously large positive effect of renewables deployment on greenhouse gas emissions reduction and, to a lesser extent on material consumption.<sup>29</sup> This result suggests that overall social welfare benefits are relatively independent from simple measures of economic growth such as GDP. Welfare improvements will

*29. Interestingly, where investment is displaced, material consumption is further reduced due to the decrease in investment and economic activity throughout the economy.*

**Box 12:** Role of renewables in achieving universal access to modern energy services

Renewable energy solutions are well suited to expanding modern energy services in a timely and cost-effective manner. An estimated 60% of the additional power generation required to achieve universal electricity access is projected to come from off-grid solutions – including both stand-alone and as mini-grids. Both are now among the most economic options for expanding access to many rural areas (IRENA, 2014d). These solutions can be deployed rapidly and customised to local needs. They offer an attractive option for electrifying areas where grid extension is technically or financially unviable.

Off-grid renewable energy solutions are already deployed at scale bringing with them a wide array of socio-economic impacts. In Africa, where about 600 million people lack access, more than 28.5 million benefit from solar lighting products (Lighting Africa, 2015). Bangladesh has deployed over 3.86 million solar home systems, and these now provide basic electricity access to around 14% of the country's population. More than 65,000 solar home systems are now installed every month under the programme. The programme replaces 180,000 metric tonnes (t) of kerosene per year, which has an estimated value of USD 225 million. Moreover, around 70,000 people are directly or indirectly employed in the off-grid solar sector.

of course differ by country (Figure 4) but they are overall positive.

The highest welfare improvements are observed in countries such as India, Ukraine, the US, Australia, Indonesia, South Africa, China and Japan. This is primarily a response to the reduced health impact of air pollution and greenhouse gas emissions reductions. Developing economies are thus as likely as industrialised economies to benefit from changes to their economies from more substantial renewable energy deployment, assuming similarly conducive policy frameworks.

**POSITIVE EFFECTS OF ENERGY ACCESS THROUGH RENEWABLES**

Energy access plays an important role in analysing welfare. Access to reliable, cost-effective and environmentally sustainable energy can have a multiplier effect on development. This is the case for reduced health effects, improved livelihoods, poverty alleviation, job creation, gender equality and enhanced access to water and food. This cross-cutting impact of energy is at the centre of the global discourse on the recently agreed Sustainable Development Goals. Globally, there are nearly 1.1 billion people who lack access to electricity and nearly 2.6 billion who rely on traditional biomass for heating (IEA and World Bank, 2015).

At the current pace of expansion, it is estimated that nearly 1 billion people will still lack access to electricity in 2030 and 2.5 billion will still be relying on traditional biomass for cooking (IEA, 2013). Achieving universal access would require annual investments to increase from the current USD 9 billion annually to nearly USD 50 billion (IEA and World Bank, 2015). This means substantial development impacts can be realised from investments in access delivery as well as from the downstream economic effects. These impacts are specifically relevant to this analysis given the vital role renewable energy will play in meeting the objective of universal access to modern energy services (see Box 12).

Accounting for renewable energy deployment for expanded energy access would increase the welfare and other benefits estimated in this report even further. Over the past decade, several institutions have attempted to develop more comprehensive quantitative approaches for measuring access as well as its multi-faceted impacts. However, all these measures are based on existing data, which are inherently limited in scope. Despite this lack of data, there is growing evidence that off-grid renewable energy technologies can create significant

value. This is related to additional household income and employment opportunities, both in the renewable energy supply chain and in downstream enterprises.

Few studies have attempted to quantify or consider these positive effects, despite universal acknowledgement of the vital contribution of access to modern electricity to socio-economic development and economic growth. Some examples include the literature on renewable off-grid and mini-grid solutions in Southeast Asia, where energy poverty continues to be widespread among many rural communities (Bose et al., 2013; Mazumder et al., 2011; Khandker et al., 2009, World Bank, 2008). The costs and benefits of rural electrification can vary substantially between countries, thus limiting an extrapolation of case-based evidence for a global analysis. This report therefore

does not include an estimate of the impact of improving energy access while acknowledging its potentially large positive impact.

IRENA's report *The Socio-economic Benefits of Solar and Wind Energy* presented a specific conceptual framework for analysing socio-economic effects in the context of energy access (IRENA and CEM, 2014). A brief exploration of such a conceptual framework highlights the need for a comprehensive approach to collecting new data and analysing and disseminating the multi-faceted effects of energy access initiatives. IRENA's continuing analysis builds the knowledge base on the socio-economic impacts of off-grid renewable energy.



**Box 13:** IRENA's work on renewable energy employment

Job creation is gaining prominence in the global renewable energy debate and represents a key argument strengthening the business case for renewables. IRENA's work on renewable energy jobs (IRENA, 2011, 2012a&b, 2013a&b, 2014a and 2015a) helps bridge the knowledge gap on the topic. It provides a comprehensive view of the various dimensions of renewable energy employment such as the current status and trends, future prospects, enabling policy frameworks, education and training requirements and energy access.



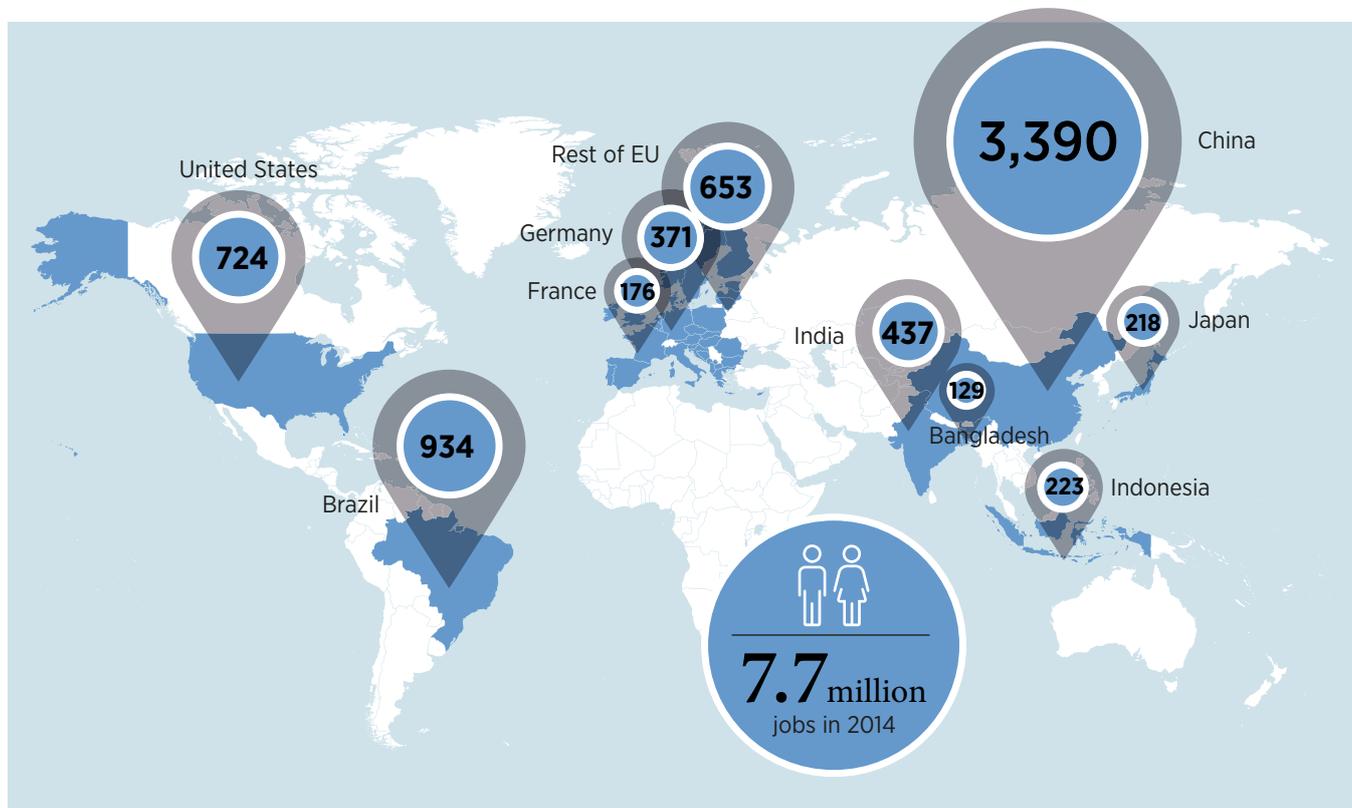
### 2.3 DOUBLING RENEWABLES CREATES MORE JOBS

Jobs are instrumental to achieving economic and social development. Beyond their critical importance to wage generation and individual well-being, they are the core of many broader societal objectives, such as poverty reduction, economy-wide productivity growth and social cohesion. The development benefits from job creation include skills acquisition, female empowerment and improved stability in post-conflict societies. Jobs that contribute to these broader goals are valuable not only for those who hold them but for society as a whole (World Bank, 2012). It comes as no surprise, then, that job creation has been and will continue to remain a key priority for governments.

The creation of employment opportunities will be instrumental in ensuring sustainable growth in GDP and welfare. The global employment gap, which measures the number of jobs lost since the start of the 2008 economic crisis, currently stands at 61 million. If new labour market entrants are taken into account, an additional 280 million jobs need to be created by 2019 to close the employment gap (International Labour Organization, 2015). The employment gap has a ripple effect throughout the economy which also illustrates the intimate interconnections between employment, wages, household consumption and aggregate demand.

Globally, the energy sector has played the dual role of fuelling economy-wide development and supporting a large number of jobs (World Economic Forum, 2012). In China, for

**Figure 5:** Renewable energy employment in selected countries as of 2014 (thousand jobs)



instance, the oil, natural gas and coal industries collectively support around eight million jobs in 2014 (China National Renewable Energy Centre, 2015<sup>30</sup>). The ongoing low oil and gas prices have had profound impacts on energy sector employment globally, with the oil sector estimated to have lost 250,000 jobs so far (Wethe, 2015). The growth of the renewable energy sector over the past decade and its impact on job creation have been a silver lining for employment in the energy sector.

As jobs in renewable energy expand, gathering sound information on the status and trends of employment in the sector will be essential to enable informed policy choices. Quality data, insights and analysis are critical to monitoring policy effectiveness and supporting policy makers communicating the benefits of these policies to the wider public using reliable facts and figures (IRENA, 2013). Recognising the pressing need, several existing studies (Strietska-Illina et al., 2011; UN Industrial Development Organization and Global Green Growth Institute, 2015; Greenpeace, 2014 and 2015) have explored various aspects of renewable energy jobs, often within the context of the wider green energy sector.

IRENA's growing body of work (see Box 14) strengthens and broadens the existing knowledge base of renewable energy employment. The latest addition to this body of work, IRENA (2015a), estimates that the renewable energy sector supported around 7.7 million direct and indirect gross jobs in 2014, representing an 18% increase from the previous year. If direct jobs in large hydropower are included, the figure reaches 9.2 million.

### STATUS OF EMPLOYMENT IN THE RENEWABLE ENERGY SECTOR

China is the largest renewable energy employer, providing jobs for 3.4 million people (see Figure 5). Its PV industry alone employs 1.6 million people, 80% of whom work in manufacturing, accounting for nearly 70% of the world's panel production. Brazil, the second largest employer, has almost 1 million employed, mostly in liquid biofuels, given the labour requirements of feedstock production. In the US there are more than 0.7 million jobs driven by solar, wind and bioenergy. In India the renewable energy sector employs almost 0.5 million people. Several other Asian countries also posted significant gains in 2013. Indonesia recorded 223,000 jobs, Bangladesh 129,000 jobs - mostly in off-grid PV. Countries from the EU employ more than 1.2 million people in renewable energy, with Germany and France in the lead.

Employment trends vary widely across renewable energy technologies. Solar PV is the largest employer, accounting for 2.5 million jobs in 2014. This is due to increasing global production of solar panels as lower costs drive accelerated growth in installations. Moreover,



30. IRENA correspondence with China National Renewable Energy Centre.

**Figure 6:** Estimated employment in the renewable energy sector (million jobs)

distributed solar PV is more widely deployed as it offers a feasible and affordable way to improve energy access. The distribution and assembly of panels and the provision of after-sales service is easy to localise, creating jobs. Liquid biofuels is the second largest employer, accounting for nearly 1.8 million jobs worldwide despite increasing mechanisation of feedstock operations in major producing countries such as Brazil.

The trends in employment reflect, for instance, regional shifts in investment, advances in technologies and manufacturing processes, structural changes in industry and falling costs, among others. As the falling cost of technology drives employment growth in installation and subsequent operations and maintenance (O&M) requirements, it introduces challenges for suppliers and causes manufacturing jobs to shift to Asian markets. This geographical shift

has been observed over the past few years as the combined share of the EU and US in global employment in the sector declined from 31% in 2012 to 25% in 2014.

#### THE FUTURE EMPLOYMENT OUTLOOK

Employment in the renewable energy sector will continue to grow in line with national and global targets for renewable energy and greenhouse gas mitigation.

The results of this study show that under a business-as-usual scenario (Reference Case), employment in the renewable energy sector would reach 13.5 million by 2030, up from current levels of 9.2 million<sup>31</sup> (see Figure 6). However, doubling the share of renewables in the energy mix by 2030 (REmap Case) could increase direct and indirect employment in the sector to 24.4 million. This is an annual growth rate of 6% until 2030 compared to 2% in the Reference

31. This total includes 1.5 million in large hydropower.

**Table 2:** Jobs in renewable energy in 2030 by country (million jobs)

	Reference Case	REmap Case	REmapE
 <b>China</b>	3.5	5.9	5.8
 <b>India</b>	1.5	3.5	3.8
 <b>Brazil</b>	1.1	2.2	1.4
 <b>United States</b>	0.4	1.4	1.1
 <b>Indonesia</b>	0.2	1.3	0.5
 <b>Japan</b>	0.5	1.1	1.3
 <b>Russia</b>	0.6	1.1	0.7
 <b>Mexico</b>	0.1	0.3	0.3
 <b>Germany</b>	0.2	0.3	0.3
<i>Rest of the World</i>	5.4	7.3	7.5
 <b>World total</b>	<b>13.5</b>	<b>24.4</b>	<b>22.9</b>



Case. Doubling the share of renewable energy through a higher electrification rate would increase employment to 22.9 million owing to reduced bioenergy feedstock production (see Chapter 3 for estimation methodology).

Doubling the share of renewable energy by 2030 will lead to increased employment in the sector dominated by China, India, Brazil, the US, Indonesia, Japan, Russia, Mexico and Germany (Table 2). Strong deployment and equipment manufacturing would allow China to retain its position as the largest renewable energy employer in the world. Employment in India is expected to increase substantially as it is scaling up its ambition for solar PV and wind deployment. Meeting its 2022 target of 100 GW of solar alone is expected to create 1.1 million jobs. Brazil would continue to be a

key employer with most of the jobs concentrated in bioenergy feedstock harvesting and processing. Employment in the US would also increase due to job gains in bioenergy as well as solar and wind energy. Indonesia would become a leading employer due to its labour-intensive bioenergy production.

Several countries, such as Brazil, Indonesia, Russia and the US, show lower employment levels in the electrification case, as seen in Table 2. This is due to a strong reliance on labour-intensive bioenergy despite continued mechanisation of processes along the value chain. In countries such as India, Japan and Mexico, an increase in jobs can be seen in the greater electrification case, mainly due to higher installation of renewable power generation.

Employment in the renewable energy sector in 2030 is expected to remain concentrated in the same technologies as it is today (solar, bioenergy, large and small hydropower and wind) with minor shifts depending on the case. In the first doubling case, bioenergy is the leading technology. By contrast, solar energy is the largest employer in the electrification case where employment in other power producing technologies, such as hydropower and wind, also increase (Table 3).



Depending on the technology, the jobs will be distributed along different segments of the value chain. This includes equipment manufacturing, construction and installation, operation and maintenance, and fuel supply in the case of bioenergy. The results, presented in Table 4, show a steady increase in the number of jobs in hydropower, solar and wind throughout all these activities as we move between both cases. This is because more renewable power generation is needed, including from bioenergy. However, the reduced use of bioenergy for heat and transport reduces jobs in fuel supply. Doubling the renewables share with higher electrification adds more than 2.5 million direct and indirect installation and equipment manufacturing jobs combined due to the increased need for renewable power capacity. Jobs in bioenergy fuel supply, however, stay at levels equivalent to the Reference Case.

While accelerated renewable deployment will create employment opportunities across the value chain, it will also demand a wide range of

**Table 3:** Estimated direct and indirect employment in the renewable energy sector by technology (million jobs)

	2014	Reference 2030	REmap Case 2030	REmapE 2030
 <b>Bioenergy</b>	3.0	4.4	9.0	4.9
 <b>Hydropower</b> (small and large)	1.7*	4.8	5.5	6.4
 <b>Solar</b> (including solar water heating)	3.3	2.6	6.4	7.2
 <b>Wind</b>	1.0	1.7	3.3	4.1
<i>Other renewables</i>	0.2	0.1	0.2	0.2
 <b>World total</b>	<b>9.2</b>	<b>13.5</b>	<b>24.4</b>	<b>22.8</b>

\* The jobs in large hydropower in 2014 are direct only.

**Table 4:** Distribution of renewable energy jobs along the various segments of value chain (million jobs)

		 World total	 Hydro-power	 Wind	 Solar	 Bio-energy	Other RE	
	Construction and installation	<b>Reference</b>	5.2	2.7	0.8	1.4	0.3	0.1
		<b>REmap</b>	8.5	3.0	1.6	3.3	0.5	0.1
		<b>REmapE</b>	9.7	3.4	1.9	3.7	0.6	0.1
	Manufacturing	<b>Reference</b>	2.8	1.3	0.7	0.7	0.1	0.0
		<b>REmap</b>	5.5	1.8	1.4	2.0	0.2	0.1
		<b>REmapE</b>	6.7	2.2	1.8	2.4	0.2	0.1
	O&M	<b>Reference</b>	2.8	1.3	0.7	0.7	0.1	0.0
		<b>REmap</b>	5.5	1.8	1.4	2.0	0.2	0.1
		<b>REmapE</b>	6.7	2.2	1.8	2.4	0.2	0.1
	Fuel Supply	<b>Reference</b>	3.9				3.9	
		<b>REmap</b>	8.1				8.1	
		<b>REmapE</b>	3.9				3.9	
<b>All Segments</b>		<b>Reference</b>	13.5	4.8	1.7	2.6	4.4	0.1
		<b>REmap</b>	24.4	5.5	3.3	6.4	9.0	0.2
		<b>REmapE</b>	22.8	6.4	4.1	7.2	4.9	0.2

skills and workforce capabilities. This raises the possibility of skills gaps and labour shortages, which are already obstructing the transition to sustainable energy in many countries (IRENA, 2013). Going forward, better training and education will play a crucial role in ensuring that renewable energy becomes a reliable part of the global energy system.

#### JOBS IN THE ENERGY SECTOR IN 2030

Looking beyond renewable energy, employment in the broader energy sector will also increase in both cases analysed (Table 5). While employment in the fossil fuel sector decreases due to lower fossil fuel demand in both cases, the nuclear sector remains stable. It shows only a slight increase in employment (6%) in the REmapE Case to compensate for the increased needs of power generation. Despite the reduction in the conventional energy sectors, the increase in renewable energy employment in both cases is such that overall energy sector employment remains larger when renewable energy is doubled. This includes not

only the power sector but also the oil, gas, coal and nuclear sectors. Global employment in the energy sector (including renewables, fossil fuel and nuclear) would reach almost 51 million in both cases doubling renewables as shown in Table 5.

The job reductions in the fossil fuel sector are lower in the electrification case since there is a need for more power generation capacity overall. Investment in the power sector thus also creates some jobs in conventional power, mainly in equipment manufacturing.

### THE NET IMPACTS ON EMPLOYMENT

Doubling the renewables share has an impact on employment in other parts of the energy sector, namely nuclear and fossil fuels. However, it is also relevant to understand the net economy-wide employment effects. This elucidates how renewable energy deployment influences other sectors in the economy or, through trade effects, the employment in other countries or regions.

An analysis of the overall net economy-wide effect of renewable energy on employment, taking into account direct, indirect and induced effects from interactions throughout the economy, yields positive impacts in both cases. Net employment in REmap and REmapE increases by 6 million and 8 million (0.14% and 0.18%) respectively in 2030 compared to the Reference Case. Most of the induced jobs are created in the services sector. These figures represent an overall improvement in the economy, which is consistent with the GDP results presented earlier.

**Table 5:** Global employment in the energy sector in 2030 (million people)

	Reference	REmap	REmapE
 Fossil fuels	27.1	24.7	26.2
 Nuclear	1.6	1.6	1.7
<b>Renewable energy: all</b>	13.5	24.4	22.8
 <b>Hydropower<sup>a</sup></b>	4.8	5.5	6.5
 <b>Wind</b>	1.7	3.3	4.1
 <b>Solar<sup>b</sup></b>	2.6	6.4	7.2
 <b>Bioenergy</b>	4.3	9.1	4.8
<b>Other renewables</b>	0.1	0.2	0.2
 <b>Total energy sector</b>	<b>42.2</b>	<b>50.8</b>	<b>50.8</b>



Notes: (a) includes large and small hydropower (b) for electricity and water heating



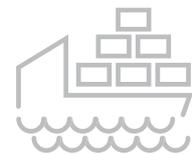
#### 2.4 A HIGHER SHARE OF RENEWABLES SHIFTS PATTERNS OF GLOBAL TRADE

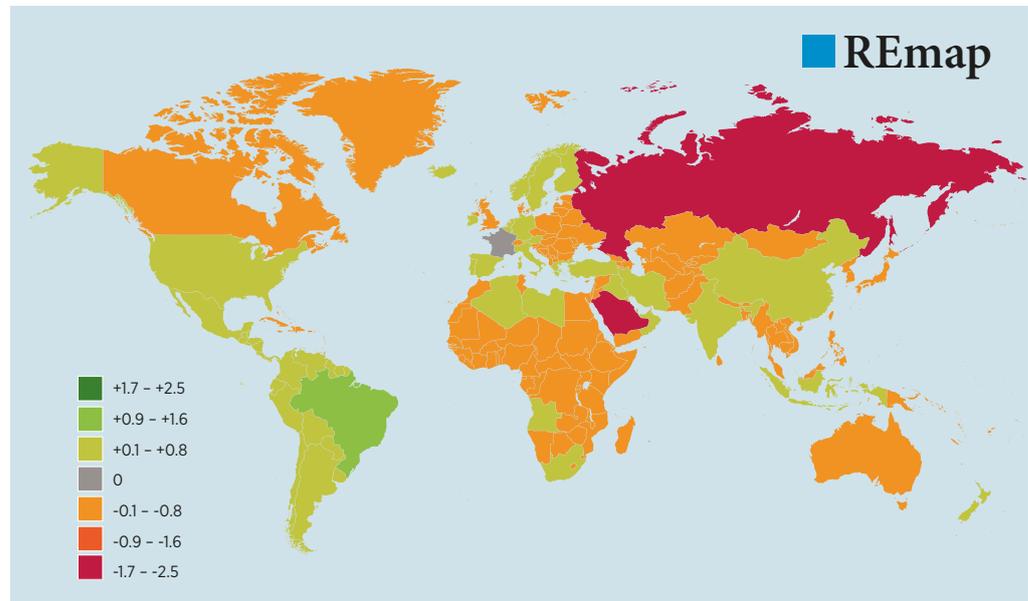
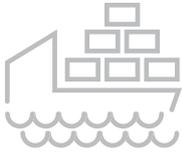
The global market for goods and services permits their exchange and transfer and thereby acts as a key enabler for economic development. The past two decades have seen a substantial increase in the global export value of goods and services, quadrupling from USD 6.3 trillion in 1995 to USD 23.4 trillion in 2014. Consequently, total global exports account for a rising share of global GDP, growing from 20% in 1995 to 30% in 2014 (World Trade Organization, 2015).

World fuel exports have increased more than any other traded product over the past two decades, with an average annual growth rate of 12%. Measured in current US dollars, fuel exports in 2014 were more than eight times higher than in 1995. Fuels represented 17% of the world's total exports in 2014 (up from 7% in 1995). The majority of countries are net fuel importers, and fuel exports are highly concentrated in a handful of countries.

Large economies, such as Japan, China, India and the EU, spend up to 7% of their GDP on energy imports. These values are in the same order of magnitude as expenditure on public health (3% in China, 8% in Japan) and education (under 4% in most countries of the world) (World Bank, 2015a). For these countries, renewable energy deployment could reduce imports. This effect could act as a significant economic benefit, specifically for countries with large trade balance deficits.

A global scale-up in renewable energy deployment provides additional opportunities for all economies to meet growing demands for associated goods and services, including energy equipment. It also presents challenges, particularly for economies heavily reliant on fossil fuel exports. Therefore, a transition towards a greater share of renewables in the global energy mix will bring about a shift in trade and energy linkages and have impacts at the global and national level.



**Figure 7a:** Changes in trade balance in the REmap case (% difference from the reference)

### IMPACT ON GLOBAL TRADE

Overall trade will be higher in 2030 than it is today, reflecting growing and increasingly interconnected economies. Under the Reference Case, total global export value of all goods and services is estimated to reach around USD 50 trillion by 2030 (2015 prices).

The analysis<sup>32</sup> suggests that the impact on overall trade is relatively low. In both cases of doubling the share of renewable energy, the decrease is expected to be around USD 40 billion (relative to Reference Case). This global result can be explained by the movements in the trade in fossil fuels and goods and services at a country-level. These movements are influenced by three key dynamics:

- Reduced demand for fossil fuels with varying implications for fossil fuel exporters and importers;
- With the adoption of capital-intensive renewables, the demand for investment goods and services increases; and
- The impacts on the demand for other goods and services resulting from impacts on GDP.

Since most renewables require no fuel, increasing the share of local renewable energy resources in the global energy mix by 2030 will reduce the volume of fossil fuel trade. In parallel, the capital-intensive nature of renewables, will increase the demand for investment goods and services. The impacts on trade play out differently for fossil fuel exporters and importers (see Figure 7).

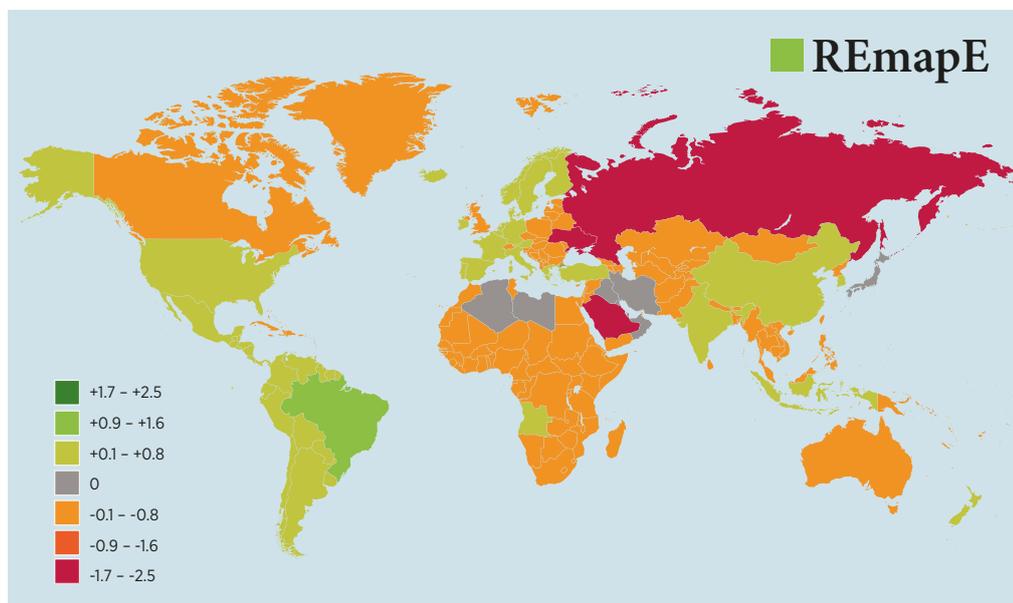
32. Excludes trade of bioenergy

33. Including the individual countries in this report, plus the rest of EU 15 and EU 13 regions.

34. Trade balance is defined as net exports (i.e. export-import) divided by GDP, expressed in percentage terms. The equivalent value in US dollars is simply the value of net exports.

35. 2015 USD

**Figure 7b:** Changes in trade balance in the REmapE case (% difference from the reference)



Countries exporting fossil fuels will see a reduction in the demand for their exports, resulting in a decrease in GDP. This would reduce the domestic demand for other goods and services and in turn potentially decrease imports. This secondary effect can counterbalance the reduction in fossil fuel exports. In the case of importers, the reduction in imports of fossil fuels would increase GDP. This may be counterbalanced by the increase in imports of other goods and services. In both cases, the balancing effects are not sufficient to reverse the primary direction of impacts (i.e., positive impacts on GDP for importers and vice versa).

For fossil fuel importers, the switch to a greater share of renewables has potentially favourable trade implications. Reducing fuel imports can improve trade balance and improve GDP. The EU<sup>33</sup> improves its net exports<sup>34</sup> by USD 15 billion when the renewables share is doubled and by USD 21 billion in the higher electrification case. These figures are comparable to the GDP of Honduras. In Brazil, they amount to USD 22 billion<sup>35</sup> in the REmap Case and

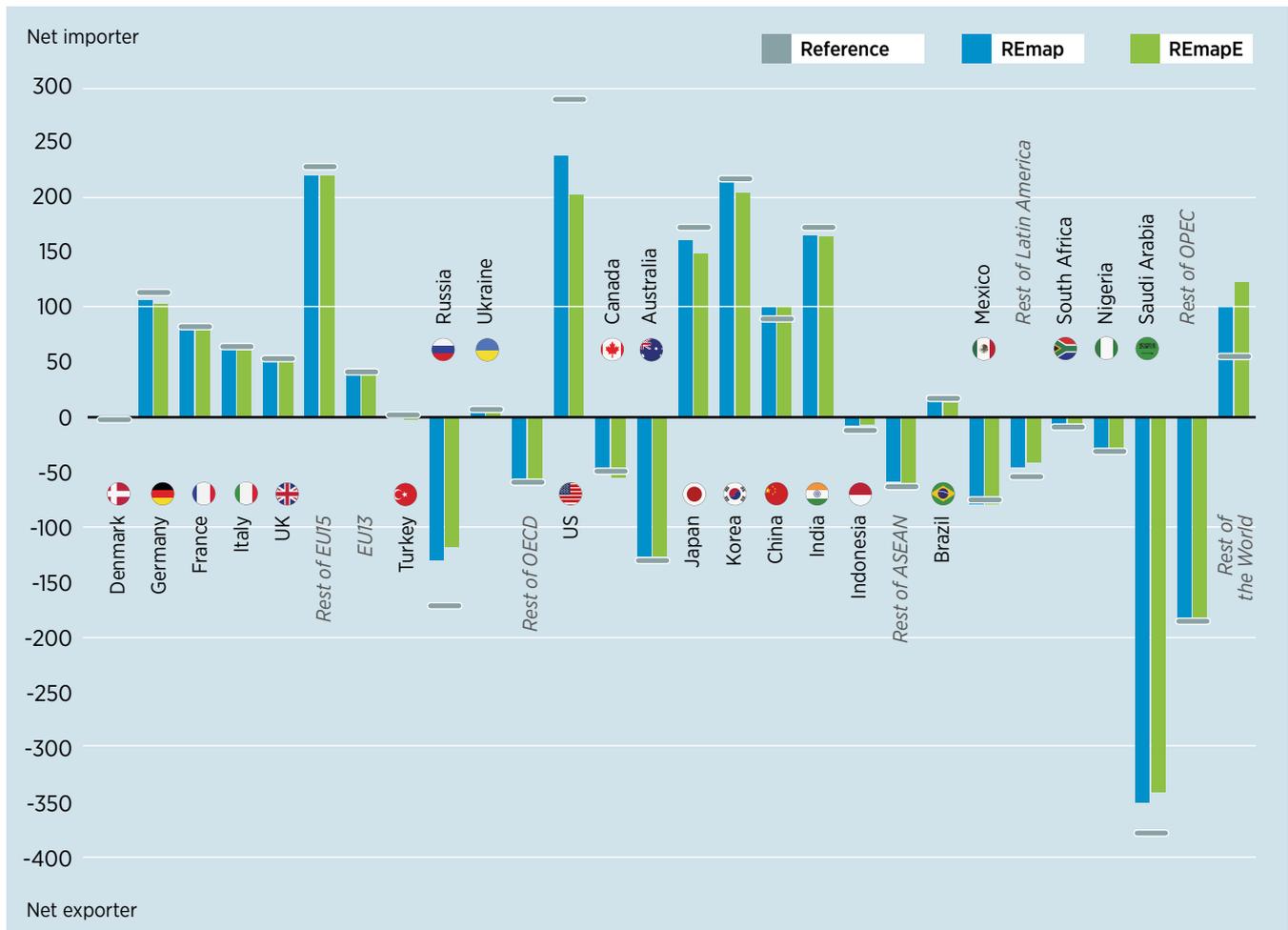
USD 19 billion in the electrification case. This equates to approximately double the annual revenue of Eletrobras, the largest power utility in Latin America. Added benefits include greater resilience to fluctuating fossil fuel prices, improved energy security and more equitable access to modern energy services in developing countries.

**Doubling renewable energy globally means**

**-50%**  
of coal imports

**-7%**  
of oil and gas imports

**Figure 8:** Net imports of fossil fuels in the Reference, REmap and REmapE Cases (USD billion, 2015)



The remainder of the section will delve deeper into each of the two dynamics that are directly related to energy sector trade, namely trade of fossil fuels and investment goods and services.

**FOSSIL FUEL TRADE**

Renewable energy deployment reduces fossil fuel use in the world and thus its trade. Doubling the share of renewables could more than halve global coal imports and reduce the oil and gas sector's imports by 7%. This would lead to a reduction in total fossil fuel imports of USD 104 billion in 2030. A further reduction of USD 181 billion can be achieved in the case of higher electrification of heat and transport. These figures correspond to an oil price of USD 129 per barrel in 2030, the reference assumption as per the IEA (IEA, 2014a).

Savings in the GCC countries:

**-2.5 billion barrels**

of oil equivalent between 2015-2030

Importing countries that stand to benefit most from the doubling of the share of renewable energy include the US, Japan, India, Germany, Republic of Korea and the other EU 15 countries (see Figure 8). Reductions are larger in the greater electrification case, where fossil fuel demand for heat and transport is lower.

Energy exporters will see an overall reduction in coal, oil and gas exports as demand for these commodities is offset by increasing renewable energy use. This does not mean that all fossil fuel exporters will be equally affected, however. Where the reductions in fossil fuel production take place depends largely on the relative extraction costs, which in the analysis is based on a supply curve<sup>36</sup> approach. In the Reference Case, the production of unconventional sources (e.g. shale, deep sea and Arctic oil) increases compared to current levels in the period out to 2030. This is due to the overall increase in demand. However, there is much less expansion of unconventional oil in the cases in which the share of renewable energy doubles, given its higher extraction costs. This suggests that the majority of 'stranded assets' would be from unconventional sources in these cases<sup>37</sup>. Fossil fuel production among low-cost producers (e.g. members of the Organization of Petroleum Exporting Countries) would thus be only marginally reduced.

The macroeconomic effect of reduced exports on national economies varies. Greater impacts are seen in countries where fossil fuel exports account for a larger share of GDP, suggesting that the countries most affected would include Saudi Arabia and Venezuela (where oil exports account for 25% of GDP) (World Bank, 2015a; Devaux, 2013), plus Nigeria and Russia (where oil exports account for 15% of GDP). In addition,

coal exports account for around 8% of GDP in Australia and 5% of GDP in South Africa. Comparing the results for Australia and Saudi Arabia is illustrative; a 4% fall in coal exports from Australia causes its GDP to fall by 0.2%, while a 6.6% reduction in Saudi Arabia's oil exports leads to a 1.8% reduction in GDP.

When considering export revenues it should also be remembered that fuel prices do not change in the analysis (see Chapter 3). If accelerated deployment of renewables led to lower global fuel prices, the impacts on the value of trade would increase in magnitude, both for fuel exporters and importers.

For fuel exporters, a timely reduction in the contribution of fossil fuels to total GDP would thus considerably reduce the risks associated with the energy transition. The renewable energy plans and targets in the Gulf Cooperation Council countries, for instance, could result in cumulative savings of 2.5 billion barrels of oil equivalent between 2015 and 2030. This equates to USD 55-87 billion (IRENA (2016a)). Even for countries exporting fuel, reducing domestic fuel consumption could have benefits, as the fuel savings could be added to exports, mitigating some of the loss of revenues.

The analysis presented here does not account for impacts on the trade of bioenergy, which could provide opportunities for some countries, such as Russia. While most national plans include increased bioenergy use, not all countries are endowed with the resources to meet growing demand, so inter-regional and possibly global trade in both solid and liquid bioenergy will be needed. The past decade has seen positive trends in both solid biomass and biofuel production and trade and this is likely to continue.

36. A supply curve relates the costs of production of each unit of energy to the total production. It is normally an upward curve, since cheaper production takes place first. By using such an approach, the model in this report allocates fossil fuel production in order of increasing unitary costs until all demand is covered.

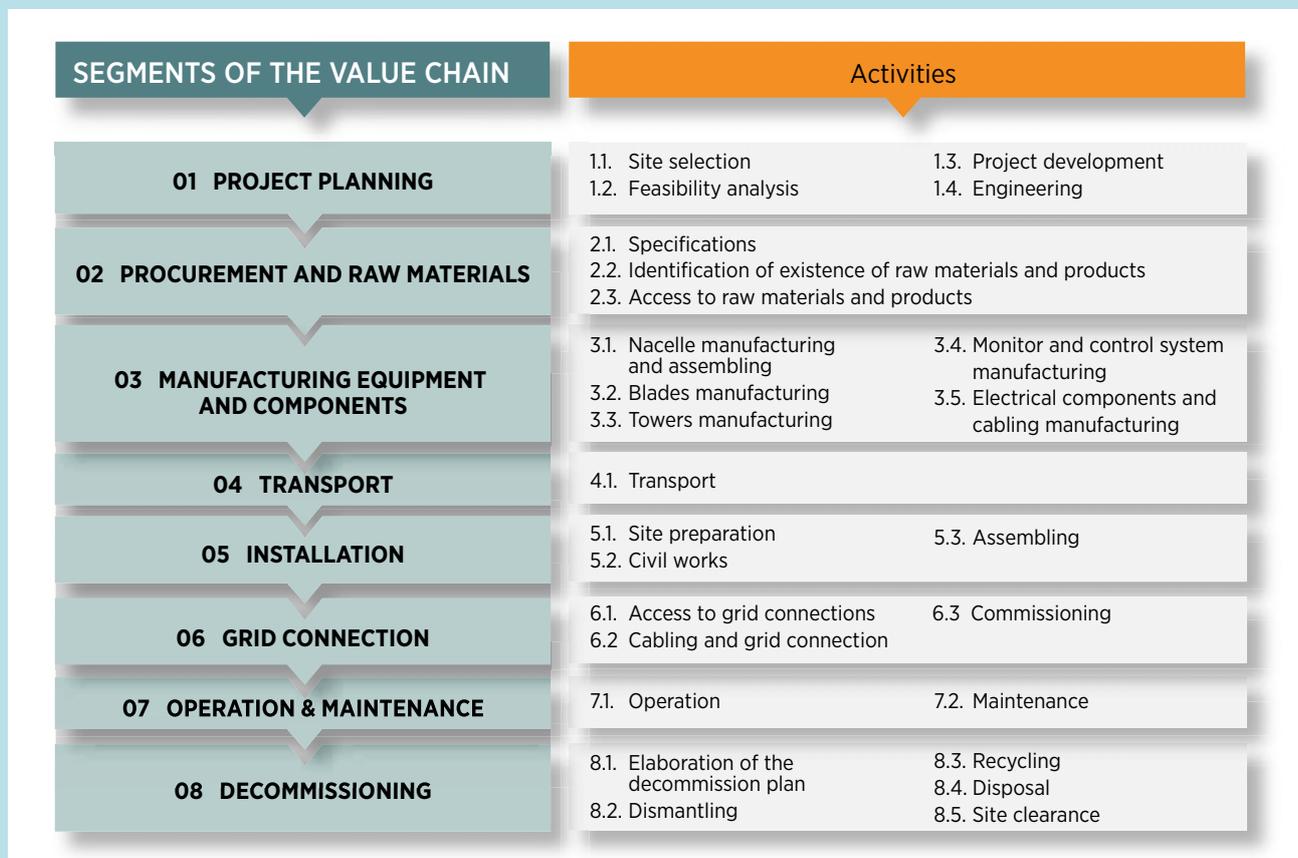
37. See discussion in McGlade and Ekins (2015). In addition, the low oil prices experienced in 2015/2016 have provided some context for this. Investment in costly sources has been scaled back at times when extraction does not appear economically viable, while production by conventional producers has not changed.

**Box 14:** Developing a local wind energy industry –  
Insights from IRENA's forthcoming report *Renewable Energy Benefits: Leveraging Local Industries*

The socio-economic impacts of renewable energy can be evaluated along the different segments of the value chain, including project planning, manufacturing, installation, grid connection, O&M and decommissioning. Further opportunities exist in supporting processes such as policy-making, financial services, education, R&D and consulting. The extent to which domestic value is created along these different segments will depend on the overall level of development of a country's renewable energy sector. Countries embarking on this path have a potential for domestic value creation in activities such as O&M or grid connection. Where the country produces

technology locally, many more opportunities for domestic value creation arise with the development of a local industry. The segments of the value chain that can be localised depend on a number of factors. These include the current state and competitiveness of local complementary industries as well as the projected demand for goods and services. A discussion of these factors is presented below in the specific context of wind energy.

**Figure 9:** Segments of a wind energy project value chain





Developing a wind energy project involves a wide array of activities and inputs along different segments of the value chain (Figure 8). Given that the majority of the project lifetime cost relates to the development phase, there is an incentive for governments to make efforts to support a domestic industry and localise as many activities as possible. This would create local jobs, reduce reliance on equipment and skills imports, and stimulate the local economy. For instance, between 64% and 85% of the total cost of a wind project is directed towards the turbines, which primarily include the tower, drivetrain and rotor blades. Countries have traditionally opted to produce towers and rotor blades domestically given the logistical challenges and costs associated with transporting them over long distances. The drivetrain or gearbox is a high-value component requiring advanced technological knowhow and resources to carry out regular O&M on operating systems (unlike towers and blades). Given these complexities, not all countries are willing to pursue the development of capacity to build gearboxes locally. Other segments of the value chain, such as installation and grid connection, also present potential opportunities for local value creation.

Identifying which segments of the value chain can be localised requires a careful assessment of the needs and the available resources and infrastructure. In this context, IRENA's report *Renewable Energy Benefits: Leveraging Local Industries* analyses the activities involved along different segments of the value chain of solar and wind projects. It outlines the requirements in terms of manufacturing capacities, skills, raw material availability, access to financing and the presence of an enabling environment to support the development of a domestic industry. This would assist policy makers assessing the local services and components needed to develop projects and the strategic drivers to develop renewable energy industries.

*Source: Renewable Energy Benefits: Leveraging Local Industries (forthcoming)*



### INVESTMENT GOODS AND SERVICES TRADE

Given the capital-intensive nature of renewable energy technologies, an increase in the demand for investment goods and services (e.g. solar panels, turbines, construction materials and engineering services) is expected as nearly all countries considered in the analysis scale-up renewable energy adoption. As industrial capacity varies from country to country, the effects of how the increase in demand for renewable equipment will be met is less clear compared to fossil fuels. What is clear is that new markets will emerge, creating new trade flows while also providing opportunities for all economies in localising different segments of the renewable energy value chain. Some of these segments, such as construction material and service, are more easily localised. Additional opportunities lie in manufacturing, which can have larger economy-wide positive effects in the case of increased exports as estimated for Germany (Edler, 2012).



Countries that already export renewables equipment clearly have a comparative advantage. As the market for renewable energy goods and services expands, economies of scale allow manufacturers to further commercialise technologies while the resulting falling costs in turn render their products increasingly competitive. Renewable energy technologies have the advantage of being largely transferrable across countries and continents. They open up opportunities to a wide range of countries, including in the developing world. Several developing countries have significantly increased their exports of renewable energy equipment such as solar panels, wind turbines and solar water heaters. China is a case in point. Having pursued an aggressive industrial policy early on, it has emerged as a major exporter of renewable energy. It exported over USD 10 billion in solar panels and cells, almost 80 times the value it exported only ten years earlier (UNEP, 2013). As countries develop their individual renewable energy sectors, localising different activities in the value chain can redirect investments. These are channelled into the local economy and would otherwise have been spent on importing fossil fuels or renewable energy goods and services (see Box 14).

Countries exporting equipment for the conventional energy industry (e.g. oil and gas, coal mining and handling units) would see demand for their products reduce. However, there is some transferability potential for skills and technology, as seen in geothermal project development. The technology and financial experience of exploring and drilling oil and gas has been applied to geothermal projects that have similar equipment needs and financial risk profiles (Hamilton, 2015; Galbraith, 2014). Simply put, many of the conventional energy goods and services exporters have the opportunity to adapt and participate in a global market for renewable energy.

## 2.5 CONCLUDING REMARKS

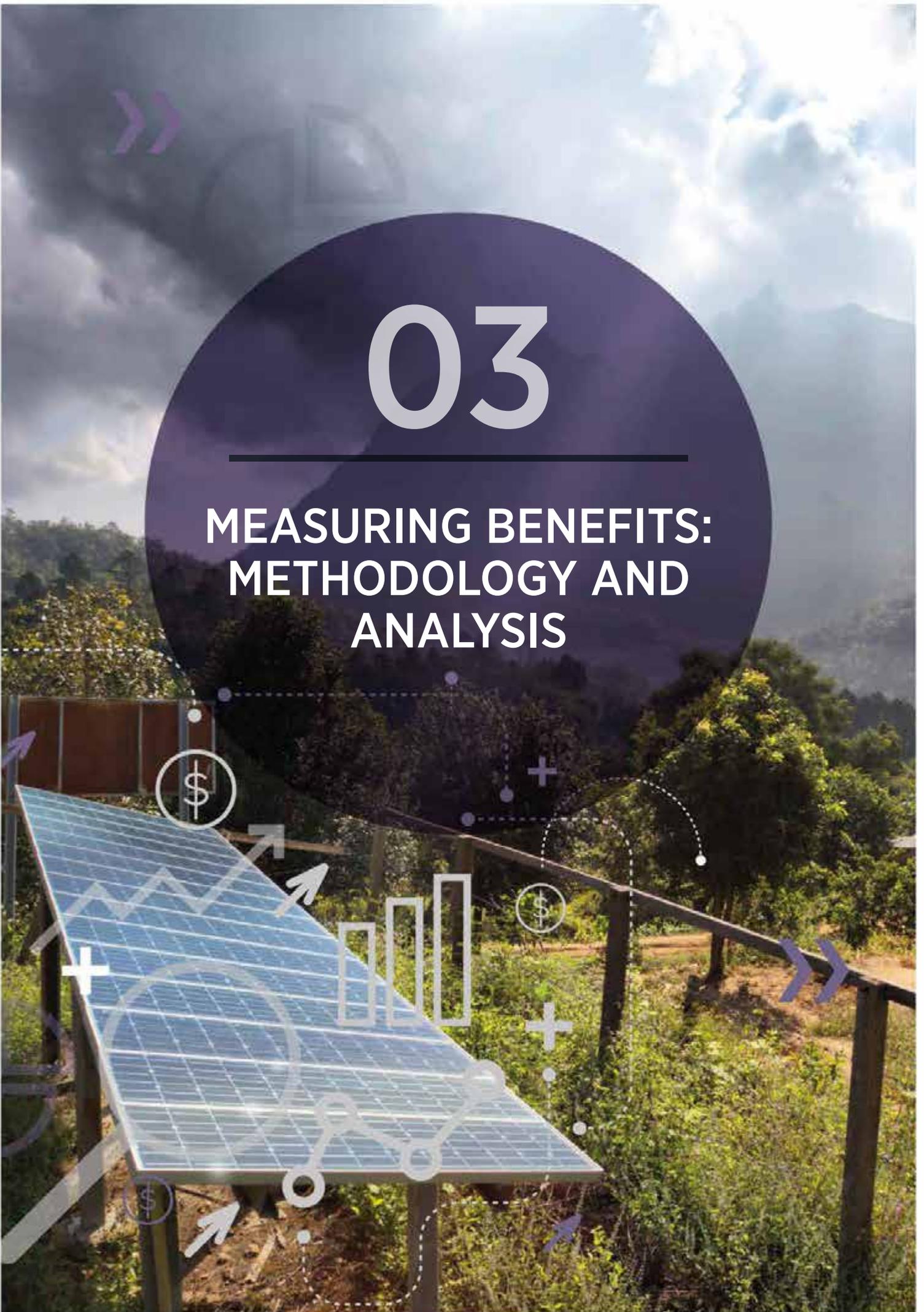
The analysis presented in this chapter displayed the positive impacts of doubling the share of renewable energy by 2030 on economic growth, welfare, employment and international trade. Achieving this goal could increase global GDP in 2030 by 0.6%, and up to 1.1% in the case of greater electrification of heat and transport (equivalent to USD 706 billion and USD 1.3 trillion, respectively). The greater impact in the electrification case results from the increased investment required for the additional renewable power capacity, but represents a slightly riskier improvement depending on whether renewable energy crowds out investment in other economic sectors. In addition to GDP improvements, doubling the share of renewable energy could increase global welfare by up to 3.6% (substantially more than GDP). In other words, renewable energy improves human well-being to an extent that

GDP fails to capture. Additionally, renewable energy could support more than 24 million jobs in 2030, and lead to fossil fuel import savings of up to USD 180 billion while creating new markets and new opportunities for exports. This first global estimation of the impacts of increasing renewable energy deployment points to a clear global opportunity to move towards a more cost-effective, reliable, secure and environmentally sustainable energy system. At the same time, the transition would reduce the traditional trade-off between economic growth and environmental conservation. While realising this opportunity, countries will benefit from calibrating their development strategies to ensure they both gain from and contribute to the transition most effectively.



# 03

## MEASURING BENEFITS: METHODOLOGY AND ANALYSIS



# MEASURING BENEFITS: METHODOLOGY AND ANALYSIS

Chapter 2 presented the macroeconomic impacts of doubling the share of renewables in the global energy mix by 2030. This chapter delves into the analytical approach and methodology backing this analysis. It has the following aims:

- To explain the methodology used for this analysis including the tool and the rationale for its selection, and present the three main cases assessed, namely the Reference Case, REmap and REmapE (section 3.1);
- To provide details on the selected variables analysed, i.e. GDP, welfare, employment and international trade (section 3.2);
- To present the sensitivity analysis for crowding out of capital, fossil fuel prices, fossil fuel subsidies, technology costs and carbon prices (section 3.3);
- To discuss the main assumptions and limitations of the analysis that should be considered when interpreting the results (section 3.4);
- To summarise the key findings and outline future areas of work building on this effort (section 3.5).

## 3.1 METHODOLOGY

The macroeconomic impacts of renewable energy deployment presented in this study were obtained using the macro-econometric tool E3ME described in detail in Annex 1. Macro-econometrics<sup>38</sup> have some limitations, especially the requirements for detailed time-series data and the Lucas Critique<sup>39</sup>, which were dealt with as follows. The data limitations can be managed by using an existing tool, such as E3ME, with tested data-sets for the countries analysed. With regard to the Lucas Critique, it is reasonable to assume limited behavioural change in this analysis; e.g. households consume the same amount of electricity across cases and do not necessarily consider the source of its generation.

Having considered these limitations, a macro-econometrics approach was selected because it has several advantages over competing approaches. First, it is based on well-established historical databases and has a proven track record of policy applications. Second, it allows the representation of additional policies or regulations drawing from idle economic resources, as is often observed in reality. Third, the approach takes unemployment into account, a key concern for policy makers. The rationale behind the selection of the approach is further explained in Annex 2 (see also IRENA and CEM (2014)).

38. A discussion on the advantages and limitations of macro-econometric approaches is beyond the scope of this study.

39. The “Lucas Critique” suggests that past observed relations (as embedded in the time-series data) cannot be extrapolated into a future under different policy conditions.

### THE E3ME TOOL

Among the macro-econometric tools available, the Cambridge Econometrics' E3ME tool was selected for two main reasons:

- It is suitable to the objective of this analysis in two main respects. Firstly, it enables the use of exogenous energy mixes, a key requirement for analysing REmap cases. Secondly, it can be tailored to different technological, sectoral and geographic disaggregation. The tool includes 24 different electricity generation technologies and 43 economic sectors. It covers 59 countries/regions globally and allows the addition of new countries, which was necessary for the analysis in this report.
- The tool has been applied extensively for previous policy analyses. In Europe, it was used for official assessments of the EU 2030 climate and energy targets and the long-term Energy Roadmap. In these studies, E3ME was used to analyse exogenously determined energy mixes similar to the analysis presented in this report. More recently, E3ME was applied in East Asia to analyse possible future energy mixes (Lee et al., 2015) and is currently being used in Latin America.

The basic structure of the E3ME tool used for this analysis is illustrated in Figure 10. The tool is composed of four main modules: energy, economy, technology and emissions. The tool links the energy system with the world's economies to provide estimates of the macroeconomic impacts of changes to the global energy mix, reflecting different shares of renewable energy. It also links the energy system with technological development and related emissions. Some of the relationships between the modules are unidirectional, but most are bidirectional. An example is the relationship between technology and the economy. As the economy grows, funding in energy R&D increases, improving energy technology. This in turn reduces the cost of investment in energy technologies per unit of capacity, which reduces

overall investment in the economy and impacts variables such as GDP.

For the purpose of this analysis, the links feeding into the energy system have been disabled (dotted arrows in Figure 10) to make the energy balances, fossil energy prices and technology costs exogenous. These values reflect results from IRENA's REmap analysis as illustrated in the right-hand side of the figure.

In E3ME, the energy system feeds into the economy through three mechanisms, namely electricity prices, energy taxes and energy consumption. These are illustrated by the blue arrow in Figure 10.

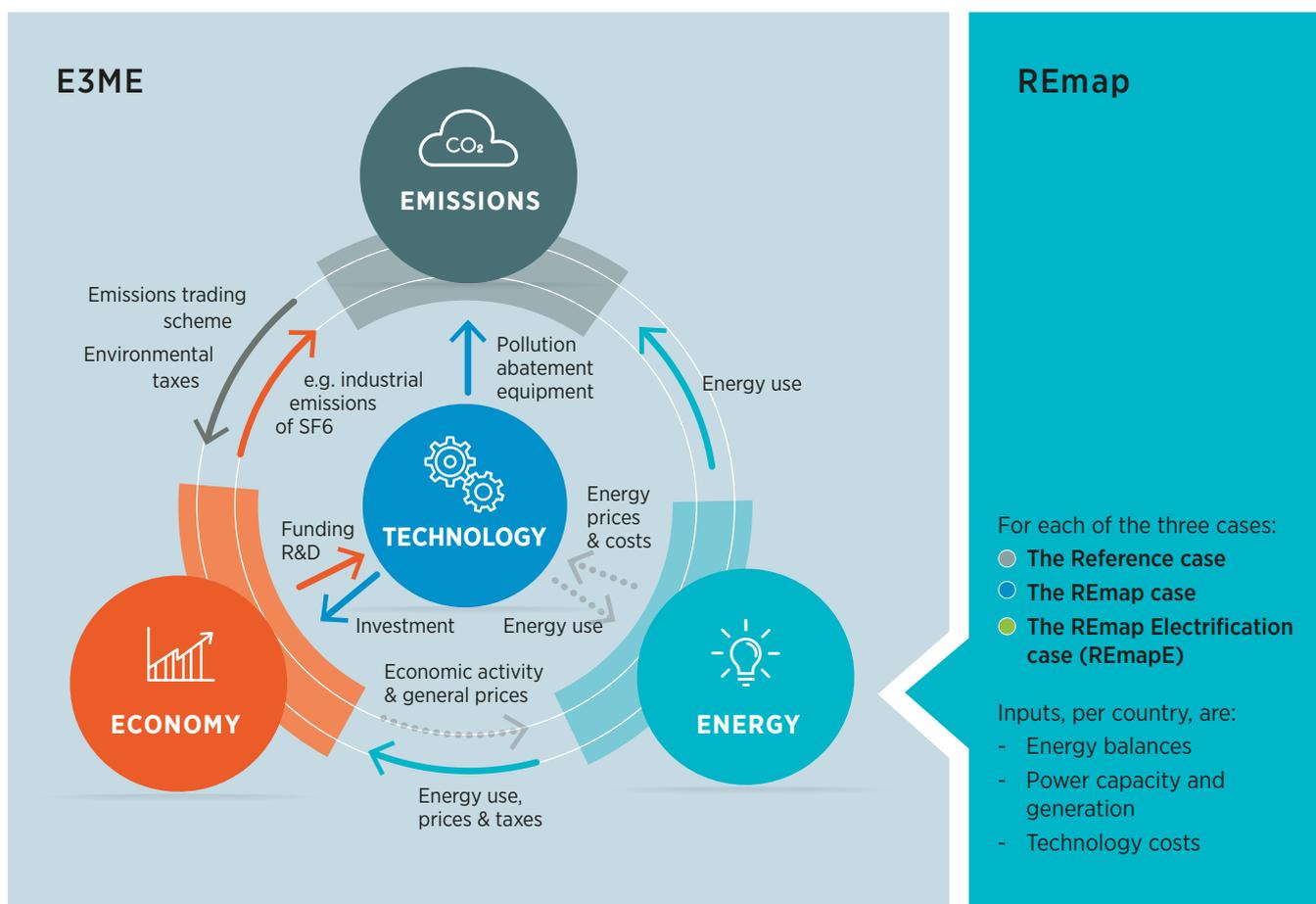
### MAIN ENERGY/ECONOMY INTERACTIONS IN THE TOOL

This subsection briefly outlines how the economic module in general, and GDP in particular, responds to changes in the energy system caused by renewable energy deployment. Renewable energy deployment can affect GDP through three main mechanisms<sup>40</sup> (see Figure 11):

- **Energy production and trade:** as renewable energy deployment is expected to reduce the consumption of fossil fuels, the activities related to the extraction and supply of fossil fuels are expected to decrease. This leads to GDP reductions in some countries. These reductions are expected to be largest in countries that heavily rely on fossil fuel exports, depending on the level of contribution of the fossil fuel sector to their GDP. Typically, oil production represents a higher share of GDP in countries producing oil than the share of coal production in countries producing coal.
- **Investment:** since renewables are more capital-intensive than conventional generation options, a higher share of renewable energy requires more investment. Higher investment leads to higher GDP, which in turn creates jobs, conditional to the availability of

*40. The tool actually includes many other important mechanisms such as government expenditure, but the figure focuses on the main ones relevant to this report.*

**Figure 10:** Basic structure of the E3ME tool used for the analysis



capital, workforce and production capacity in the different sectors.

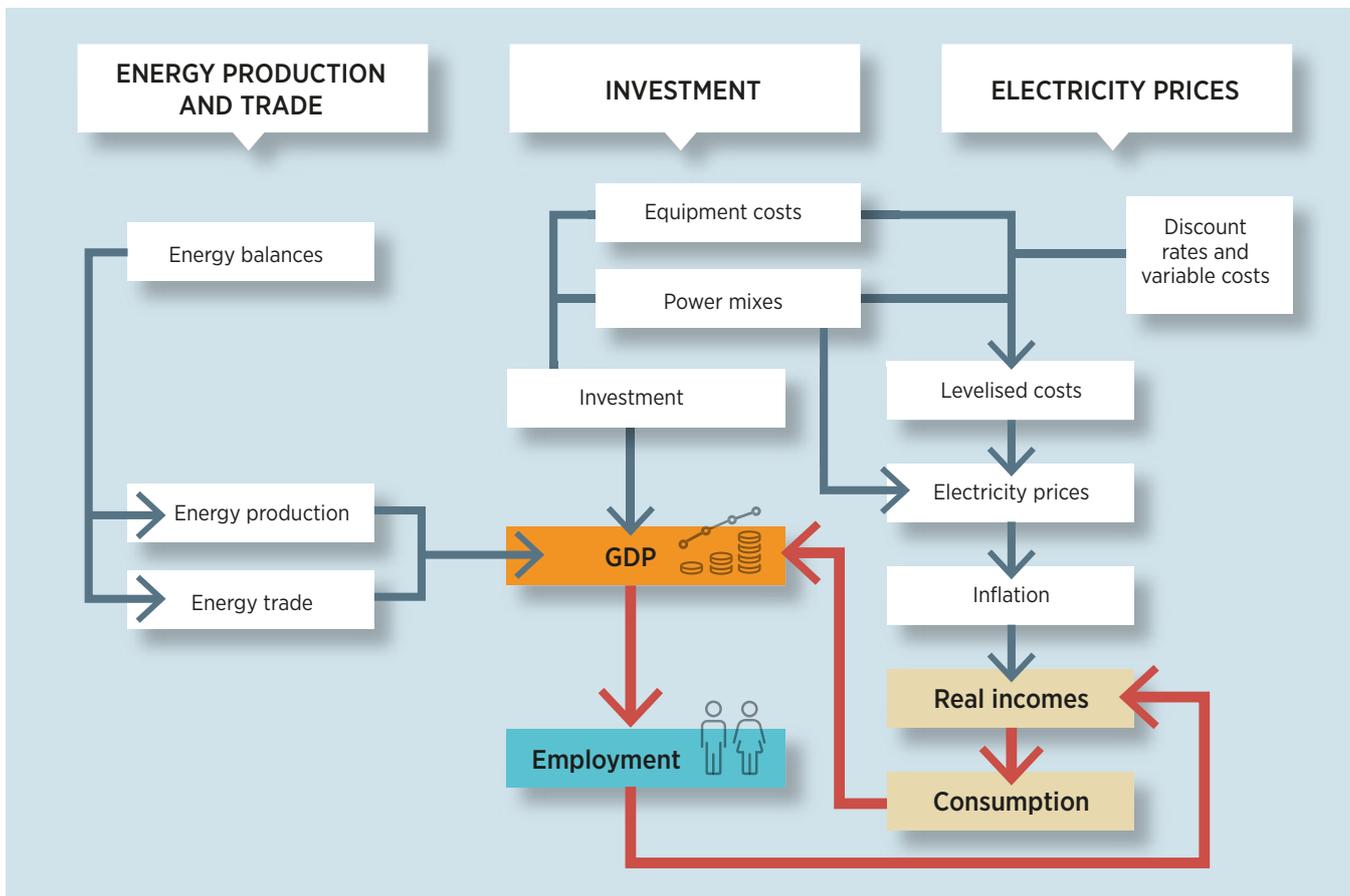
■ **Prices:** electricity prices are expected to change as the shares of individual technologies in the power mix and the levelised cost of generation evolve. Higher electricity prices can increase inflation, depress real incomes and reduce economic activity in energy-intensive sectors. However, a number of renewable technologies are expected to have lower costs than conventional technologies by 2030 and thus can reduce electricity

prices. The resulting lower electricity prices can stimulate economic activity and contribute to GDP growth.

The multiplier effects are an important dimension of the interactions between energy and the economy. In particular, E3ME captures how an increase in GDP from renewable energy deployment would raise employment. This in turn would raise incomes<sup>41</sup> and consumption, resulting in a further increase in GDP. This multiplier effect, represented as a red loop in Figure 11, has an impact on other parts of the

41. In the figure, the label indicates 'real' incomes because the variable also takes the inflation level into account.

**Figure 11:** Main mechanisms in the E3ME tool



economy. For instance, the additional workers would spend part of their incomes on local goods and services, further increasing GDP<sup>42</sup>.

Therefore, the main strength of this tool is that it takes all economic interactions into account within a single quantitative framework. The results presented are thus net, meaning that they cover impacts on all economic sectors and include both positive and negative impacts. Annex 2 presents further insights on the approach used, comparing net methods with sector-specific gross approaches (see also Chapter 4 of IRENA and CEM, 2014).

<sup>42</sup> These types of multiplier effects can only be captured through complex tools such as the one used in this report.

## MAIN CASES ANALYSED

This report analyses different cases of exogenously determined energy mixes using the E3ME macro-econometric tool. These energy mixes are obtained from IRENA's global roadmap for doubling the share of renewable energy in the world's energy mix by 2030, entitled REmap2030. The roadmap is designed to demonstrate possible pathways and priority actions for meeting this target (i.e. from 18% in 2010 to 36% in 2030) in conjunction with improved energy access and efficiency. These pathways are articulated into different levels of renewable energy deployment and combinations of technologies, referred to as cases. The three main cases include:

**The Reference Case**, a business-as-usual case that reflects the most up-to-date official national plans under existing legislations. For countries which have not yet been covered by REmap, the New Policies Scenario of the 2014 edition of the IEA WEO (IEA, 2014) is used.

**The REmap Case**, which assesses the potential for the world to double its share of renewable energy by aggregating bottom-up country analysis representing approximately three-quarters of world energy demand. For countries not covered by REmap, the IEA 450 ppm Scenario is used (IEA, 2014).

**The REmap Electrification Case (REmapE)**, which doubles the renewable energy share, with a greater emphasis on electrification of heat and transport. This requires a greater deployment of renewables for power generation.

For the purpose of this analysis, all other exogenous factors and policy measures are kept constant across the three main cases. This allows the impacts of different renewable energy shares to be isolated in line with the three cases, thereby facilitating the interpretation of results. Several interrelated factors (e.g. oil prices) would be expected to respond to changes in the share of renewable energy. However, they have been kept constant between cases. The most relevant of these factors have been tested in the sensitivity analysis presented in section 3.3. Table 6 presents the structure of the main cases analysed and the key exogenous variables. The table has three main components:

- Exogenous variables that vary across the three main cases: the only assumptions that change are the renewables shares, derived from IRENA's REmap analysis. They include the full power mix in each country in each case (including both gigawatts of installed capacity and gigawatt-hours of generation per technology) and the mix in final energy use in each case, by sector (industry, residential, commercial, transport and others).
- Exogenous variables that are kept constant throughout the analysis. These do not vary in any of the main cases or in the sensitivity analyses. They include population, exchange and discount rates, fiscal policies and all econometric parameters embedded in the tool.
- Exogenous variables that are kept constant throughout the main cases but tested in the sensitivity analyses. These include assumptions about the crowding out of capital, fossil fuel prices, fossil fuel subsidies, technology costs and carbon prices. Further details on these assumptions are provided in section 3.3.

**Table 6:** Structure of exogenous variables in the main cases

	Reference	REmap	REmapE	
<b>Key exogenous variables that vary in the main cases</b>				
Renewable energy share as represented by the energy balances and power mixes	<b>Reference Case</b> from REmap analysis (or WEO New Policies Scenario for additional information)	<b>REmap Case</b> (or WEO 450 ppm Scenario for additional information)	<b>REmap Electrification Case</b> (or WEO 450 ppm Scenario for additional information)	
<b>Key exogenous variables that are kept constant throughout the analysis</b>				
Population projections	Total population of 7.3 billion in 2015 and 8.2 billion in 2030, originally derived from the UN and consistent with the IEA WEO. In case of discrepancy, the analysis goes with the most detailed and updated projections (UN). Differences between IEA and UN are less than 5% so a limited impact is foreseen.			
Exchange rates	Held constant in line with the most recent year of data and projections available.			
Discount rates for LCOE* calculations	Representing the cost of borrowing capital and kept fixed throughout the cases. The values used are 7.5% for OECD countries and China, and 10% for the rest of the world. For all countries, a technology-specific risk premium is added (2% for nuclear, 2.5% for offshore wind and concentrated solar power, and 3% for less mature technologies).			
Characteristics of power technologies	Technical characteristics (e.g. efficiency, capacity factors, emission factors) and all costs (except for investment costs) are consistent with REmap and held constant.			
Bioenergy prices	Based on ongoing IRENA work (IRENA, 2014c), ensuring consistency with REmap.			
Grid reinforcement and back-up generation costs	Simple representation of the costs of integrating variable renewable energy based on ongoing IRENA work (IRENA, 2015e). An electricity price mark-up was added according to the share of variable renewable energy.			
Econometric parameters	Derived from historical time series data.			
<b>Key exogenous variables that are kept constant throughout the main cases but tested in the sensitivity analyses</b>				
Assumptions about the crowding out of capital	No crowding out of capital i.e. investment in renewables does not displace investment elsewhere.			
Fossil fuel prices (oil, gas and coal)	Taken from REmap and IEA WEO 2014 New Policies Scenario. In real 2015 USD:			
	Oil	Gas	Coal	
	2015	USD 112.6/barrel <sup>43</sup>	USD 11.2/MMBtu**	USD 94.4/t
	2030	USD 128.7/barrel	USD 12.7/MMBtu	USD 112.3/t
Fossil fuel subsidies	Based on REmap (IRENA, 2014b)			
Technology costs	Overnight investment costs based on REmap			
Carbon prices	Taken from IEA WEO New Policies Scenario and modelled as a fixed carbon price <sup>44</sup> .			

43. The oil prices that were used in the analysis are based on the New Policies Scenario of the IEA's World Energy Outlook (WEO) 2014, in line with the 2014 REmap analysis. The figures do not take into account the recent drop in oil prices that occurred while the analysis was being carried out. To address this issue, one of the tests in the sensitivity analysis (see chapter 3) considers an oil price based on the "Low Price Scenario" of the latest World Energy Outlook (IEA, 2015).

44. The same price is considered for both possible carbon pricing policies: a carbon tax or a trading scheme. In reality, each of the two policies would imply different behaviour among economic agents involved, different levels of perceived risks and, overall, different economic impacts. Such analysis is beyond the scope of this report.

\* Levelised cost of energy

\*\* Million British thermal units

**Table 7:** Main inputs and outputs in the analysis

INPUTS	OUTPUTS
<ul style="list-style-type: none"> <li>→ Population projections</li> <li>→ Exchange rates</li> <li>→ Discount rates for LCOE* calculations</li> <li>→ Characteristics of power technologies</li> <li>→ Bioenergy prices</li> <li>→ Grid reinforcement and back-up generation costs</li> <li>→ Econometric parameters</li> <li>→ Energy balances</li> <li>→ Assumptions about the crowding out of capital</li> <li>→ Fossil fuel prices (oil, gas and coal)</li> <li>→ Fossil fuel subsidies</li> <li>→ Technology costs</li> <li>→ Carbon prices</li> </ul>	<div style="text-align: center;">                       GDP                 </div> <div style="text-align: center;">                       Renewable energy jobs                      Economy-wide jobs                 </div> <div style="text-align: center;">                       Welfare                 </div> <div style="text-align: center;">                       Trade in fossil fuels                      Trade in other goods and services                 </div>

In addition to the exogenous variables, the Cases analysed are assumed to have a neutral effect on governmental budgets. This demonstrates the impacts driven by a shift to renewables rather than by an overall fiscal stimulus or contraction. The E3ME tool does not include the full details of each national tax system. However, it is expected that the government balances will be affected by a higher share of renewable energy. This occurs directly through changes in excise duties on energy products, carbon tax receipts and energy subsidies, and indirectly through income/corporate taxes, sales tax receipts, etc. Income tax has been used as the adjustment needed to balance the budget. This is the largest tax share in most countries and therefore should not influence results very much. It is assumed that the other tax rates remain fixed on the basis of the last year of available data. As a result, government expenditure increases in line with GDP growth, keeping constant the government’s fiscal position.

It is assumed that investments in renewables and other power generation technologies are financed by energy companies through future

sales of electricity. The price of electricity is set in each country by taking an average levelised cost (i.e. including both capital and operating costs) with a mark-up added for additional integration costs, hence a shift to cheaper sources of generation can lead to lower electricity prices if the reduction in levelised costs outweighs the integration costs. When interpreting the results, it is also important to be aware of the temporal dimension of investments. While there are upfront benefits from higher initial investment, the costs are distributed over a longer period as loans are repaid. There is also increased borrowing in the economy as a whole because E3ME does not impose crowding out of capital (meaning that in E3ME investment in renewables does not displace investment in other sectors). This is discussed further in Section 3.3.

### 3.2 VARIABLES ANALYSED

Four main variables have been selected for the present analysis:

- GDP, aiming to measure economic output and growth;
- welfare, a broader measurement of human well-being;
- employment, a variable of significant importance to policy makers given its key economic and social implications;
- trade, in order to understand how renewable energy can affect trade of fossil fuels and other goods and services.



#### GDP

GDP, the most common measure of economic development and growth, has been selected as a variable. The results provided in the report are in constant US dollars in 2015 omitting purchasing power parity.



#### WELFARE

The welfare indicator aims to capture a broader measure of human well-being and how it is affected by renewable energy deployment. Despite intensive work in the field over the last few decades, there is no consensus on an indicator of human welfare. The substantive literature on measuring welfare (see Box 11) broadly identifies three possible dimensions important in determining overall levels of human welfare: economic, social and environmental.

To construct the welfare indicator used in this report, the relevant E3ME results are used as proxies of these three dimensions. This provides the respective sub-indicators of economic, social and environmental welfare described next.

#### Economic dimension of welfare; one sub-indicator:

- Consumption plus investment: consumption is often used as a welfare measure. For example, the Intergovernmental Panel on Climate Change has used this approach (Intergovernmental Panel on Climate Change, 2001). However, this ignores improvements in capital that contribute to future consumption. The sub-indicator here thus includes the sum of both household consumption and economy-wide investment (i.e. capital formation) both measured in constant US dollars in 2015.

#### Social dimension of welfare; two sub-indicators:

- Total employment: the rationale behind using employment as a sub-indicator for social welfare derives from its social value (e.g. in terms of status and self-esteem). This extends beyond pure wage effects. While there is a probable correlation between economic welfare (i.e. the previous dimension) and employment effects, employment is retained as a separate sub-indicator. Economy-wide employment is measured in terms of total jobs in all the 43 economic sectors considered.
- Spending on health and education, corrected for health effects from poor air quality: this sub-indicator draws on the example of the UN HDI. E3ME does not include measures of literacy or life expectancy. Spending on health and education is, therefore, used as a proxy. Also, the changes in healthcare costs resulting from different levels of air pollution are included so that the overall value of this sub-indicator is closer to a measure of welfare. The effects of air quality on human health can actually be substantial and when

45. The coefficients employed to estimate health impacts are the lower end figures of the coefficients used in REmap.

46. Surface temperature or atmospheric concentrations would be more accurate but this is beyond the scope of the tool. The trends over time are quite smooth so the direction of the effect would probably be similar, although dimensions would vary.

monetised, they can even outweigh the GDP effects estimated by macroeconomic tools (e.g. Ackerman and Daniel, 2014). In the present report, health expenditures due to air pollution<sup>45</sup> are subtracted from total expenditure on health and education. As such, an increase in renewable energy deployment will likely reduce air pollution, and hence improve this sub-indicator. This sub-indicator is measured in terms of constant US dollars in 2015.

**Environmental dimension of welfare;  
two sub-indicators:**

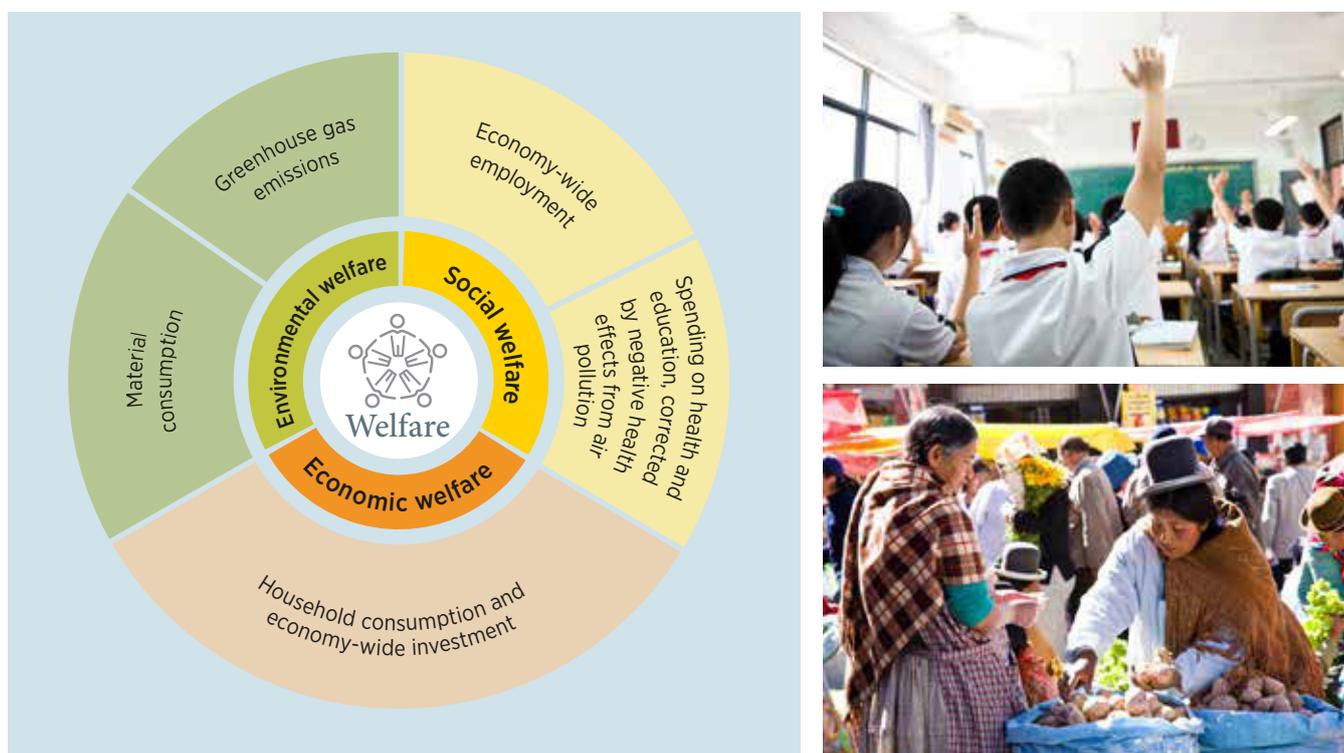
- Greenhouse gas emissions: analysis using E3ME excludes climate change feedbacks into the economy. This is why reductions in emission (and implicit benefits) are included separately in the welfare indicator. This sub-

indicator is measured in annual greenhouse gas emissions in 2030 (tonnes of CO<sub>2</sub> equivalent).<sup>46</sup>

- Materials consumption: linked to the notion of depletion of natural capital, this sub-indicator considers the use of non-energy resources, measured as direct materials consumption (a measure of the use of raw materials). Agricultural residues used for bioenergy are not counted here because the materials would have been produced in any case. This sub-indicator is measured in tonnes.

These quantitative sub-indicators are then aggregated into the overall welfare indicator. The aggregation and overall construction of the welfare indicator raises three main methodological concerns:

**Figure 12:** Welfare indicator proposed, including the three dimensions of welfare, the sub-indicators and their weights



- Double counting: given the interrelated nature of many of these sub-indicators, a special effort is made to avoid double counting.
- Units of different sub-indicators: the aggregation of sub-indicators means each needs to be measured using the same units, which is in turn problematic. A possibility would be to express all of them in monetary units but this has a range of shortcomings. Firstly, some cannot be easily monetised. Secondly, there is a wide range of uncertainty relating to other sub-indicators about existing estimates for monetisation factors (e.g. damage values assigning a US dollar value to each tonne of emissions). Thirdly, the monetisation of other sub-indicators is feasible but has potential ethical implications. This study thus opted not to monetise, measuring each sub-indicator in its own units and working with the percentage difference from the Reference Case when evaluating the overall welfare indicator.
- Weighing the sub-indicators to obtain the overall welfare indicator: this issue, which reflects the subjective importance attributed to each sub-indicator, has been rarely

addressed in previous studies. In this report, equal weights are applied across each of the three dimensions of welfare (economic, social and environmental) and its associated sub-indicators (see Figure 12). The results are presented separately for each sub-indicator so that estimates of the aggregated welfare indicator can be made using different weights if needed.

There are important distributional effects relating to welfare and the aggregate analysis presented does not provide a complete analysis. Many of the relationships are non-linear and adding the impacts across countries and across social groups within countries does not take into account significant differences. These distributional effects are beyond the scope of the current study but are clearly important for future analysis. Nevertheless, the broad trends identified in this study are illustrative of the probable main impacts.



#### EMPLOYMENT

Employment is instrumental to achieving economic and social development. It is thus a variable of significant importance for policy makers. The employment results provided by E3ME cover each of the 43 economic sectors represented. When constructing the tool, these sectors have been determined on the basis of data availability and the industrial classification system adopted in the tool (i.e. the way in which national economic statistics are compiled) (see Box 15).

Given that renewable energy is a relatively new sector, national economic statistics do not include it as an individual sector (as is the case for oil and gas, or coal) – and, as many of the jobs relate to investment, they are classified under the sectors that produce or install the investment goods.

Additional steps are therefore required to estimate the number of jobs directly attributable to

#### Box 15: Relationship between economic sectors and value chain segments

The E3ME tool includes a representation of 43 economic sectors, thus providing employment estimates for each. However, the analysis of renewable energy employment is normally carried out via segments of the value chain (e.g. equipment manufacturing, construction and installation, fuel supply or O&M). Although related, these are not equivalent. For example, jobs in the construction and installation segment of the value chain will be mainly in the construction, engineering and metal goods economic sectors, while jobs in the fuel supply segment will be mainly in the agriculture and forestry, coal or oil and gas sectors. The employment estimations are provided for each economic sector, and they are allocated to segments of the value chain based on expert judgement. Such allocation affects the distribution of jobs but not the total number.

renewables. The following paragraphs describe how this is done, and how the total estimate is split by technology and by segment of the value chain (equipment manufacturing, construction and installation, operations and maintenance and fuel supply).

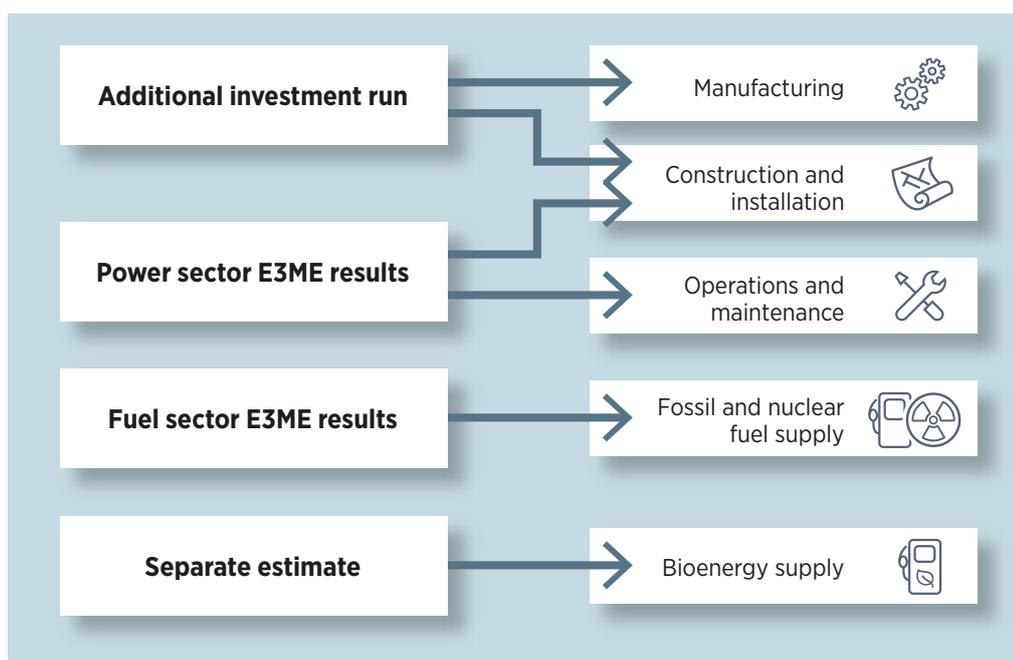
Figure 13 provides an overview of the approach. Four inputs are used to estimate impacts by value chain segment:

- Many of the jobs related to renewables result directly from the additional investment in new capacity. In E3ME, most of these jobs lie in the construction and engineering sectors. However, to estimate the jobs in the sectors that relate to renewables, it is necessary to separate investment in renewables from all the other investment that goes on in the economy. An additional tool run is set up for this purpose. Investment-related jobs are then allocated to **manufacturing**, and **construction and installation** (see Box 4).

- The E3ME results for the power sector are used to derive jobs in **operations and maintenance**. As the sector in E3ME also includes employment in grid operations and maintenance, power retailing and customer support, the number of jobs in operations and maintenance is lower than the sectoral results for the tool. Furthermore, some of the jobs classified as the power sector also fall under **construction and installation**.
- The E3ME results for the fuel sectors are used to estimate jobs in **fossil and nuclear fuel supply**.
- As E3ME does not cover biofuels in detail, jobs in **bioenergy production** are estimated based on employment factors (jobs per GJ) derived from previous studies.

The total jobs are also allocated by generation technology (both conventional and renewable). For investment jobs, the allocation is made by the share of investment. For jobs in operations and

**Figure 13:** Methodology used for renewable energy jobs estimation

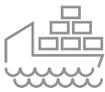


*Note: The employment results provided in this report are expressed as headcount number of jobs.*

maintenance, an employment factor approach<sup>47</sup> is applied, while maintaining consistency with the aggregate results. For fuel supply, the jobs are linked to the relevant technologies.

The approach applied for the estimation of renewable energy jobs is broadly consistent with that used for the macroeconomic results presented for the economy as a whole. The possible improvements in labour intensity/productivity over time are also accounted for in this estimation through the econometric equations that estimate sectoral employment.

The main differences relate to secondary effects such as changes in real wage rates, which are captured by the whole-economy approach but not included in the estimates of jobs solely in the renewable energy sector.



## TRADE

Energy sector trade is composed of two main segments: fuels and investment goods and services. Both segments will experience changes since most renewables do not rely on fuels and are more capital-intensive than conventional

generation technologies. Trade is thus greatly affected by renewable energy deployment in both exporting and importing countries as described in Chapter 2. In the doubling cases, there is likely to be lower international fossil fuel trade and increased trade of investment goods and services. Additional trade effects can result from economy-wide induced effects. For example, as renewables improve GDP, consumption may increase and imports of certain consumption goods could grow.

To analyse trade, two main indicators are used. The first is the trade balance expressed as total net exports (exports–imports of all goods and services, measured in terms of constant US dollars in 2015 and expressed as a share of GDP under the same terms). The analysis of the overall trade balance provides insights into trade in investment goods and services required for renewables, and trade in all other goods and services due to economy-wide induced effects. The second indicator is fossil fuel trade expressed in terms of constant US dollars in 2015. It has traditionally been considered energy trade.



47. For more details on the employment factor methodology see (IRENA, 2013).

### 3.3 SENSITIVITY ANALYSIS

There are many potential sources of uncertainty in any macroeconomic modelling exercise and it is not possible to assess all of them. For example, it is assumed that the data used in the modelling are accurate, even though they may be subject to some measurement error. This section focuses on the two key areas of uncertainty that could affect the results and conclusions of the study.

First, and most important, are the tool parameters, which determine the results of the analysis. In the E3ME tool, these parameters are estimated empirically using econometric equations. While it is not possible to provide standard errors for the tool as a whole, standard errors are reported for each individual equation.

The system of estimation is automated so that there is consistency between regions, sectors and equation sets. The method used maximises the Akaike Information Criterion (AIC) so non-significant parameters are typically excluded from the estimation. The tool estimation system provides a range of diagnostic tests, and equations which do not pass these tests are excluded from the tool solution.

The other main uncertainty relates to baseline assumptions. A sensitivity analysis has been carried out to test the changes in the main results when the key assumptions vary. The sensitivity analysis carried out can be grouped into two broad categories:

- Sensitivities affecting the economy: economic assumptions that could affect the results of

**Table 8:** Structure of the sensitivity analysis

Exogenous variables	Main cases			First sensitivity			Second sensitivity			Additional		
	Reference	REmap	REmapE	Reference	REmap	REmapE	Reference	REmap	REmapE	Reference	REmap	REmapE
 <b>Assumptions about the crowding out of capital</b>	Not assumed			Partial (50%) crowding out			Full crowding out			–		
 <b>Fossil fuel subsidies</b>	Not reduced			Partial (50%) reduction			Full (100%) reduction			–		
 <b>Fossil fuel prices</b>	REmap Reference Case and IEA WEO New Policies Scenario			High (IEA WEO 2014, Current Policies Scenario)			Lower (IEA WEO 2014, 450 ppm Scenario)			Even lower prices (as of IEA WEO 2015, Low Oil Price Scenario)		
 <b>Technology costs</b>	REmap Reference Case			Optimistic case for renewables (lower costs for renewable energy systems, higher for fossil fuel technologies)			Pessimistic case for renewables (higher for renewable energy systems, lower for fossil fuel technologies)			–		
 <b>Carbon prices</b>	Reference (IEA WEO New Policies Scenario)			High (IEA WEO 2014, 450 ppm Scenario)			Low (IEA WEO 2014, Current Policies Scenario)			–		

the analysis include taxation policy, income and price elasticities and crowding out of capital. The latter has been chosen given its importance, as indicated by the literature, specially that dealing with the economic costs of climate change mitigation.

- Sensitivities affecting the energy system: as noted earlier, the energy system inputs are exogenous and fixed based on IRENA's REmap analysis. As such, any sensitivity analysis carried out would mainly capture the secondary effects. As an example, a decrease in fossil fuel prices would not translate into increased demand as the quantity remains fixed, blocking the primary effects of the sensitivity. The effects that will be observed are those related to the income effect. Nevertheless, in line with standard practice in the literature, four sensitivities affecting the energy system have been tested, namely: fossil fuel prices, carbon prices, technology costs and fossil fuel subsidies.

Table 8 displays the structure of the sensitivity analyses. In the first column, it shows the three main cases (i.e. the analysis presented in Chapter 2). The second and third columns show the two sets of sensitivity analyses carried out. For the fossil fuel price assumption, an additional tool run is carried out using low energy prices (notably oil). This is in line with the significant fall in prices registered during 2015 as shown in the fourth column.

The sensitivity analyses are not intended to be used as scenarios in their own right. The purpose is not to understand how crowding out of capital, for instance, affects the global economy but to test whether the economic impacts of a shift towards renewables are dependent on the assumptions made about crowding out of capital.

In order to isolate and assess the particular effects of each exogenous assumption, the sensitivity value for each is tested independently, keeping the other assumptions fixed to their original values. The sensitivity analysis on fossil fuel subsidies, for instance, reduces subsidies while holding constant other exogenous variables tested (oil, gas and coal prices, technology costs, carbon prices and assumptions about crowding out of capital) fixed. This assumes that the exogenous variables are independent from each other even though correlations might exist in some cases. For instance, reduced energy subsidies could decrease demand for oil products, affecting oil prices.

A brief discussion of each variable tested follows. The results are presented only for one of the macroeconomic variables analysed in this report, GDP. This encapsulates how the overall results are affected by each sensitivity.



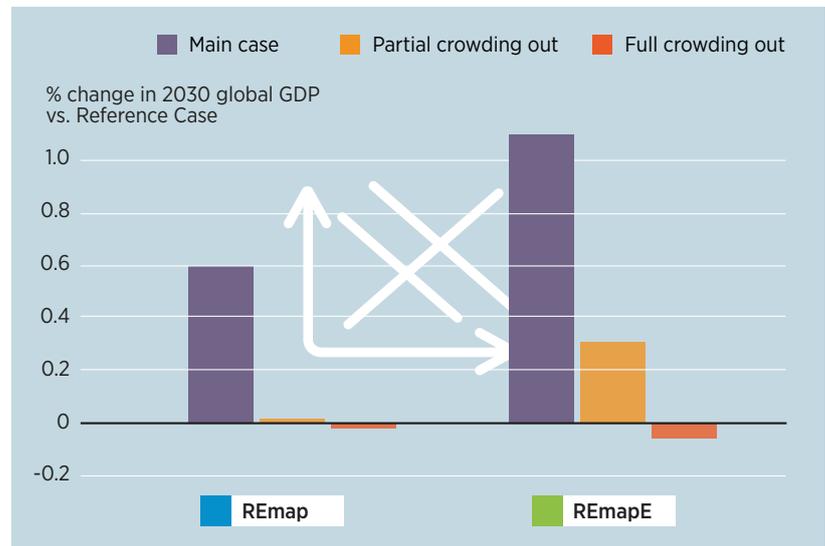
### SENSITIVITY AFFECTING THE ECONOMY

The literature on the economic costs of climate change mitigation suggests that crowding out of capital is a key concern, potentially increasing costs. A shift from a fuel-intensive world to a capital-intensive world will require higher upfront borrowing to finance the investments. The analysis assumes that these investment costs are earned back over time through electricity prices but the necessary financing for the initial investments must be available. Some economists have asserted that making this finance available could “crowd out” available finance to other sectors, potentially harming the economy. For instance, it could reduce investment in transport infrastructure or manufacturing capacity.

The potential effects of crowding out have been tested in the study through two sensitivities (see Table 8). In the full crowding out case, the tool forces savings in the economy to be equal to investment and excludes additional lending from banks (i.e. a fixed money supply). In the partial crowding out case, the tool assumes that savings need to be at least 50% of investment. The main case assumes there is no crowding out, and that the financial sector can provide the necessary loans for investing in renewables without reducing lending to other sectors.

The results show that the crowding out effect has a major influence on the results (Figure 14) in line with the literature on the topic. In the case of a full crowding out of capital, the impact on GDP is close to zero or slightly negative. This is particularly relevant in the REmapE Case, where investment is highest, and the crowding out assumption thus has the biggest effect. However, these negative effects are minor, and the sensitivity with a partial (50%) crowding out effect remains positive. Therefore, unless full crowding out takes place, GDP impacts are positive.

**Figure 14:** Impacts of crowding out of capital (2030 GDP size, % change vs the Reference Case)



### SENSITIVITIES AFFECTING THE ENERGY SECTOR

Four sensitivities are analysed on exogenous variables affecting the energy sector, namely fossil fuel subsidies, fossil fuel prices, technology costs and carbon prices. Since the energy balance is fixed in this analysis (as per the REmap analysis), these sensitivities only capture secondary effects. Future work could address this limitation in order to observe the full implications of these sensitivities on the results.



#### Reducing fossil fuel subsidies.

In the first sensitivity, fossil fuel subsidies are halved and in the second they are completely eliminated. While global GDP increases 0.60% and 1.10% in the REmap and REmapE cases, these values range from 0.57% to 0.60% and from 1.05% to 1.07% respectively in the sensitivities.



#### Changing fossil fuel prices.

The main cases in this study are assessed on the basis of the prices of fossil fuels from the IEA's New Policies Scenario in the 2014 WEO (IEA, 2014a) and in line with REmap analysis. In the first sensitivity, fossil fuel prices

are kept higher than in the main cases and are adopted from the Current Policies Scenario of the IEA WEO 2014. In the second sensitivity, the fossil fuel prices considered are lower than in the main cases and are adopted from the WEO's 450 ppm Scenario. A third additional case is analysed, in which prices are even lower, to reflect the recent developments in the oil market. The price for this sensitivity is based on the Low Oil Price Scenario of the latest WEO 2015 (IEA, 2015), which estimates a price of USD 55 per barrel in 2020 and USD 70 per barrel in 2030. The results show that, while global GDP increases by 0.60% and 1.10% in the main cases (REmap and REmapE respectively), these values range from 0.49% to 0.62% and from 0.86% to 1.10% respectively in different sensitivities.



#### **Evolving technology costs.**

The reference technology costs in the main cases are based on REmap. Two sensitivities of different evolutions of technology costs have been tested. In the first sensitivity, an optimistic case for renewables is considered i.e. lower

technology costs for renewables and slightly higher costs for conventional technologies with technological uncertainty. In the second sensitivity, a pessimistic case for renewables is considered where the opposite conditions are tested. In these sensitivities, the global GDP improvements in the REmap and REmapE cases range from 0.45% to 0.67% and from 0.77% to 1.17% respectively.



#### **Different carbon prices.**

The values and sectoral/geographical application of carbon prices in the main case are based on the New Policies Scenario of IEA's World Energy Outlook 2014 (IEA, 2014a). Two sensitivities are tested, one based on the 450ppm Scenario and the second on the Current Policies Scenario of the World Energy Outlook 2014. Compared to the main cases, where global GDP improves 0.60% and 1.10% in the REmap and REmapE cases respectively, the values range from 0.50% to 0.64% and from 0.92% to 1.14% in the respective sensitivities.



### 3.4 MAIN LIMITATIONS

Quantitative tools are useful for assessing the effects of policy decisions – in this case, the increased deployment of renewable energy. However, they are all based on assumptions and have limitations that should be considered when interpreting the results. This section outlines some of the main assumptions and limitations of the analysis along with a discussion of how they may affect the results.

#### EXOGENOUS AND FIXED ENERGY MIX

The energy mix of each country is exogenous to the analysis and is based on IRENA's REmap. It is also considered fixed in that any relationship between variables that may affect the energy mixes are excluded. The demand for the different energy sources, for example, does not respond to prices (i.e. zero price elasticity), which largely conditions the results of the sensitivities conducted. This limitation is linked to the objective of the study which was to analyse the economic effects of doubling the share of renewable energy as per the REmap analysis. This approach does have advantages. Most notable is the high degree of technological detail behind the exogenous energy mixes, especially given that REmap follows a bottom-up approach.

#### MACROECONOMIC AND WELFARE IMPACTS OF ENERGY ACCESS

Renewables can play a significant role in providing access to modern energy services and has a vast potential to improve welfare (see Box 12) and local economies. The benefits can be realised through two main mechanisms. The first is the economic ripple effects of the investments needed to provide energy access, nearly USD 50 billion each year until 2030 (IEA and World Bank, 2015). The second is the induced economic effect through, for instance, new opportunities for local businesses, reduced time spent collecting traditional sources of energy or enhanced productivity. The

present analysis does not account for these macroeconomic and welfare benefits due to data and methodological limitations. The GDP and welfare estimations provided in this report could thus be considered conservative. The socio-economic benefits of improved energy access through renewable energy are the subject of ongoing IRENA analysis.

#### AVAILABILITY OF RESOURCES TO SUPPORT RENEWABLE ENERGY DEPLOYMENT

The analysis assumes that the production capacities of the supplying sectors and the resources needed (financial and human, among others) are sufficient and do not impose a limit on renewable energy deployment. An analysis of how limited resources and capacities might affect the results is beyond the scope of this report. The results should therefore be interpreted in this context.

##### **Production capacity of the supplying sectors.**

Assumptions on the rates of capacity utilisation within the economy are among the most influential in economic modelling exercises. In many cases, it is assumed that all the available capacity is utilised, limiting the total production in the economy to the baseline values. However, the E3ME tool does not assume this, and therefore, if a policy is able to draw from underutilised resources, its overall impact is positive. For example, it is assumed that the steel, transport and service sectors do not have any limiting capacities and can continue generating output as needed to support the renewable energy deployment plans. In this way, the tool results include the multiplier effects of increased production and investment in supply chains.

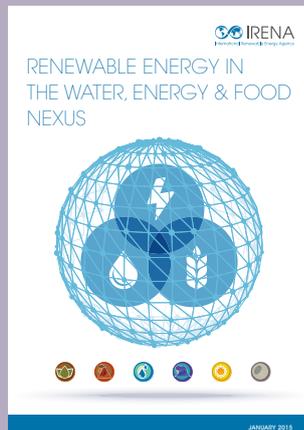
**Availability of financial resources.** The same principle is applied to capital markets, where it is assumed that additional financial resources are available. If banks see profitable opportunities for investment, they will be able to provide loans without reducing lending elsewhere (i.e. without crowding out investment in other sectors). As

**Box 16:** Impact of renewable energy deployment on water use in the power sector

The energy sector relies heavily on water for energy extraction and production, accounting for 15% of water withdrawals globally and up to 50% in some countries. In a water-constrained world, conflicts with other end uses, such as agriculture, are intensifying and further affected by climate change. It is, therefore, becoming necessary to decouple energy sector expansion from water use. Renewable energy technologies can contribute to this objective.

Solar PV and wind withdraw up to 200 times less water than conventional power generation options including coal, natural gas and nuclear. IRENA analysis of selected REmap countries (UK, US, Germany, Australia and India) finds that increasing renewables penetration significantly reduces water use in the power sector. On the back of a substantial scale-up of renewable energy deployment, especially solar PV and wind, water withdrawals in 2030 could decline by nearly half for the UK, by more than a quarter for the US, Germany and Australia, and over 10% in India. Although there is more hydropower capacity in the REmap cases, most plants are multi-purpose storing water in reservoirs. This is used for irrigation, water supply, flood control or recreation in addition to power generation. Therefore, allocating the entire evaporation from reservoirs to electricity generation is generally considered incorrect. Such assessments, however, require detailed data on cooling technologies and country-specific water withdrawal factors for all power generating options.

Source: IRENA, 2015



shown in the sensitivity analysis on crowding out, this can make an important difference to the results.

**Availability of human resources and skills.**

Limits on labour are set by the world's active population, and only one factor limits the jobs created as a result of renewable energy deployment. This is the total number of people who supply of labour for the production of economic goods and services, with no explicit treatment of skills requirements and availability. However, skills shortage in the sector poses one of the barriers for deployment today, necessitating policy makers to take action.

**Availability of other resources.**

Other resource limitations that may be considered in renewable energy plans are restrictions with land use and water availability, which impacts certain renewable sources such as bioenergy and hydropower. This limitation is particularly relevant to the REmap Case as it includes a significant bioenergy contribution by 2030. Land use requirements are likely to depend on the source of the bioenergy. For example, the share of biomass that comes from residues and waste has no additional land requirements while the share that comes from, energy crops requires additional land. This type of analysis requires a dedicated tool that goes beyond the capabilities of the current version of E3ME and is the subject of ongoing IRENA analysis. Nevertheless, the REmap electrification case shows that it is possible to double renewables without relying excessively on bioenergy. This reflects the literature, which indicates that the higher electrification of end uses can facilitate the transition. The same limitation applies to water use, where it is assumed that water needed for renewable energy is not in competition with any other end uses (see Box 16).

The analysis of the possible shortages of other resources needed for renewable energy deployment (e.g. basic elements like silicon) is beyond the scope of this report.

## ENERGY INVESTMENTS BEYOND THE POWER SECTOR

This study does not include the investments needed in end use sectors to achieve the REmap and REmapE cases, which is another disadvantage. This has some impact on the comparison of results between cases. However, this is not a major limitation in the analysis, since the capital stock in end use sectors needs to be replaced more often. The additional required investments compared to the Reference Case are thus lower than those in the power sector. Indeed, IRENA analysis (IRENA, 2015c) highlights that the power sector would require around three-quarters of the total investments needed to double the renewable energy share. In addition, the investments needed in biofuel production capacity in the REmap Case are not represented. However, these should be relatively minor in comparison to investments in the power sector in line with the 450 ppm Scenario in the IEA World Energy Investment Outlook (IEA, 2014b). In other words, the analysis in this report accounts for the majority of the investment needed, namely in the power sector.

The representation of investment in the power sector is more accurate than that in the oil and gas sectors, which is represented as a fixed proportion of output. This is another possible limitation to this analysis. It means the reduction of investment in the oil and gas sectors may be slightly undervalued in this analysis. This is because the price of fossil fuels between the analysed cases is assumed to be the same. Thus the decline in output and hence investment in these sectors is a result of reduced volume alone and not lower prices (which could be expected in a world with falling fossil fuel demand). This implies that the effects of renewable energy deployment on overall investment in the economy are overvalued

because the reduction from the oil and gas sectors is not entirely captured. However, this effect would be counterbalanced with the increased investments required in end use and biofuels, so the overall conclusions of this report are unlikely to be affected.

## COMPOSITION OF RETAIL ELECTRICITY PRICES

Retail electricity prices are determined as a fixed mark-up of wholesale electricity prices, which are based on the LCOE of each technology. This is weighted according to its share in the generation mix in each country and case. This can be considered as average rather than marginal pricing, which means that fixed and investment costs are included and there is no 'missing money' problem.<sup>48</sup> In computing the LCOE of each technology, investment, fuel and carbon costs are taken into account. Sensitivity analyses relating to technology costs, fossil fuel prices and carbon prices have been carried out for each one of these parameters. Once wholesale electricity prices are obtained, retail electricity prices are worked out as a fixed mark-up of the wholesale price. The mark-up includes the system costs associated with increased penetration of renewable energy (e.g. grid integration). This impact is relatively minor because the analysed power mixes from IRENA's REmap study already include additional back-up capacity needs.<sup>49</sup>

Calculating retail electricity prices in this manner fails to account for two factors. Firstly, the possible cost of supporting renewables (in cases where such costs are charged to electricity consumers). Secondly, the merit order effect and other influences that renewables may have on wholesale power markets. However, these prices only affect the overall macroeconomic results through the consumer price index,

48. 'Missing money' is a common problem in macroeconomic models representing the power sector in detail. If marginal pricing is assumed, only variable costs are covered for those technologies in the margin so the money corresponding to fixed and investment costs is missing (i.e. not paid from consumers to producers).

49. By adding additional gas capacity and assigning it a rather low capacity factor of around 35%.

in which electricity is a small fraction. These limitations are thus considered to have a limited impact on the overall results.

#### EXOGENOUS VARIABLES ACROSS CASES

This study assumes several variables to be constant across cases, notably technology costs, fossil fuel prices and carbon prices (as shown in Table 2). This makes the scenarios slightly less realistic. It influences the observed trade effects in fossil fuel exporting countries where the reduction of exports in the REmap Case is due to reduced volumes and not to reduced prices. However, it is necessary to keep these assumptions constant across cases to isolate the economic effects of renewable energy from the economic effects of a lower oil price, for instance.

#### CLIMATE CHANGE AND OTHER ENVIRONMENTAL EXTERNALITIES

The macroeconomic results presented do not incorporate an economic estimation of the effects of renewable energy on climate change mitigation nor the reduction of other environmental externalities. While these effects are accounted for in the welfare indicator, the GDP results do not include such valuation in terms of US dollars. This is due to the uncertainties and a wide range of conversion values (e.g. social costs of carbon, damage values) reported in the literature. The GDP improvements highlighted in this analysis could thus be considered conservative.

A ballpark estimation proves that additional benefits are in the same order of magnitude as reported GDP improvements. Renewable energy deployment in line with REmap could achieve an annual reduction of CO<sub>2</sub> emissions<sup>50</sup> of around 8.4 gigatonnes by 2030 (IRENA, 2016, forthcoming). This would indicate a social cost of carbon of USD 20-50/t<sup>51</sup>, implying an improvement in the global economy of USD 170-420 billion in 2030. This is comparable to the USD 706 billion added to global GDP

in 2030 in the REmap Case. These additional benefits would be even greater if reduced emissions from other greenhouse gases are included or if reduced environmental externalities from other pollutants are factored in.

#### BIOENERGY TRADE

Modern bioenergy will probably have a significant role in a global system based on renewable energy. Bioenergy is expected to increase, as outlined by IRENA research on the topic (e.g. IRENA, 2014c). Some countries, such as Canada, Nigeria, Russia and Ukraine, have the potential to become major bioenergy exporters. Bioenergy exports could partly offset the decline in the trade balance observed for some fossil-fuel exporting countries, such as Russia. However, bioenergy trade is not characterised in this analysis so these effects are not shown in the trade balance results presented in this report.

#### DATA GAPS

Macro-econometric tools are data-intensive. They require, for instance, detailed historical datasets on the structure of the economy (time series covering the period since 1970 and input-output tables with sectoral disaggregation). The data are collected from statistical offices and compiled according to accounting conventions. There is at present no equivalent to the Global Trade Analysis project (GTAP) database maintained by Purdue University and widely used in computable general equilibrium (CGE) modelling for time series. This means a large amount of resources must be put into collecting suitable datasets. Data limitations can prove to be a particular drawback when trying to obtain country-level results for economies without solid statistical institutions and procedures. The quality of existing renewable energy data thus remains uneven, necessitating greater harmonisation of data reporting categories.

50. Excluding other greenhouse gases such as methane. If the avoided emissions of these gases were also taken into account, the additional economic benefit of renewable energy deployment could be even greater.

51. Real 2015.

### 3.5 KEY FINDINGS AND WAY FORWARD

The analysis presented in this report shows that doubling the share of renewables in the energy mix will bring substantial benefits to the global economy. In particular, global GDP in 2030 will increase by 0.6%-1.1%, adding between USD 706 billion and USD 1.3 trillion to the economy. These GDP improvements can be considered conservative since they do not account for the avoided negative economic impacts of climate change and environmental externalities, the positive impacts of expanding access to modern energy services, or the contribution of bioenergy-related activities to the GDP.

The results obtained in this report stand the normal tests of econometrics. A sensitivity analysis has been carried out, which highlights the importance of crowding out of capital.

Like all quantitative tools, the one used for this analysis has limitations that need to be considered when interpreting its results. One of this study's drawbacks is that it assumes an exogenous, fixed energy mix. The resulting price elasticity of demand in the study's underlying tool is thus zero. Secondly, energy access remains an undervalued variable due to pre-existing data and methodology limitations. Thirdly, and owing to the scope of this report, the tool assumes that the production capacities of supplying sectors and the financial, human and other resources needed are sufficient. It assumes they do not impose a limit on renewable energy deployment. The results of this report should therefore be interpreted in this context.

#### Finally, the main limitations of this analysis define a path forward for future research outlined below;

- Use a more dynamic approach and explore the effects of variable demand elasticity.
- Estimate the macroeconomic and welfare impacts of enhanced energy access through renewables, building on IRENA's continuing work;
- Examine the structural and distributional effects of renewable energy deployment to understand the economic sectors most affected;
- Analyse skills availability and needs in the renewable energy sector to address skills shortages (IRENA, 2013);
- Develop an indicator of energy equipment trade based on work carried out by institutions such as the OECD or UNEP. An indicator of this type would shed light on the location of energy equipment (e.g. turbines, solar panels) manufacture and demand. It would thus reveal trade flows, and
- Refine the analysis by adding more countries or new economic variables such as household incomes and consumption.





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THE WAY  
FORWARD

# THE WAY FORWARD

The great energy challenge of the future is to meet the demand growth of a growing world. Decisions made today on energy sector investments and infrastructure have long-lasting implications. Environmental consciousness and energy security concerns have compelled policy makers to explore energy supply options that are cost-effective, reliable, secure and environmentally sustainable. Renewable energy is a key part of the solution. It can contribute to the long-term resilience of the global energy system, which underpins economic development.

Recent global agreements on climate and sustainable development confirm the emerging consensus on the role of renewables, which is further attested by the adoption of renewable energy targets in at least 164 countries to date. As countries around the world step up efforts in this direction, a better understanding of the wider economic impact will support informed decision-making. This, in turn, will help to maximise the benefits of an accelerated transition to renewables.

*Renewable Energy Benefits: Measuring the Economics* provides the first global quantification of the macroeconomic impact of renewable energy deployment, as estimated by selected variables. The assessment uses a macro-econometric tool which allows to estimate the impact of deployment on GDP, welfare, employment and trade. As the results show, doubling the share of renewables in the energy mix by 2030 would increase global GDP by up to 1.1 percent, improve welfare by up to 3.7 percent and support over 24 million jobs in the sector.

Despite their many benefits and their growing competitiveness, the deployment of renewable energy technologies still falls short of its potential. This is partly because markets fail to account for externalities and to consider asymmetry of information, further aggravated by system inertia. As a result, renewable energy deployment requires a conducive enabling environment to level the playing field supported by firm government commitment.

## THE WAY FORWARD: THE CENTRAL ROLE OF ENABLING FRAMEWORKS

Government commitments can take the form of credible, time-bound renewable energy targets, which serve to anchor investor confidence and set out the trajectory for development of the sector. Importantly, targets must be backed by dedicated policies and regulatory frameworks. These ensure predictable revenue stream for projects, create a stable investment environment and can help to overcome non-economic barriers. While a deployment policy triggers investment in the sector, a mix of policies can support the broader development of the enabling environment.

Effective **deployment policies** have supported the growth of renewables globally. More than 145 countries (as of early 2015) have introduced regulatory (e.g. feed-in tariff, net metering, auctions), and fiscal incentives and public financing (e.g. capital subsidy, investment or production tax credit). This number has increased nearly ten times over the past decade. Renewables now make up a distinct share of the energy mix in several countries, with substantial growth anticipated in the coming decades. Rapidly declining technology costs and increasing shares of variable generation have led



to a dramatic shift in the factors that influence policy-making in recent years. Accordingly, governments are adapting existing policies to ensure that incentives are appropriately set, while increasing transparency and stability. For example, to adapt to rapidly decreasing costs, a clear shift towards market-based mechanisms, such as renewable energy auctions, is observed. Renewable energy policies have focused mainly on the electricity sector. There is already a trend towards greater adoption of policies for the heating/cooling and transportation sectors, but further attention will be required for the end-use sectors.

Deployment policies need to be part of a broad range of cross-cutting policy instruments – the “**policy mix**” – that supports the energy transition. Tailored to specific country conditions and the level of maturity of the sector, the policy mix should focus on adopting a system-level approach, building institutional and human capacity, strengthening domestic industry and creating an investment-friendly environment.

■ **A system-level approach to policy making is required.** Renewable energy costs continue to fall and parity with conventional options is reached in many more markets over the coming years. With greater competitiveness, support will need to shift from an exclusive focus on financial incentives for renewables towards ensuring their deeper integration with the overall design and functioning of the energy market. Growing renewable energy deployment is already transforming the ownership structures in the energy sector, driven mainly by the rise in distributed generation. Households, cooperatives and large energy consumers across markets are increasingly making a choice to localize energy production – a trend that is expected to continue. This transformation would mean that the economy-wide effects of the transition, estimated in this report, would be distributed differently across energy sector stakeholders. Taking these developments into

account, policy-making will have to adopt a system-level approach to balance the ambitions of established players with those of new entrants and other stakeholders. This will ensure the smooth integration of renewables and the long-term reliability of the energy system.

■ **Institutional development is essential to support sustainable renewable energy deployment.**

The pace of the energy transition will be strongly influenced by the abilities of individuals and institutions in the energy sector to take informed and effective decisions on the use of available resources. In many countries, institutional capacities remain weak, affecting awareness, policy design and implementation processes. Where such capacities exist, they are commonly restricted by a lack of resources. To strengthen and empower institutions, it is crucial to identify, assess and address existing barriers to their modes of operation and development. Cross-sectoral needs assessments should guide the elaboration of national capacity-building programmes for the energy sector. Such initiatives should focus on establishing appropriate steering processes, institutionalising inter-sectoral coordination mechanisms, and creating or strengthening specialised energy and renewable energy institutions. Renewable energy deployment also requires strategies that achieve better synergies between different stakeholders in the sector. For example, power utilities and Independent Power Producers are typically active in energy reforms and should systematically be involved in national and regional energy dialogues as well as in setting renewable energy targets. Targeted capacity-building activities should be provided to stakeholders, including ministries in charge of energy, renewable energy funds or facilities, regulatory authorities, and electricity production, distribution and transmission companies. All these activities should respond to needs and opportunities on a demand-driven basis.



■ **Skills development through education and training is essential to support the expansion of the renewable energy sector.**

This requires systematic access across all layers of the society to education and training in relevant fields, including engineering, economics, science, environmental management, finance, business and commerce. Professional training, as well as school or university curricula must evolve adequately to cover renewable energy, sustainability and climate change. Vocational training programmes can also offer opportunities to acquire specialisation and take advantage of the growing renewable energy job market. The elaboration of specific, certified skills and the categorisation of trainees based on their level of experience and training is recommended. Policies and measures should target the development of skills, both through financial support and through strategic planning to meet demand for specific skills. Planning that integrates education and training policies within national renewable energy strategies has proven to be essential. National renewable energy policies and action plans

could include support policies that incorporate renewable energy into technical and tertiary curricula, develop training institutes and centres of excellence and provide dedicated financial support. These policies should be accompanied by continued collaboration between industry and policy makers from the energy and education sectors. In addition, **R&D** is needed to stimulate technological breakthroughs, improve products and services, and increase the applicability of technologies to local conditions. These can accelerate deployment, reduce costs and address country-specific issues.

■ **Strengthening domestic capabilities and boosting the development of local industries can help to maximise the benefits of deploying renewables.**

As a result of increasing renewable energy deployment, new markets will emerge, creating new trade flows while providing opportunities for all economies to localise different segments of the renewable energy value chain. The segments that can be localised depend on the state and competitiveness of local complementary industries as well as the



projected demand for goods and services. Some segments, such as construction materials and services, are more easily localised than others, such as manufacturing. Cross-cutting policy interventions, like industrial upgrades, supplier-development programmes and industrial-cluster cultivation can contribute to increased competitiveness and production quality. Nascent industries can be further supported through measures that create demand for local goods and services. However, these measures need to be planned with a target deadline and designed in a way that ensures technology transfer and leverages existing industrial capabilities.

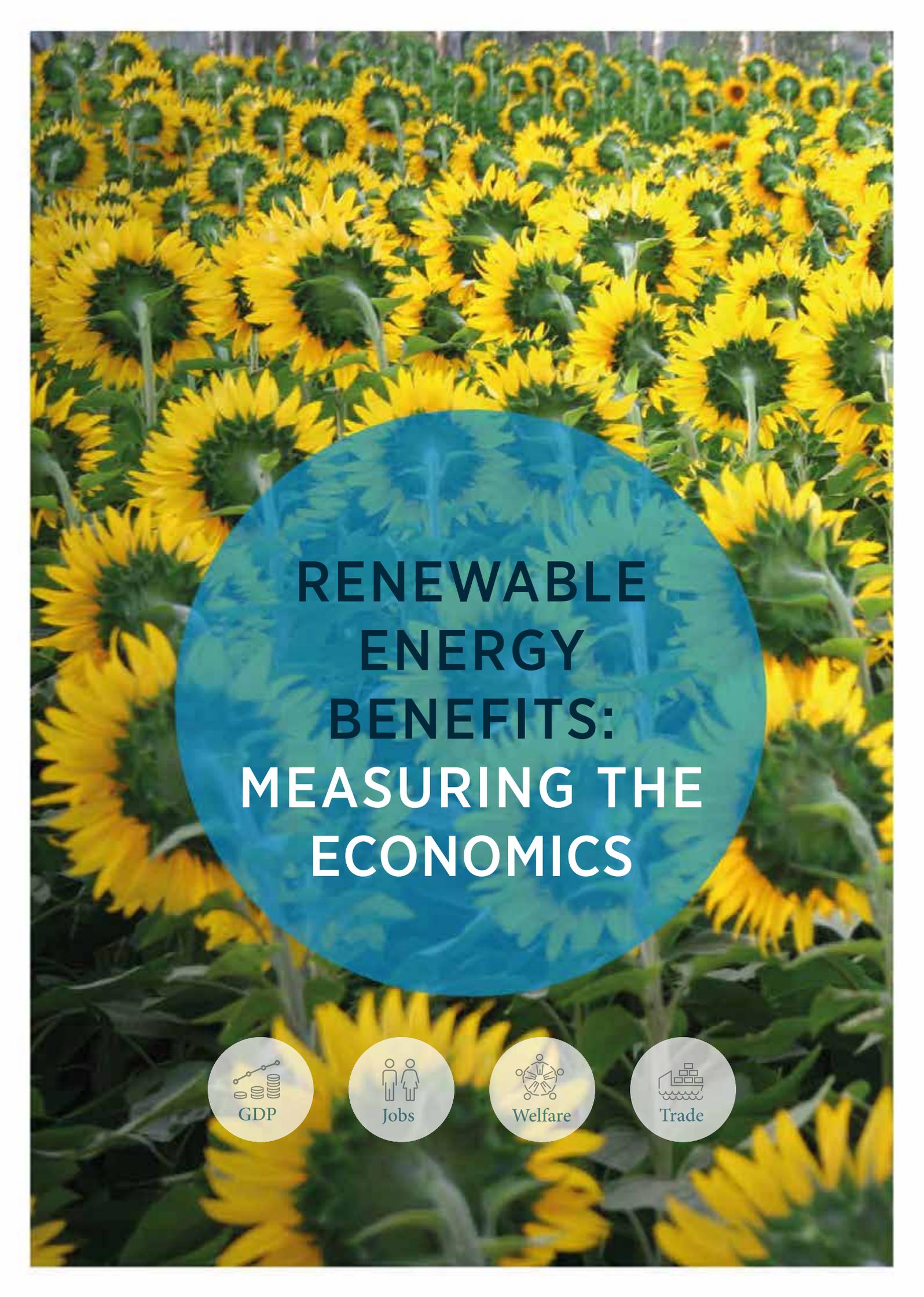
■ **An investment-friendly environment is essential to overcome financing barriers and attract investors.** To double the share of renewables by 2030, global annual investments in the renewable power sector need to be in the range of USD 500 billion to USD 750 billion between now and 2030 (compared to over USD 270 billion in 2014). The lion's share of new investments will need to come from private sources. As deployment grows and new markets emerge, developers are improving in forecasting cash-flows, while financiers are able to more accurately assess risk and design financing products suited for renewable energy projects. Nevertheless, actual and perceived risks continue to slow down investment growth in renewable energy, especially in new markets. Policy makers and international financial institutions must deploy the right policy and financial tools to address these risks and mobilise private sector investment. Public funding will continue to remain an important catalyst and will need to increase. Ample experience shows that public finance can de-risk investments and thus leverage considerable funding from private sources, both domestic and international. Any strategy to mobilise private investment needs to focus on risk mitigation instruments and other financing tools, both to develop a strong pipeline of projects, and to unlock private

project financing and refinancing opportunities. Investment strategies need to be tailored to each phase of the renewable energy project cycle: planning, construction and operation. Given that investment decisions today can lock-in energy systems and associated emissions for decades, a greater focus is needed on planning in the short-term to ensure the development of a pipeline of attractive renewable energy projects. The success of any investment strategy will rely on the active participation of a broad spectrum of private and public actors, including development finance institutions, climate finance institutions, private equity funds, institutional investors, export credit agencies and green and commercial banks.

## CONCLUSIONS

As countries strengthen their policy and regulatory frameworks to transform their energy systems, they have a unique opportunity to meet climate goals while also fuelling economic growth and improving welfare. Scaling up renewable energy can generate new sources of growth, increase incomes, create jobs and improve welfare. Going forward, holistic, adaptable frameworks that capture and measure the multiple impacts of renewable energy deployment can tip the balance in favour of low-carbon investments.

Policy makers responsible for taking today's critical investment decisions need more complete analysis and evidence of the broad impacts of their choices. *IRENA's Renewable Energy Benefits: Measuring the Economics*, provides a first glimpse of the great opportunities offered by the energy transition, paving the way for further exploration of the topic.



# RENEWABLE ENERGY BENEFITS: MEASURING THE ECONOMICS



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# ANNEX 1: DETAILED DESCRIPTION OF THE E3ME TOOL

## INTRODUCTION

This section provides a summary of the E3ME tool. A more complete description including the full technical manual is available on the tool website [www.e3me.com](http://www.e3me.com)

## KEY STRENGTHS

E3ME is a computer-based tool of the world's economic and energy systems and the environment.

### The key strengths of E3ME are:

- close integration of the economy, energy systems and the environment with explicit linkages between each component;
- detailed sectoral disaggregation in the tool's classifications allowing for the analysis of similarly detailed cases;
- global coverage while allowing for analysis at the national level for major economies;
- bottom-up treatment of the power sector allowing a detailed analysis of the renewables mix. For other sectors, renewable energy is represented with a top-down framework;
- the econometric approach, which provides a strong empirical basis for the tool and means it is not reliant on some of the restrictive assumptions seen in CGE models; and
- the econometric specification of the tool, making it suitable for short and medium-term assessment as well as longer-term trends.

## MAIN DIMENSIONS OF THE TOOL

### The main dimensions of E3ME are:

- 59 regions – all major world economies, the EU 28 and EU candidate countries plus other countries' economies grouped;
- 43 or 69 (Europe) industry sectors based on standard international classifications
- 28 or 43 (Europe) categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of airborne emissions (where data are available) including the six greenhouse gases monitored under the Kyoto protocol

## TOOL APPLICATIONS

### E3ME has recently been used in the following studies:

- the EU's official assessment of its 2030 climate and energy targets and an assessment of the EU's long-term Energy Roadmap
- assessment of decarbonisation options in Latin America
- assessment of low-carbon policy in East Asia
- assessment of the impacts of phasing out fossil fuel subsidies in India and Indonesia

The tool website provides a full list of academic publications that have used the tool, stretching back to the 1990s.

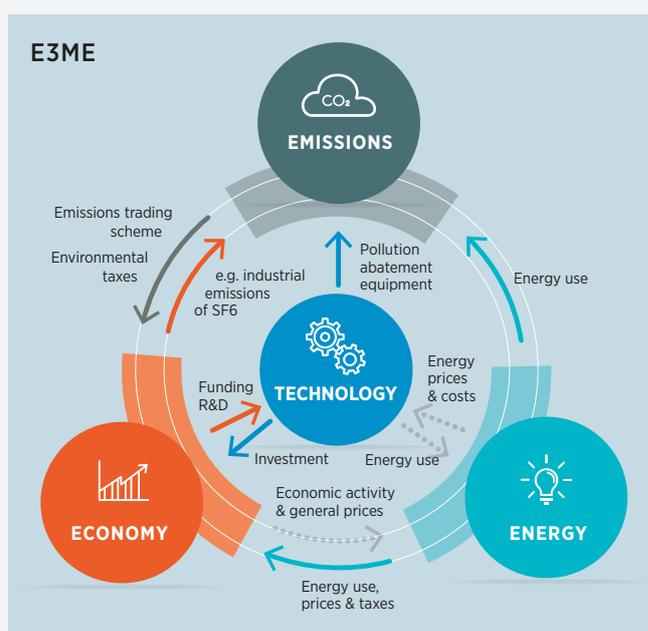
## E3ME AS AN E3 TOOL

### The E3 interactions

Figure below shows how the three components (modules) of the tool – energy, environment (emissions) and economy (i.e. the three Es in an E3 tool) fit together. The linkages between the tool components are shown explicitly by the arrows that indicate which values are transmitted between components.

The dotted arrows show interactions built into the tool but disabled for this report. These affect the energy sector and are fixed to match the results from REmap (as explained in Chapter 2).

**Figure A1:** E3 linkages in the E3ME tool



### Estimations of energy demand and feedbacks to the economy

The standard version of E3ME includes five sets of equations for energy demand – an aggregate equation set and one set for each of the four main fuel types. However, in this study the equations were not used because energy demand was instead made consistent with the projections in REmap.

However, the linkages to the economy are included. Feedbacks to the economy for the main section occur through the input-output relationships in the tool, which determine output levels within the energy extraction and distribution sectors. For example, if the steel sector uses 10% less coal in energy terms, it is assumed that (after correcting for prices) consumption of coal by the steel sector in economic terms also falls by 10%. Production of coal will be affected either in the same country or through the trade relationships described below.

### Treatment of renewables

E3ME covers low-carbon technologies in the power sector through the FTT power sector model (Mercure, 2012). Although FTT can provide estimates of renewable shares itself, when considering cases of different renewables penetration rates it can fix the renewables shares as defined in the cases analysed. The tool will then determine an electricity price based on average LCOE of the power mix. The tool will also feedback fuel consumption and the required investment to the economic part of the tool.

Final use of biofuels is also included in the tool's energy equations. The use of other renewables by final energy users (e.g. decentralised solar) is covered by the tool's classifications but at a lower level of detail.

### The role of technology

Technological progress plays an important role in the E3ME tool, affecting all three Es: economy, energy and environment. The approach to constructing the measure of technological progress in E3ME is adapted from that of Lee et al. (1990). It adopts a direct measure of technological progress by using cumulative gross investment but this is altered by using data on R&D expenditure, thus forming a quality adjusted measure of investment. The tool's endogenous technical progress indicators appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in E3ME's energy and materials demand equations to capture energy/resource savings technologies as well as pollution abatement equipment.

As described above, E3ME includes a set of specific technologies for the power sector, including both conventional and renewable options. These options are assigned specific characteristics, relating to cost, build time and intermittency, for instance.

### Energy prices

A large global reduction in fossil fuel demand could prompt a fall in global energy prices. In the analysis in this report, fossil fuel prices are set as exogenous across all cases to match the assumptions in REmap. Cost-supply curves have been used only to determine the source of fuel supplies rather than prices. Electricity prices are set using an average LCOE calculation as described above.

### Material consumption

The specification of the materials submodel in E3ME follows that of the energy submodel. The units of analysis are thousands of tonnes, and materials demands are split into seven types of material and 16 user groups. The level of material consumption is estimated as a function of economic activity rates, relative prices and technology. Feedbacks are provided to the material extraction sectors (agriculture and mining).

Materials used for energy are not included in the materials demand equations but are instead estimated using a fixed energy-weight ratio. In the analysis in this report, biomass used for energy was not counted in the results for materials demand.

## GDP AND ECONOMIC INDICATORS

### GDP and output

GDP is formed as the sum of household expenditure, government consumption, investment and international trade (see below). With the exception of government consumption, which is treated as exogenous, there are estimated econometric equations for each component. Each equation includes a combination of quantity and price terms, and tool parameters are estimated using historical datasets covering each year since 1970. They are summarised in turn in the paragraphs below.

The tool also provides estimates of economic output and Gross Value Added by sector. Output by product group is worked out in a similar way to GDP by summing across the components of demand (including intermediate demand). Gross Value Added by industry is calculated by subtracting intermediate costs from output and correcting for net taxes.

### Household consumption

Household consumption (or household expenditure) is determined using two sets of econometric equations. The first estimates total household budgets, which are assumed in the long run to move in line broadly with changes in real incomes. However, other factors like demographic development may affect aggregate savings ratios so the relationship is not entirely one-to-one. In the short run, additional factors may also affect rates of consumption. Changes to inflation rates or to unemployment rates may cause households to delay major purchases due to uncertainty over future incomes or prices.

Once the tool has estimated the aggregate consumption, a second set of equations determines spending by product group. In these equations, relative prices are used to estimate spending on each product. Consumption by each product is then scaled to be consistent with the total.

### Investment

Investment (Gross Fixed Capital Formation) is one of the most important equation sets within the tool. Following post-Keynesian theory, investment is made by companies in expectation of future profits. Although relative prices and interest rates can also determine rates of investment, there is no explicit representation of finance in E3ME and it is assumed that banks make the necessary money available for lending. This assumption is tested in the crowding out sensitivities in the main report.

Stock building can be an important component of short-term economic growth but is less important in the long term. In E3ME, stock building is treated as exogenous.

### Bilateral trade between regions

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). For most sectors, trade is modelled in three stages:

- econometric estimation of regional sectoral import demand
- econometric estimation of regional bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

### Trade in fossil fuels

Trade in fossil fuels is modelled using a different approach because the commoditised nature of fuels violates the Armington assumption of differentiated production. A cost-supply curve approach is applied instead. It is assumed that the lowest-cost sources are used first given the existing rates of extraction (as a ratio of reserves) and within a range of uncertainty (i.e. production is not fully optimised). As discussed in the report, this approach provides important insights into the aggregate trade effects.

### Welfare

As discussed in this report, there is no standardised treatment of welfare in macroeconomic analysis. The indicator designed draws on the outputs available from the model and covers the economic, social and environmental dimensions of welfare. Results for each component are provided as percentage difference from reference so readers can use their own weightings to estimate aggregate welfare outcomes.

## Economic multipliers and price formation

### Multipliers in E3ME

There are several loops of dependency in E3ME, which result in effects similar to multipliers. Supply chains are represented by input-output tables which produce Type I multipliers. There is another loop from output to employment, incomes, household demand and further output, which gives the induced effects associated with Type II multipliers.

However, there are additional feedback loops in E3ME. Expectations of higher future output can lead to additional investment, in turn leading to demand for investment goods (plus supply chain effects). There are also trade interactions because an increase in GDP in one country will lead to higher demand for imports from other countries (which can feed back to the first country etc).

It should also be noted that E3ME includes measures of capacity that could limit multiplier effects. The limit is most obvious in the labour market where population places a constraint on participation. Rising wages caused by a tighter labour market could crowd out some employment increases (see labour market section below). In other sectors, implicit capacity constraints are modelled using econometric equations which can affect prices (see below). These equations are described in more detail in the tool manual.

### Price formation in E3ME

Aside from wages (see below), E3ME's economic module includes three sets of prices: domestic prices, import prices and export prices. Each is determined in the tool as a mark-up of unit costs.

In the long run it is assumed that all changes in production costs are passed on to final prices unless international competition prevents this from happening (e.g. in commoditised sectors). However, this constraint is not applied in the short run so there is an adjustment path for prices. Other factors that could affect prices included investment and R&D since a higher quality product commands a higher price.

As noted above, the measures of capacity in the tool can also affect price formation. If a sector's output increases towards capacity, firms will have the incentive to increase prices and their rates of profitability. This is typically a short-term effect since in the long run companies will invest in new capacity. Nevertheless, it is important as a determinant of overall output levels.

## THE LABOUR MARKET

The treatment of the labour market distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

Employment is a function of economic output, real wage rates, average working hours and technology. In the results presented in this report, employment impacts are mostly determined by changes in economic output (notably in sectors that produce renewables equipment) and changes in wage rates. Wage rates are determined in the tool using a union-bargaining approach and typically increase when unemployment falls, offsetting some of the initial employment gains.

A full specification of all the E3ME equations is provided in the tool manual.

### Unemployment

The labour force is determined by multiplying labour market participation rates by population. Unemployment (both voluntary and involuntary) is worked out by taking the difference between the labour force and employment.

### Econometric specification

The econometric techniques used to specify the functional form of the equations are the concepts of cointegration and error-correction methodology, particularly as promoted by Engle and Granger (1987) and Hendry et al. (1984). The process involves two stages. The first is a levels relationship, whereby an attempt is made to identify the existence of a cointegrating relationship between the chosen variables. This is selected on the basis of economic theory and a priori reasoning. For example, the list of variables for employment demand contains real output, real wage costs, hours worked, energy prices and the two measures of technological progress. If a cointegrating relationship exists then the second stage regression is carried out. This is known as the error-correction representation. It involves a dynamic, first-difference regression of all the variables from the first stage. This is accompanied by lags of the dependent variable, lagged differences of the exogenous variables and the error-correction term (the lagged residual from the first stage regression).

Stationarity tests on the residual from the levels equation are performed to check whether a cointegrating set is obtained. Due to the size of the tool, the equations are estimated individually rather than through a cointegrating VAR. For both regressions, the estimation technique used is instrumental variables. This is principally because of the simultaneous nature of many of the relationships e.g. wage, employment and price determination. E3ME's parameter estimation is carried out using a customised set of software routines based in the Ox programming language (Doornik, 2007). Its main advantage is that parameters for all sectors and countries may be estimated using an automated approach.

## COMPARISON WITH CGE MODELS

E3ME is often compared to CGE models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, beneath the surface there are substantial differences, and it is important to be aware of this when interpreting tool results. The two types of models come from distinct economic backgrounds. They are in general consistent in their accounting and identity balances but differ substantially in their treatment of behavioural relationships.

Ultimately this comes down to assumptions about optimisation. The CGE tool favours fixing behaviour in line with economic theory. For example, it assumes that individuals act rationally in their own self-interest and that prices adjust to market clearing rates. In this way aggregate demand automatically adjusts to meet potential supply, and output levels are determined by available capacity.

By contrast, econometric models like E3ME interrogate historical datasets to determine behavioural factors on an empirical basis. They do not assume optimal behaviour. The tool is demand-driven and makes the assumption that supply adjusts to meet demand (subject to any supply constraints) but at a level likely to be below maximum capacity.

This has important practical implications for scenario analysis, including scenarios of energy policy. The assumptions of optimisation in CGE models mean that all resources are fully utilised and it is not possible to increase economic output and employment by adding regulation. On the other hand, E3ME allows for the possibility of unused capital and labour resources that may be utilised under the right policy conditions. It is therefore possible (although not guaranteed) that additional regulation could lead to increases in investment, output and employment. For example, as demonstrated in this report, the additional investment required to increase renewables capacity could lead to additional job creation and multiplier effects, depending on how the investment is financed.

The econometric specification in E3ME follows an error-correction methodology that estimates both the impacts of short-term shocks and the path that the key tool variables follow towards a long-term outcome. The equations are estimated separately for each sector and region. Further information about the approach is provided in the tool manual.

## ANNEX 2: METHODS TO ESTIMATE SOCIO-ECONOMIC IMPACTS

A range of methods, both quantitative and qualitative, can be applied to assess the economic impact of implementing different energy policies and deploying varying energy technologies across diverse geographical areas. A comprehensive review of these methods employed to analyse the impact of future scenarios of renewables deployment can be found in IRENA's report *The Socio-economic Benefits of Solar and Wind Energy* (IRENA and CEM, 2014).

### GROSS METHODS: THE RENEWABLE ENERGY SECTOR ALONE

Gross methods consider only the effects of a particular sector and potentially its supply chain on the economy. For the renewables sector, this implies assessing its contribution to the economy, but without taking into account the effects on other sectors such as fossil fuels. Gross methods on their own cannot provide estimates of macroeconomic impacts and are therefore less relevant to the present study. The Box A1 provides some examples of gross methods. Further information about the approach is provided in IRENA and CEM (2014).

### NET METHODS: THE FULL ECONOMY

Net methods aim to examine the effects of a sector across the economy as a whole, including the positive effects in the sector itself and its suppliers and the negative impacts of displaced activities. The following methods are examples of such an approach:

- Net input-output methods show how goods and services are bought and sold across the productive sectors of the economy. They compare two scenarios to obtain net results.<sup>52</sup> They have two key limitations in that they exclude the effects of changes in electricity prices as well as international trade and important economic actors such as households and governments.
- Macro-econometric models go beyond the input-output analysis and include households, the public sector and international trade. They also introduce price-based interactions through econometric relationships based on historically observed data.
- CGE models are similar in coverage to macro-econometric models. However, they model the economy from a supply side perspective (see next section) and assume that markets are perfect.
- Economic simulation models provide an ad hoc representation of real world relationships without a specific underlying economic paradigm.

### Box A1: Examples of gross methods

One of the most commonly used methods for gross analysis is the employment factors, which enables the calculation of gross employment effects without using a large-scale modelling tool (IRENA, 2013). Employment factors are recommended for quick and simple assessments and can only provide employment figures without other aspects of economic value creation. This method has been used to estimate employment in renewable energy at a global scale (IRENA, 2015; Teske et al., 2012) and a national scale, for instance in Brazil (Simas and Pacca, 2014), South Africa (Rutovitz et al., 2010) and the US (Wei et al., 2010). It has been used at a regional scale (e.g. for the Middle East by van der Zwaan et al., 2013). The study on the Middle East concludes that to achieve ambitious climate change mitigation goals, the renewable energy sector in the region would employ around 180,000 direct and indirect workers in 2030.

More advanced gross methods estimate employment and value added for the renewable energy sector and its suppliers (e.g. the steel sector). Examples are the supply chain and gross input-output analyses used in studies carried out in the US (the JEDI tool developed by the US National Renewable Energy Laboratory) and Spain (Greenpeace & Abay Asesores, 2014). The latter, for instance, concludes that the renewable energy sector contributed around 1.3% to Spanish GDP in 2015.

Table A1 presents an overview of the main features of each method, including key attributes, applicability, resources needed and data requirements. It shows that the net input-output method requires less data than the other methods reviewed because it only accounts for productive sectors. The other methods require more data as they cover a broader set of variables.

A key methodological challenge in net macroeconomic analyses is how to bring together the technologically detailed approach needed to assess the energy system and the broader economy-wide analysis required to provide macroeconomic results. This report adopts a soft link (i.e. output from the former being an

### Box A2: Linking energy systems and macroeconomic analysis

Energy systems analysis is based on detailed representations of the energy sector and its technologies but usually fails to represent the economic implications of each energy mix. Meanwhile, macroeconomic analysis tends to be less detailed when it comes to representing the energy sector (since it is only one of many sectors). Cutting edge research aims to link both together – a challenging task.

A soft link is a possible approach in which the results of an energy systems analysis are the inputs to a macroeconomic tool to provide a full set of economic indicators. For example, the European Commission has often adopted this approach by first applying the PRIMES energy system model and then feeding the results into macroeconomic models such as the E3ME and GEM E-3 (European Commission, 2014). Another example is Pöyry's energy system model, which was employed jointly with the E3ME macro-econometric model to assess the deployment of wind energy in Ireland (Pöyry Management Consulting and Cambridge Econometrics, 2014). This report follows a similar approach, in which the energy mixes produced by REmap 2030 are the input for the macroeconomic model E3ME.

input to the latter but without the two approaches being part of one single quantitative framework). This is the approach of the European Commission when analysing the macroeconomic impacts of energy and climate policies (see box).

Following the review of the methods that can be used to conduct a net assessment, two were identified that best meet the objectives of the present study (i.e. using a proven theoretical foundation to estimate the impacts of renewables deployment on GDP, welfare, employment and trade). The CGE and macro-econometric modelling methods are discussed in the following section.

#### NET METHODS: CGE VERSUS MACRO-ECONOMETRIC

The two modelling methods that are most commonly applied for whole-economy analysis of energy policies are computable general equilibrium (CGE) models and macro-econometric models.

Although the two methods are applied for similar types of analysis, they follow different sets of assumptions and economic theories. CGE methods are based on neoclassical assumptions about perfect markets, complete rationality and optimising behaviour, while macro-econometric methods follow a post-Keynesian approach. They are based on estimates of imperfect (real) behaviour based on historical datasets. The box below provides more details on the theoretical differences between both methods.

Table A1: Overview of Net Approaches

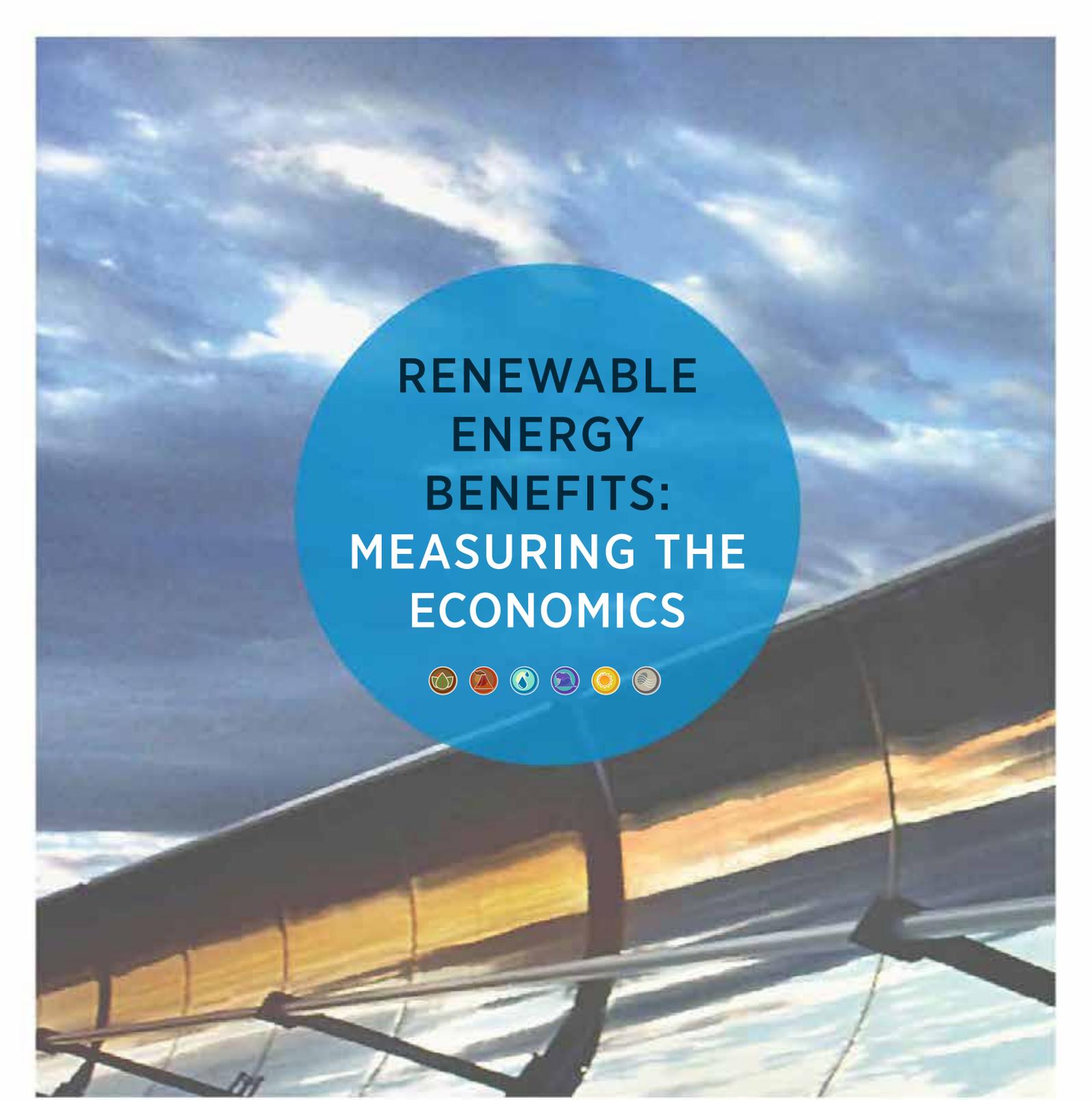
Net approach	Net input-output modelling	Comprehensive economic models (all economic sectors)		
		Macro-econometric	Computable general equilibrium (CGE)	Economic simulation
Key attributes	Medium data requirements: very limited dynamics	Assumed relations require time-series data for parameterisation	Assumption of optimising agents and perfect markets	Complex structures with many feedback loops
Applicability	Rough net assessment for the short term	Short to medium term assessments	Long term assessments	Long term assessments
Resources needed	Medium to high	Very high	Very high	Very high
Critical assumptions/data requirements	<ul style="list-style-type: none"> <li>■ Imports (and hence domestic production), exports, labour productivity, labour input by RET</li> <li>■ Development of economic and demographic growth, energy efficiency, fossil fuel prices, RET generation costs and CO<sub>2</sub> prices</li> </ul>			

**Box A3:** Details on the theoretical differences between CGE and macro-econometric methods

CGE tool:	Macro-econometric tool:
<ul style="list-style-type: none"> <li>■ perfect competition</li> <li>■ constant returns to scale</li> <li>■ equilibrium solution</li> <li>■ full employment or voluntary unemployment only</li> <li>■ projection based on a base year of data</li> <li>■ can be guess-estimated parameters</li> </ul>	<ul style="list-style-type: none"> <li>■ varying competition over sectors</li> <li>■ varying returns to scale</li> <li>■ supply matches demand but may be less than potential supply</li> <li>■ voluntary and involuntary unemployment</li> <li>■ projection based on historical relationships, with time-series data required</li> </ul>

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