Assessing the missed benefits of countries' national contributions

Results and methodology to quantify the possible co-benefits from ambitious greenhouse gas reductions of countries

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Niklas Höhne, Thomas Day, Gesine Hänsel, Hanna Fekete

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NewClimate – Institute for Climate Policy and Global Sustainability gGmbH
www.newclimate.org | info@newclimate.org | T +49 221 999 833-02 | F +49 221 999 833-19
Cologne office: Am Hof 20-26 | 50667 Köln | Germany | Berlin office: Luisenstraße 41 | 10117 Berlin | Germany

Managing Directors N. Höhne, C. Warnecke | Commercial registry Amtsgericht Köln
| Company registration no. HRB 82685 | Tax no. 219/5890/2198

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1. Introduction

Ahead of the next UNFCCC Conference of the Parties in Paris (COP21) in December 2015, governments are preparing their Intended Nationally Determined Contributions (INDCs). INDCs are a key input to the negotiations of a new international climate agreement that will be finalized at COP21 and come into effect in 2020. By designing ambitious INDCs over the next few months, countries have the opportunity to lay the foundation for a new climate agreement that sets the path towards maintaining temperature change below 2°C relative to pre-industrial levels.

Existing emission reduction commitments or pledges from countries that were put forward under the UNFCCC for the time leading up to 2020 – when the Paris agreement will take effect and the INDCs kick in - are not compatible with a 2°C target[1]. INDCs can bring us closer to that target, but countries don't have to wait till 2020 to do more. Especially as the latest science has confirmed that economies cannot prosper without mitigating and adapting to climate change. Furthermore, delaying the implementation of additional mitigation efforts now bares the risk of substantially increasing the costs of a transition to low emissions levels later, and could reduce the range of options consistent with maintaining temperature change below 2°C (IPCC 2014).

It is up to each country to determine an ambition level for their INDC that reflects national priorities, capabilities and responsibilities. When formulating their plans, countries can consider the additional incentives that come with taking more ambitious action. Rigorous accounting of co-benefits of mitigation actions could be one way to help tip the balance towards more ambitious INDCs.

This report first provides an overview of the general co-benefits that climate action may have and how they could be used to incentivise further ambitious greenhouse gas (GHG) reductions. We then provide illustrative results for the forgone or missed benefits that could have been achieved with 2°C compatible action as compared to the current policies and/or the INDC of USA, China and EU.

[1] The UNEP emissions gap report (UNEP 2014) finds a gap of 8 to 10 $GtCO_2e$ in 2020 between expected emissions and what would be necessary to be on track for 2°C. For 2030, the emissions gap is estimated to be 14-17 $GtCO_2e$ – but the emission reduction potential is also large enough to close the emissions gap (UNEP 2014).

2. Co-benefits of climate change mitigation

Policies that target climate change mitigation can positively or negatively influence the achievement of other goals that are important to society, such as food security, human health, energy access, energy security and environmental services (IPCC 2014). In this context, the benefits from mitigation policies are also labeled as co-benefits, acknowledging that most policies that reduce GHG emissions have other, often at least equally important, rationales. The integration of multiple objectives in policies can strengthen the support for such policies and increase the cost-effectiveness of their implementation. In the following we take a closer look at co-benefits of mitigation and their intersection with other important policy objectives, including air pollution and health, energy security, energy access, employment and ecosystem impacts.

Air pollution and health

GHG emissions and air pollutant emissions often derive from the same sources, such as power plants, factories and cars. Hence, mitigation measures that reduce the use of fossil fuels typically have a large potential to also cut in emissions of pollutants, which have a variety of detrimental impacts on health and ecosystem effects at various scales. The magnitude of these effects varies across pollutants and atmospheric concentrations and is due to different degrees of population exposure, whether indoor or outdoor or in urban or rural settings (IPCC 2014).

The World Health Organization (WHO, 2014) reports that in 2012 one in eight of total global deaths - around 7 million people - died as a result of air pollution exposure. This makes air pollution the world's largest single environmental health risk. About 4.3 million of the total premature deaths were caused by indoor air pollution, mostly from cooking and heating with solid fuels. Reducing air pollution could result in significant welfare gains. Recent climate mitigation scenarios have estimated global average health co-benefits of reduced air pollution at US$50 to more than US$200 per tonne of CO_2 avoided (The New Climate Economy 2014). In the US, for example, the introduction of a clean energy standard in the electricity sector could result in human health benefits of reduced air pollution that are worth US$ 39 billion. A cap-and-trade system with economy wide caps could deliver net-co-benefits that amount to US$ 125 billion (Thompson et al. 2014).

Energy security

Energy security is a timeless and compelling policy goal that ranks high on the list of priorities of many countries. The International Energy Agency (IEA) defines energy security as the uninterrupted availability of energy sources at an affordable price. Mitigation strategies can have a positive impact on energy security by reducing the import dependency of countries and by increasing the resilience of energy systems through diversification of energy sources used in the transport and electricity sectors (IPCC 2014). The EU, for example, spends US$ 1 billion a day on energy imports ((European Commission 2014b)

Policies that promote the increase of renewable energy in the national energy matrix are one way to increase energy security. By early 2014, at least 144 countries had renewable energy targets and 138 countries had renewable energy support policies in place. Growing number of cities, states and regions also seek to transition to 100% renewable energy in either individual sectors or economy wide (REN21 2014). However, with 82%, fossil fuels still remain at the heart of global energy use (IEA 2014c).

Energy efficiency policies adopted principally with the goal of advancing energy security can also lead to lower emission of GHGs and other pollutants.

Energy access

Universal energy access is likely to have a small impact on GHG emissions (IPCC 2014), but it has a central role in helping to bring people out of poverty. To date, about 1.3 billion people have no access to electricity and 2.6 billion lack modern cooking facilities (IEA 2014c). More than 95% of this unmet demand is in sub-Saharan African or developing Asia and 84% is in rural areas. Such energy poverty has a serious impact on peoples' livelihoods and is one of the key barriers to sustainable development. The strong correlation between poverty and a lack of access to modern energy is shown by the fact that countries, in which a large share of the population is living on an income of less than $2 per day, tend to have low electrification rates and heavily rely on traditional biomass as a source of energy (OECD, ILO 2010). Providing reliable access to modern forms of energy is essential for the provision of services such as clean water, sanitation and health care and provides the basis for sustainable development though the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services.

Employment

Assessing the employment benefits of mitigation is not straightforward. The creation of jobs in the renewable energy sector, for example, can lead to job losses in the fossil fuel industry. The International Labour Organization (ILO) (ILO 2013b), however, states that enough evidence is available that shows that climate change action does not need to threaten current jobs, but can, on the contrary, lead to more and decent jobs, poverty reduction and social inclusion. Important in this context is to ensure a just transition for workers into new jobs, for example, by providing social protection, securing rights and strengthening social dialogue.

Taking the renewable energy sector as an example, approximately 6.5 million people were working directly or indirectly in the sector in 2014, which is an increase of 12% compared to 2013 IRENA (2014). The number of countries that have renewable energy targets indicate a large potential for further job creation in the sector over the coming years.

Ecosystem impacts

Mitigation strategies can have a variety of ecosystem impacts when they alter the use of biodiversity, water and land. A through analysis of synergies and trade-offs between mitigation and other policy objectives is fundamental since ecosystems services are closely interlinked (IPCC 2014).

Land and forest restoration generate important co-benefits in terms of environmental services generation. Initiating forest restoration of at least 350 million hectares by 2030, could generate US$170 billion/year in net benefits from watershed protection, improved crop yields, and forest products (The New Climate Economy 2014). This would also sequester about 1–3 Gt CO2e/year, depending on the areas restored. Looking at the agricultural sector, the restoration of just 12 percent of degraded agricultural land could reduce GHG emissions by almost 2 $GtCO_2e$ annually. The restored land has the capacity to feed 200 million people within 15 years and to boost smallholders' annual incomes by US$ 35-40 billion (The New Climate Economy 2014).

3. Benefits and challenges of linking mitigation measures and co-benefits

Establishing the joint consideration of mitigation potentials and co-benefits as a "good practice" in the design of INDCs – and of mitigation policies and actions in general - could be beneficial from many points of view:

- ***Highlighting co-benefits in the design of INDCs could increase the willingness to undertake ambitious mitigation actions.*** Highlighting the links between GHG emission reduction and co-benefits, by expressing "emissions reduced" also as "benefits gained", or a lack of ambition in emission reductions as forgone benefits or "benefits missed" (Figure 1), could help to depict the negative impacts of GHG emissions and the consequences of too little action. This, in turn, could increase the willingness of a society to invest in mitigation actions and, therefore, increase ambition levels.

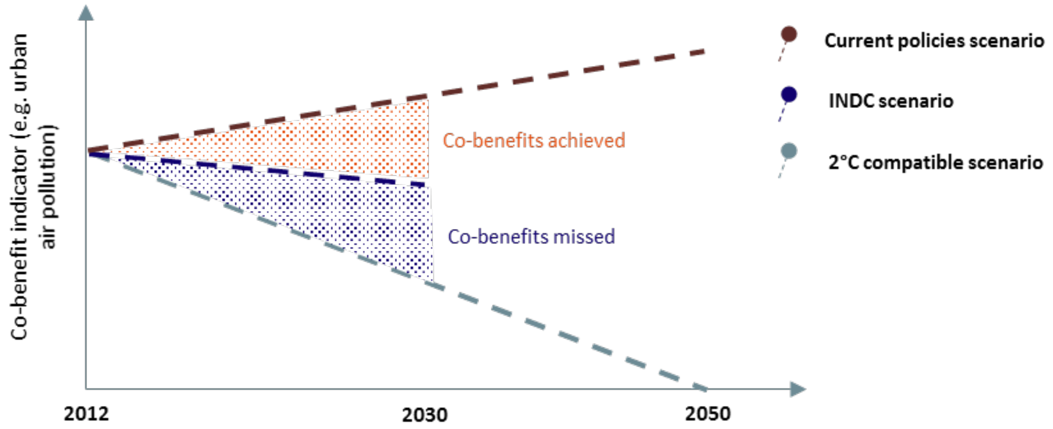

Figure 1 Missed benefits under different policy scenarios

Figure 1 takes air pollution from fossil fuel burning as an example to illustrate how the lack of ambition of an INDC results in missed benefits, i.e. the reduction of premature deaths caused by air pollution exposure. Without policy interventions (brown line) that seek to reduce or eliminate the use of fossil fuels, air pollution will increase over the years. Under the INDC scenario, air pollution is reduced, for example, by implementing mitigation measures that increase energy efficiency or substitute fossil fuels by renewable energy sources. These measures also bring down the air pollution (upper shaded area). But additional air pollution could be avoided if the country strived for phasing out fossil fuels (lower shaded area).

- ***The joint consideration of mitigation actions and co-benefits could increase the cost-effectiveness of policies***. Even though mitigation actions and their co-benefits are interdependent, policies around them are often designed in isolation or the design process is lacking inter-ministerial coordination. Integrated approaches that achieve related policy objectives simultaneously, for example, the reduction of GHG and air pollutant emissions, show higher cost-effectiveness than policies where objectives are achieved alone (IPCC 2014). However, weighting the costs of mitigation against multiple benefits for other objectives, which are traditionally measured in different units, is challenging in practice (IPCC 2014).

- ***Consideration of co-benefits could speed up the implementation of mitigation actions and thereby reduce the costs of climate change mitigation.*** Immediate mitigation action at levels that are compatible with a 2°C pathway will significantly reduce the costs of climate change compared to scenarios where action is delayed (IPCC 2014). Considering co-benefits and their welfare gains in the selection of mitigation measures could be a trigger for accelerating their implementation. Most aspects of mitigation co-benefits have short-term effects, but they support long-term mitigation policies by creating a central link to sustainable development objectives (IPCC 2014). Because of these features, co-benefits have a more "tangible" impact than emission reductions. Mitigation opportunities that also deliver important co-benefits can thus contribute not only to the 2°C objective but also to a national transformation of patterns of economic consumption and production which enables societies and economies to move to a sustainable development pathway, reducing poverty and creating inclusive growth.

In sum, the consideration of (the missed) co-benefits of ambitious greenhouse gas reductions can be a strong argument to trigger additional activities.

4. Illustrative results for co-benefits of INDCs

Of the various co-benefits from greenhouse gas reduction policies described in section 2, we selected three for illustrative quantification: reduced fossil fuel imports, reduced air pollution and creation of green jobs. They were selected as they present very important arguments for action and at the same time can be quantified in a simplified manner.

4.1 Methodology

We here briefly describe the methodology used. Details are provided in Annex I.

Reduced fossil fuel imports

Many countries spend very significant amounts for the import of fossil fuels. This not only presents an economic burden but also a threat to energy security. The cost savings associated with the reduced imports of fossil fuels can be enormous, due to the reduced demand for these fuels in sectors due to reductions in energy demand and shifts to alternative sources of energy.

We consider reduced coal imports for power generation, reduced oil imports for transport and reduced natural gas demand for all sectors. We use projected market prices of theses fuels from the International Energy Agency (IEA 2014c) to express the savings in monetary value.

Reduced air pollution

Assessing air pollution is complex. The level of air pollution depends on the emissions of many gases, technologies used and the weather conditions. Sophisticated models with high technological, temporal and spatial resolution can explain and project air pollution levels well. They also include the complex relationship between the level of air pollution and human health.

We have applied here a very simplified method to estimate the order of magnitude of the effects on human health. We assume that the level of air pollution is directly linked to energy related CO_2 emissions, because many air pollutants derive from fossil fuel combustion processes. We use a relationship between CO_2 emissions and pollution levels derived from country specific models runs. We also then assume a simple relationship between air pollution and health impacts applying standard factors from the literature. Due to these simplifications, our estimates can only considered first order estimates to illustrate the order of magnitude. This approach reflects the number of premature deaths per year, and as such it underestimates the impacts on human health and the related costs from non-lethal conditions such as chronic and acute bronchitis, or asthma.

Creating of green jobs

Estimation of created jobs as a result of an activity is complex: the activity could directly create new jobs, but also could prevent the continuation of jobs elsewhere or could shift economic activity away from even more job intensive activities. In addition, jobs can have very different quality, e.g. varying pay grade, social conditions or permanence. The most sophisticated way to calculate the impact on jobs would be through economic models (usually input-output models) that take into account the various interactions between sectors of the economy. These models can be used to calculate job factors per activity, e.g. how many jobs are created for 1MW of wind capacity installed.

We use here a collection of these job factors to derive a first order estimate of the number of jobs created from renewable energy in the electricity sector. These factors are approximations and therefore do not include all possible feedbacks in the economy. For energy efficiency measures, we discuss the impact on green jobs only qualitatively, due to the complexity of the sector and no suitable simplified methodologies.

Scenarios

For each country we estimate three scenarios. We start with the "current policies scenario" that simulates the conditions expected in the country should it continue with its currently implemented policies, programmes and measures.

We compare this scenario to the INDC (or early announcements of it). The INDC is usually only given at the national level, but implementation per sector is need to estimate the co-benefits. Were this is the case, we make assumptions on the possible implementation of the INDC per sector drawing on the Climate Action Tracker analysis (CAT 2015),

We finally also use a 2°C compatible pathway defined as trajectory, which a country should take, if it is to be consistent with the internationally agreed goal to limit global temperature increase to less than 2°C. As an illustration, we define here as 2°C compatible a pathway that leads from the current situation to 100% renewable energy supply by the year 2050. This includes possibly increased energy demand in some regions but stringent energy efficiency measures.

4.2 European Union

The EU was the second country to communicate an INDC in March 2014 to the UNFCCC. It put forward a binding target of **at least 40% aggregate domestic emissions reductions below 1990 levels by 2030**. The INDC itself does not provide a sectoral breakdown of the required reductions, but studies are available that led to this target and that provide further detail.

Based on our illustrative method, EU's INDC in comparison to current policies trajectory in 2030 will:

- Save an estimated USD 33 billion each year in reduced fossil fuel imports.
- Prevent in the order of 6,000 premature deaths each year from air pollution.
- Create an additional 70,000 full-time equivalent green jobs in the domestic renewable energy sector.

If the EU would strengthen its INDC further to meet a 2°C compatible trajectory, it could achieve the following benefits *in addition* to those already achieved by the INDC:

- Cost savings of USD 140 billion each year from fossil fuel imports.
- Prevention of in the order of 40,000 premature deaths each year from air pollution.
- Creation of 350,000 full-time equivalent green jobs in the domestic renewable energy sector.

4.2.1 Reduced fossil fuel imports

The European Union imports fossil fuels to a large extent. The European Commission estimates that under current policies the cost for the import of fossil fuels will reach around 500 billion € in 2030 (European Commission 2013). It estimates that the implementation of the INDC would reduce fossil fuel imports by around EUR 10 billion per year in 2030 (European Commission 2013).

The following section provides an overview of our estimates from some of these imports by sector. They differ from the commission estimates due to our use of a simplified method and different reference scenarios, fuel prices and share of domestic production.

Coal in the power sector

In 2010, solid fuels accounted for 15.9% of the total gross inland energy consumption (European Commission 2013). According to the European Commission's 2013 assessment of the proposed INDC scenario, the reduction in coal use for primary energy consumption in 2030 of the INDC would only be small compared to the reference case for 2030. Compared to the reference case, coal will actually account for a slightly larger *share* of power generation under the INDC, although the *total amount* of energy demand will be considerably reduced.

Figure 2 shows that the **EU's INDC will reduce coal demand in 2030 by an estimated 10 Mtoe, resulting in a cost saving of around USD 1.8 billion in coal imports**. However, a further 40 Mtoe reduction in coal consumption from the INDC level would be required for a 2°C compatible scenario. If the EU would strengthen its INDC further in order to meet a 2°C compatible trajectory, **a further USD 6.7 billion in cost savings per year through coal imports for the power sector could be achieved**.

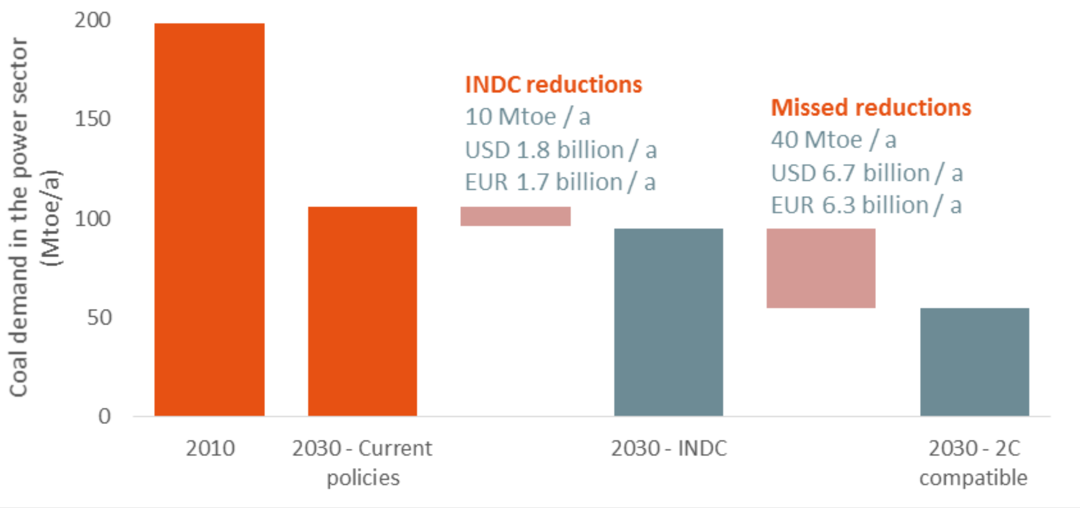

Figure 2: Reduced coal demand in the EU power sector

Oil in the transport sector

Oil accounted for 35.1% of gross inland energy consumption in 2010, and the volume of oil imports amounted to 94% of this total consumption (European Commission 2013). The transport sector accounts for nearly half of oil consumption in the European Union. Under the EU's INDC, the use of oil for primary energy demand in 2030 will be 9% lower than for the reference case for 2030. The results in this section assume that the overall energy sector trend remains constant for the transport sub-sector.

Figure 3 shows that **the EU's INDC will reduce oil demand in the transport sector in 2030 by an estimated 4 Mtoe, resulting in a cost saving of around USD 4 billion in oil imports**. A further 72 Mtoe reduction in oil consumption from the INDC level would be required for a 2°C compatible scenario. By strengthening the INDC to meet the 2°C compatible trajectory, the **EU could achieve a further USD 71.5 billion in cost savings per year through oil imports for the transport sector**.

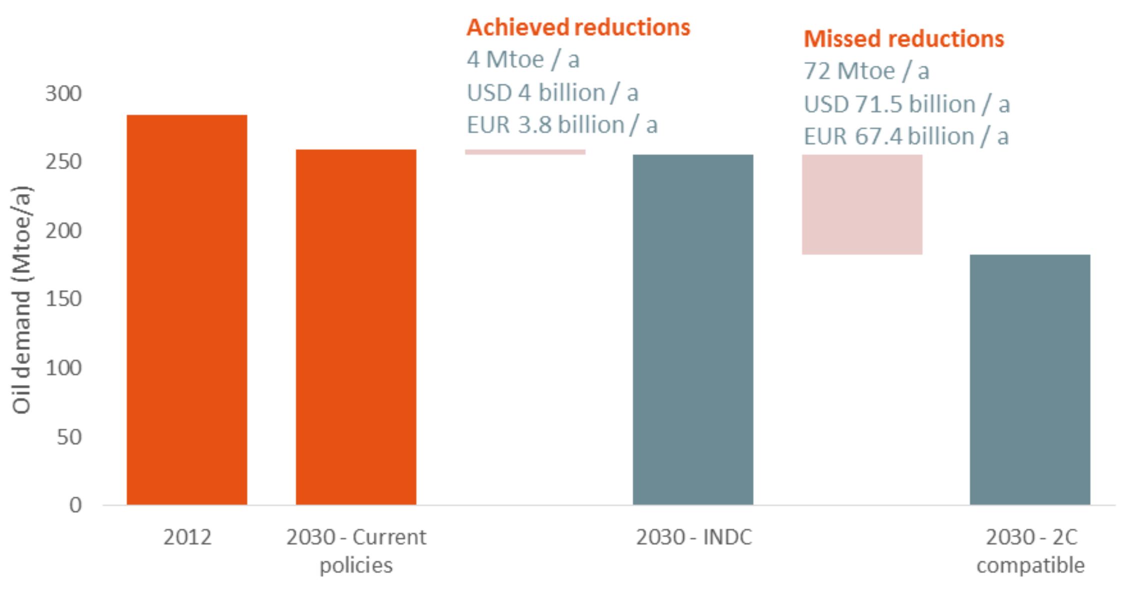

Figure 3: Reduced oil demand for the EU transport sector

Natural gas

Natural gas accounted for 25% of gross inland energy consumption in the EU in 2010 (European Commission 2013).

Under the scenario implied by the INDC, the EU will save USD 27 billion per year by 2030 through reducing gas imports by 52 Mtoe. The definition of a 2°C compatible scenario is subjective for natural gas, since different models attach different importance to natural gas as a reduced carbon alternative to coal and oil combustion. Therefore, Figure 4 shows the further savings that could be achieved if all of the cost effective potential to reduce gas consumption was taken (Bossman et al. 2012). As the figure shows, **further cost savings of USD 63 billion per year could be achieved through reduced imports** if these measures are taken.

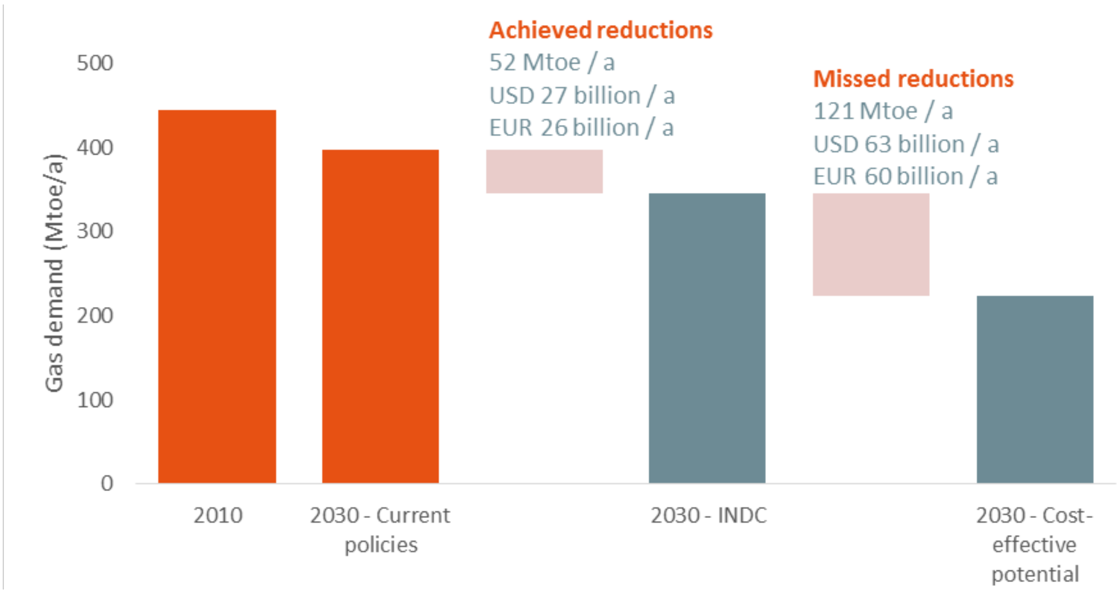

Figure 4: Reduced gas demand in the EU

4.2.2 Reduced air pollution

Pollution levels have fallen considerably across the European Union in recent decades. Nevertheless, air pollution is the top environmental cause of premature death in Europe (EEA 2014). With our illustrative method we estimate that around 5% of all mortality from all causes in the EU in 2012 is attributable to the excessive ambient concentration of fine particulate matter ($PM_{2.5}$).

We estimate that the EU's INDC could decrease 2012 concentrations of $PM_{2.5}$ by approximately half by 2030. As Figure 5 shows, the **EU's INDC would significantly reduce the number of premature deaths compared to 2012 and prevent in the order of 6,000 premature deaths per year** by 2030 compared to the current policies scenario. **If the EU would further strengthen its INDC to meet a 2°C compatible trajectory, a further roughly 40,000 premature deaths could be avoided each year**.

The European Commission estimates that the benefit of the INDC over the reference is a reduction of 5.7 million life years lost due to $PM_{2.5}$ (European Commission 2013), page 66). This could translate into roughly 26,000 premature deaths per year, when we assume the commonly adopted rate of 12 lost life years per premature death attributable to $PM_{2.5}$ and assume that the figure is a cumulative value from 2012 to 2030.

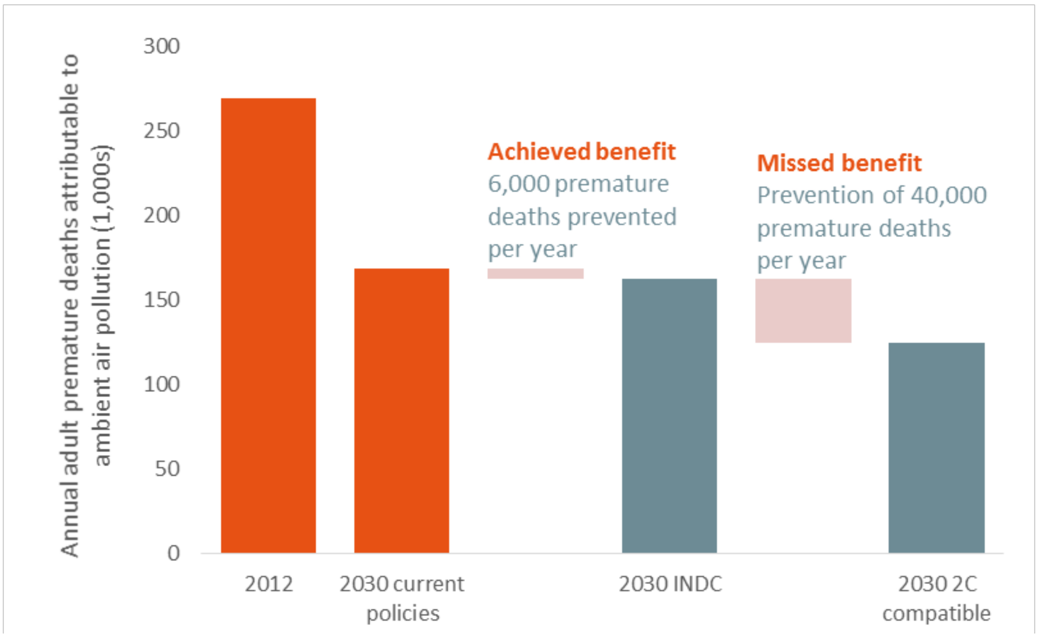

Figure 5: Premature deaths from air pollution in the EU

4.2.3 Creation of green jobs

Green jobs created in the renewable energy sector

IRENA (IRENA 2014a) estimated that the European Union was home to around 1.2 million jobs related to renewable energy altogether in 2013. As shown in Figure 6, we estimate that 312,000 people were employed in the manufacturing, construction, operation and maintenance of domestic solar, wind and hydro-electricity installations in 2012. This does not include jobs created through the renewable energy technology export industry, jobs more broadly related to the renewables industry (e.g. research, consultation, project development etc.), or jobs associated with other renewable technologies, such as biomass.

The number of people employed in the sector in 2030 under the current policies trajectory will be moderately higher than in 2012, due mostly to the increased total capacity and the number of workers required for ongoing operation and maintenance. The INDC will boost this further by increasing the rate of installation of renewables, and therefore increasing the number of workers required for manufacturing and construction, as well as workers required for operation and maintenance of the total installed stock. The INDC is estimated to create 70,000 additional jobs compared to the current policies trajectory. If the EU were to substantially increase the rate of installation of renewables, to a level consistent with a 2°C compatible trajectory, an estimated 350,000 additional jobs could be created.

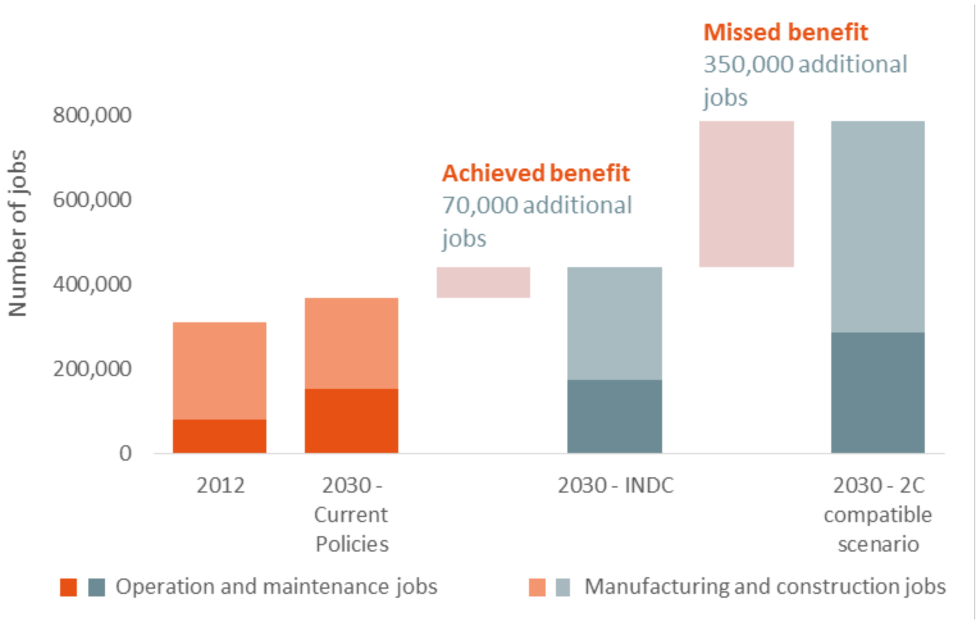

Figure 6: Job creation from renewable energy in the EU

Our results are in line with the estimates of the European Commission, which estimates 32,000 additional jobs in the electricity sector for the INDC compared to the reference scenario (62,000 new jobs in renewable electricity supply are offset by 31,000 jobs lost in fossil fuel based and nuclear production (European Commission 2013), page 92).

Green jobs created though energy efficiency measures

The European Commission's Impact Assessment (European Commission 2014a) analysed also the impact energy efficiency measures would have on net job creation. The INDC would create 273,000 additional jobs in the EU by 2030 compared to reference. This is an order of magnitude larger than for renewable energy in the electricity sector, since the energy efficiency measures are considered more labour intensive, e.g. renovation of buildings.

An alternative study quantifies the full employment impact of all efficiency measures (not only the impact of the INDC compared to a reference): If both direct and indirect jobs from improved energy efficiency are considered, the gross employment impact of these measures in the EU is up to 1.3 million jobs by 2030 (Ecofys et al. 2014). Indirect and induced jobs are created, for example, through energy savings that free up money for investments or consumption that leads to new jobs in the same or other sectors.

Looking at job creation from an investment point of view, IEA (2014a) estimates that approximately 8 to 27 job years could be created through every 1 million EUR investment in energy efficiency measures.

4.3 United States

In November 2014, the US announced that by 2025, they would aim at reducing emissions by 26% to 28% below 2005. We use this announcement for the analysis, although the USA has not yet officially submitted an INDC. We assume that INDC will be implemented in art through additional renewable energy as per the declaration under the 2013 President's Climate Action Plan to double the installed capacity of renewables by 2020.

Based on our illustrative method, the USA's INDC compared to current policies trajectory in 2030 will:

- Significantly reduce demand for domestically produced coal (132 Mtoe reduction) and gas (91 Mtoe reduction).
- Prevent in the order of 7,000 premature deaths each year from air pollution.
- Create an additional 470,000 full-time equivalent green jobs in the domestic renewable energy sector.

If the US would strengthen its INDC further to meet a 2°C compatible trajectory, it could achieve the following benefits *in addition* to those already achieved by the INDC:

- Cost savings of USD 160 billion each year from reduced oil imports in the transport sector.
- Prevention of in the order of 20,000 premature deaths each year from air pollution.
- Creation of 180,000 full-time equivalent green jobs in the domestic renewable energy sector.

4.3.1 Reduced fossil fuel imports

For reduced fossil fuel imports in the U.S., only oil for the transport sector is considered. This is due to the large volume of coal and natural gas produced in the U.S.; the U.S. is a net exporter of these fuels and reductions in domestic consumption would increase the volume available for export rather than decrease the volume imported. For completeness we still show coal and gas reductions in the section below in units of energy without a value in US$.

Coal in the power sector

Coal accounted for 43% of power demand in 2012 in the United States (IEA 2014c). The United States is a major producer of coal, and therefore will not gain directly from reduced fossil fuel imports when reducing the demand for coal for power generation. However, reducing the dependence on coal has many potential benefits for the United States. Resource scarcity is already an issue and the costs of coal production will increase as resources in more remote areas are sourced. Reduced reliance on coal also holds great health benefits, primarily through air pollution (see section 4.3.2), and benefits for a transition to a greener and more sustainable labour force (see section 4.3.3).

The U.S. INDC is forecast to reduce coal demand by 132 Mtoe per year by 2030 compared to the current policies scenario. A further 130 Mtoe of demand could be reduced if the INDC would be strengthened to meet a 2°C compatible trajectory.

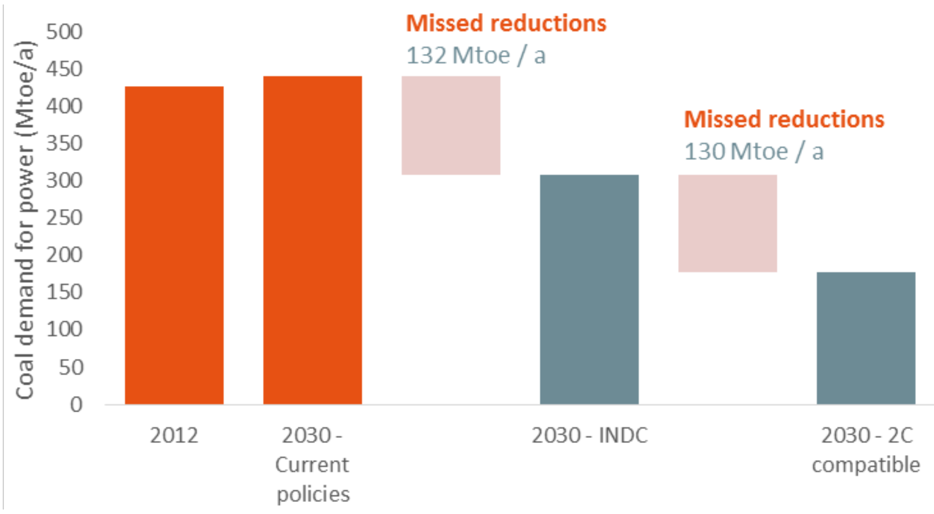

Figure 7: Reduced coal demand from the power sector in the U.S.

Oil in the transport sector

Oil accounts for 97% of energy demand in the transport sector in the U.S. (IEA 2014c). In total, the sector account for 28% of national primary energy demand, and 72% of total oil consumption (IEA 2014c).

As Figure 8 shows, that in our interpretation the anticipated INDC of the USA includes no additional measures for the transport sector beyond the current policy reference. USA is unlikely to change its recently implemented new fuel economy standard for cars. We assume here it aims to achieve the INDC with measures in other sectors.

This leaves a sizeable gap between the INDC and a 2°C compatible trajectory, which would require a further reduction of 159 Mtoe oil demand in the transport sector in 2030, with **potential cost savings of USD 158 billion per year from oil imports**.

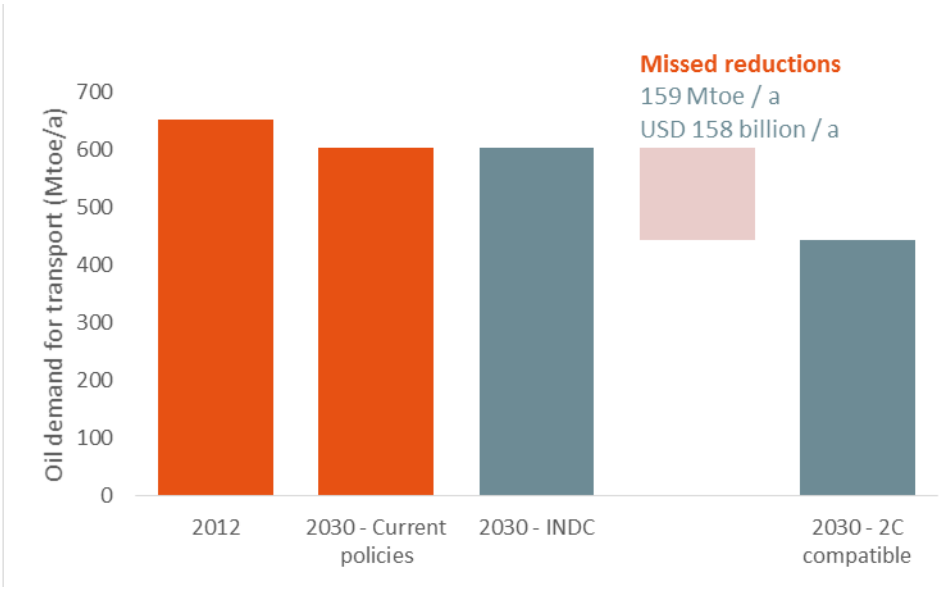

Figure 8: Reduced oil demand from transport in the U.S.

Natural gas

The United States is one of the world's major consumers of natural gas, which satisfied 28% of total primary energy demand in 2012 (IEA 2014c). Under current policies this share will persist and marginally increase to 30% by 2030. The U.S. is a net exporter of natural gas, and will not gain directly from import cost savings by reducing demand for natural gas. However, as in the coal sector, the U.S. has a great deal to gain from reducing its reliance on this scarce resource, from savings on increasing production costs, air pollution considerations (see section 4.3.2), and a shift to a more sustainable labour market (see section 4.3.3).

As Figure 9 shows, it is expected that the U.S.'s emission reductions under its INDC will be in part achieved by an increase in natural gas consumption to offset coal combustion. The figure therefore shows a small increase in demand of natural gas in the 2030 INDC scenario compared to the current policies scenario. If the ambition of the U.S. INDC were further strengthened to be in line with a **2°C compatible trajectory, reductions in natural gas demand of 228 Mtoe/a compared to the INDC scenario would be possible**.

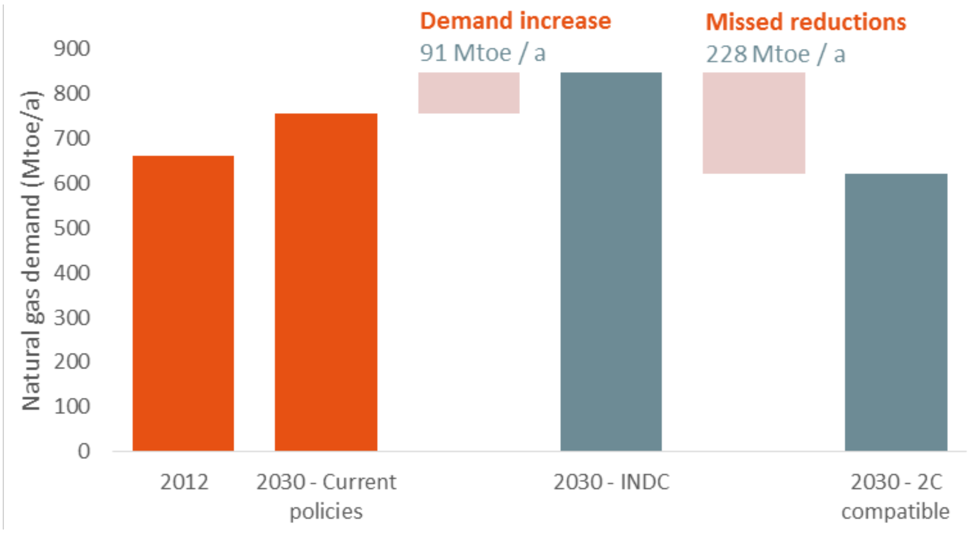

Figure 9: Reduced natural gas demand in the U.S.

4.3.2 Reduced air pollution

With our illustrative method, we estimate that 4% of all mortality from all causes in the U.S. is attributable to the exposure to excessive ambient concentration of fine particulate matter ($PM_{2.5}$).

Under the current policies scenario, average ambient $PM_{2.5}$ exposure levels would decrease by around a third between 2012 and 2030. The U.S's INDC could reduce the exposure level by roughly 40% by 2030 compared to 2012, whilst a 2°C compatible trajectory would entail a reduction in $PM_{2.5}$ exposure of around 50%. Figure 10 shows that **the U.S.' INDC will prevent 7,000 premature deaths per year** by 2030 compared to the current policies scenario. If the INDC would be further strengthened to meet a 2°C compatible trajectory, **a further 20,000 premature deaths could be avoided each year.**

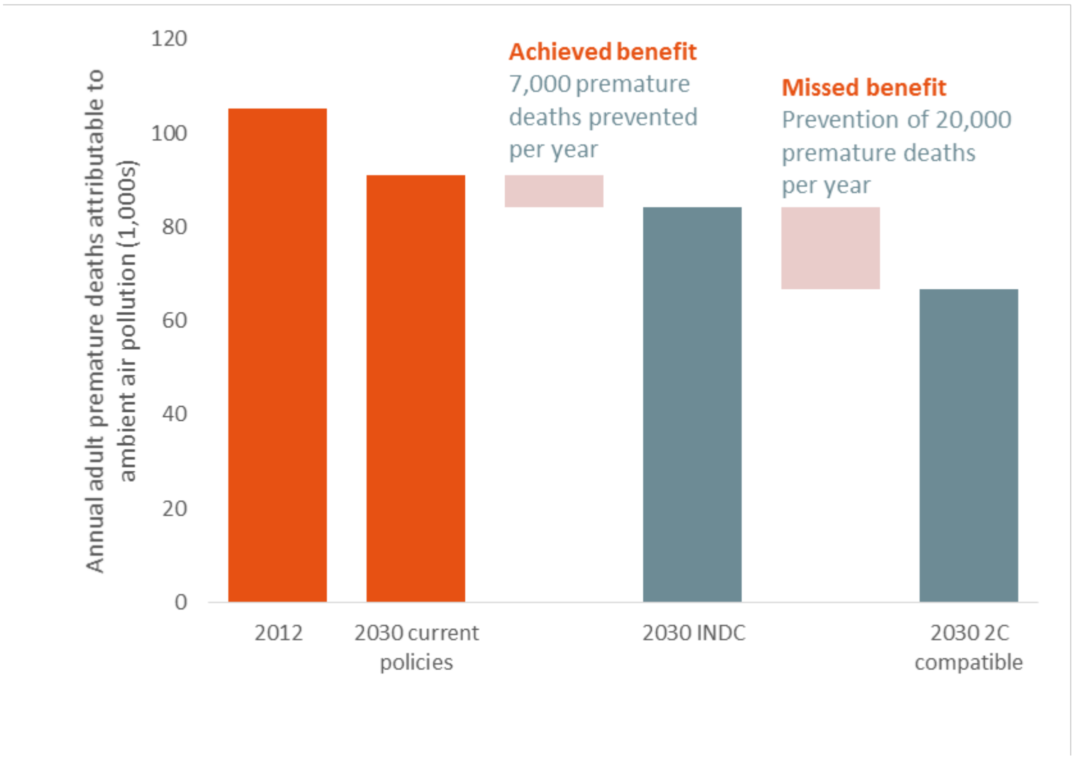

Figure 10: Premature deaths from air pollution in the U.S.

4.3.3 Creation of green jobs

Green jobs created in the renewable energy sector

This study estimates that 297,000 people were employed in the manufacturing, construction, operation and maintenance of solar, wind and hydro-electricity installations in 2012 in the United States. This figure relates only to the specific job roles indicated and only for domestic installations. This is in line with other literature estimates, which calculate slightly larger employment levels when including all associated jobs within both the domestic and export industries. According to the Solar Foundation (2014), the solar industry employed 173,807 people by 2014, representing a growth rate of 21.8% compared to 2013. In 2013, the wind industry directly supported 55,500 jobs (AWEA 2015), while the hydropower industry supported 200,000 to 300,000 jobs (ACORE 2014).

As shown in Figure 11, the sector is estimated to employ fewer people in the job roles considered for this study in 2030 than in 2012 due to a significant decrease in jobs for manufacturing and construction. Under current policies, the US will install an average of around 5 GW renewable energy capacity per year until 2030, compared to around 10GW per year between 2008 and 2012. **The INDC scenario**, reverses this trend significantly, and **will create an estimated additional 470,000 green jobs compared to current policies**, more than doubling the number of jobs in the sector compared to 2012. If the U.S. were to increase the ambition of its INDC further, in order to meet a **2°C compatible trajectory, a further 180,000 jobs could be created**.

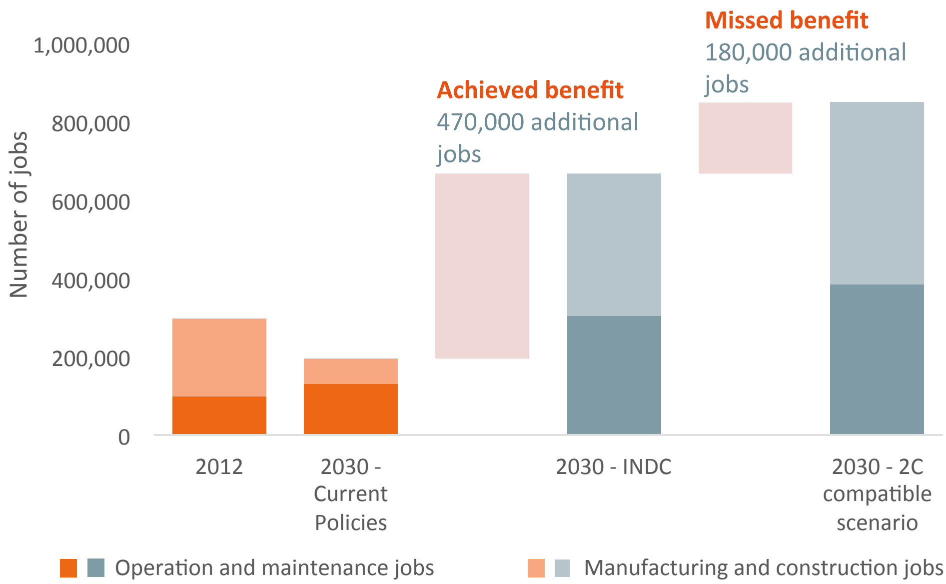

Figure 11: Job creation from wind, solar and hydro energy in the U.S.

Green jobs created through energy efficiency measures

The American Council for an Energy Efficient Economy (ACEEE 2011) estimates that every US$ 1 million in energy efficiency improvements supports around 20 jobs in the US economy, including direct, indirect and induced jobs. This is larger than the economy-wide average of 17 jobs supported per US$ 1 million on investment.

A study on the socio-economic benefits from clean energy technology deployment finds that aggressive energy efficiency measures combined with a 30% renewable energy target in 2030 could generate over 4 million job-years by 2030 (Wei et al. 2010) .

Looking at employment generation through energy efficiency measures by sector, the buildings sector is one of the largest sources for energy efficiency jobs in the US. Between 2009 and 2020, 600,000 to 900,000 national jobs could be created by retrofitting buildings for energy efficiency. The public transportation sector, which is another active sector for job creation in energy efficiency in the US, employed more than 400,000 Americans as of 2013. The US auto industry had added more than 263,000 jobs related to hybrid and electric vehicles by early 2013 (EESI 2014).

4.4 China

China announced in November 2014 that it would peak energy related CO_2 emissions by 2030 at the latest, and increase the share of non-fossil energy carriers of the total primary energy supply to at least 20% by then. We use this for the analysis, although China has not yet officially submitted an INDC.

Based on our illustrative method, China's INDC in comparison to its current policies trajectory in 2030 will:

- Begin to reduce the country's reliance on coal for power generation (by 21%).

- Prevent in the order of 100,000 premature deaths each year from air pollution.
- Create an additional 500,000 full-time equivalent green jobs in the domestic renewable energy sector.

If China would strengthen its INDC further to meet a 2°C compatible trajectory, it could achieve the following benefits *in addition* to those already achieved by the INDC:

- Cost savings of USD 190 billion each year from fossil fuel imports.
- Prevention of in the order of 1.1 million premature deaths each year from air pollution.
- Creation of 1.4 million full-time equivalent green jobs in the domestic renewable energy sector.

4.4.1 Reduced fossil fuel imports

Coal from the power sector

Coal is by far the major source of power generation in China, fuelling 87% of the power demand (IEA 2014c), and accounting for nearly half of global coal consumption (US EIA 2014). Furthermore, energy demand for power will nearly double between 2012 and 2030, despite considerable forecast improvements in energy efficiency. Accordingly, China has become the world's largest producer of coal in recent years. Because of its status as a major producer of coal covering all of its domestic demand, China does not stand to gain directly from the economic benefit of reduced fossil fuel imports in the power sector. However, a reduction in the dependence on coal carries multiple other benefits for China: energy security is threatened by reserve depletion, and the marginal costs of production will become increasingly expensive as the accessibility of coal reserves deteriorates. The creation of decent green jobs associated with a shift away from coal is also explored in section 4.4.3, below.

Figure 12 shows that the INDC achieves a 333 Mtoe reduction in coal dependency each year by 2030. If China's targets would be further strengthened to meet a 2°C compatible trajectory, a further 399 Mtoe per year reduction in coal dependency would be possible.

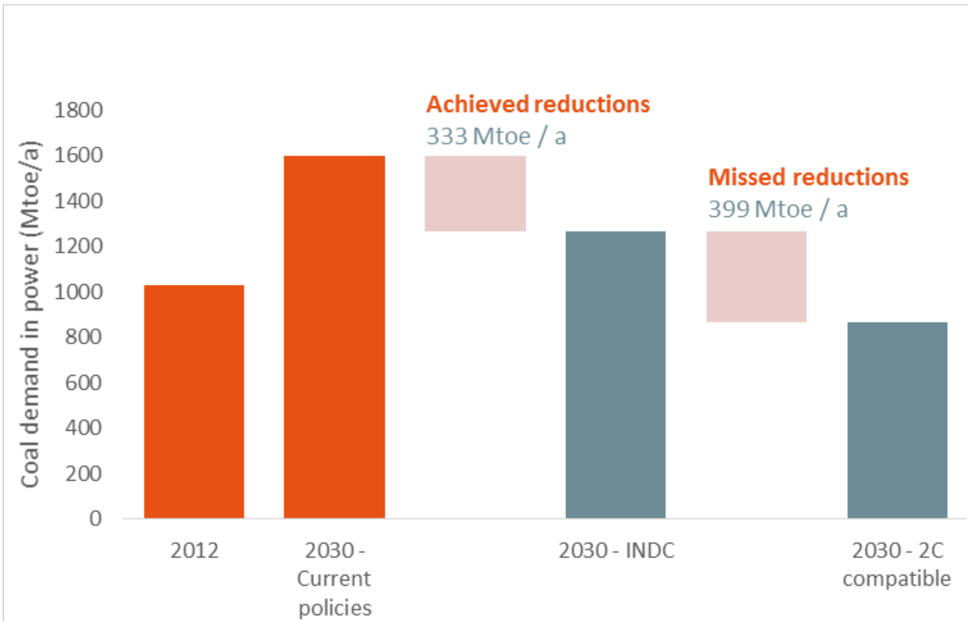

Figure 12: Reduced coal demand from power in China

Oil from the transport sector

Due to rapid economic growth and a boom in personal car ownership in the past two decades in China, energy demand from the transport sector increased by nearly 700% between 1990 and 2012; oil accounted for 92% of this energy demand in 2012, and China became the world's greatest importer of oil in 2014 (US EIA 2014). The energy demand of the sector under current policies is forecast to nearly triple again by 2040 (IEA 2014c).

China's INDC is not sector specific. We assume here that it does not include specific measures for the transport sector that go beyond current policies as China already has fuel efficiency standards. For this reason, Figure 13 shows no distinction between current policies and the INDC scenario. Oil demand under the INDC in 2030 is more than double the demand in 2012. Indeed, demand in 2030 is also significantly higher than in 2012 in the 2°C compatible scenario, recognising the major increase in transport activity in China. However, it must be noted that China's current policies have made a significant positive impact on the reduction of oil demand compared to a scenario under which these policies would not exist, although such a scenario could not be modelled. In particular, China's policies on light duty vehicle fuel efficiency and emissions will make an enormous impact on fuel consumption and emissions, which would otherwise be much higher in 2030. However, a gap still exists between the INDC and 2°C compatible scenarios. **Closing this gap would save an estimated 138 Mtoe of oil imports in 2030 with cost savings of USD 137 billion per year, compared to the INDC scenario**.

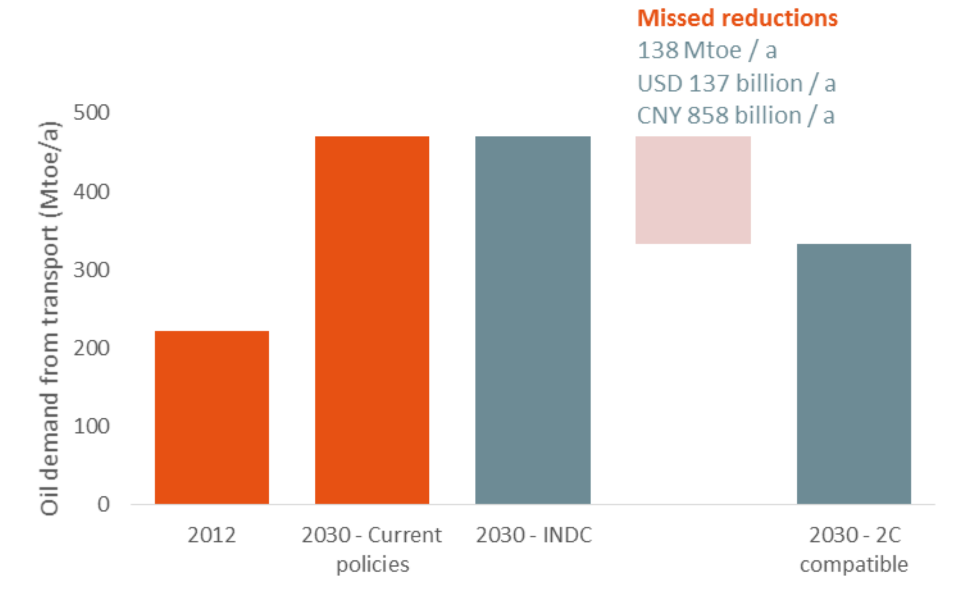

Figure 13: Reduced oil demand from transport in China

Natural gas

Although natural gas accounted for just 4% of China's total energy demand in 2012, the production and consumption of gas is forecast to triple by 2040, as part of the national strategy to reduce the country's reliance on heavily polluting coal consumption. China was a net gas exporter until 2007, since when its imports have increased rapidly to meet the significant increase in consumption (IEA 2014c).

Under current policies, demand for natural gas by 2030 would have increased by over a factor of 25 compared to 1990 levels. By this time, gas will be the third major provider of energy in China, after coal and oil. Under China's INDC, a significant increase in the demand of natural gas is forecast, in order to offset the need for coal combustion, which has a higher emissions intensity. This will require an estimated 146 Mtoe increase in natural gas demand per year, carrying an increase in the cost of natural gas imports of approximately USD 67 billion per year.

By increasing the ambition of its INDC to match a 2°C compatible scenario, **China would save 111 Mtoe of natural gas in 2030, with potential savings from imports of USD 51 billion per year**.

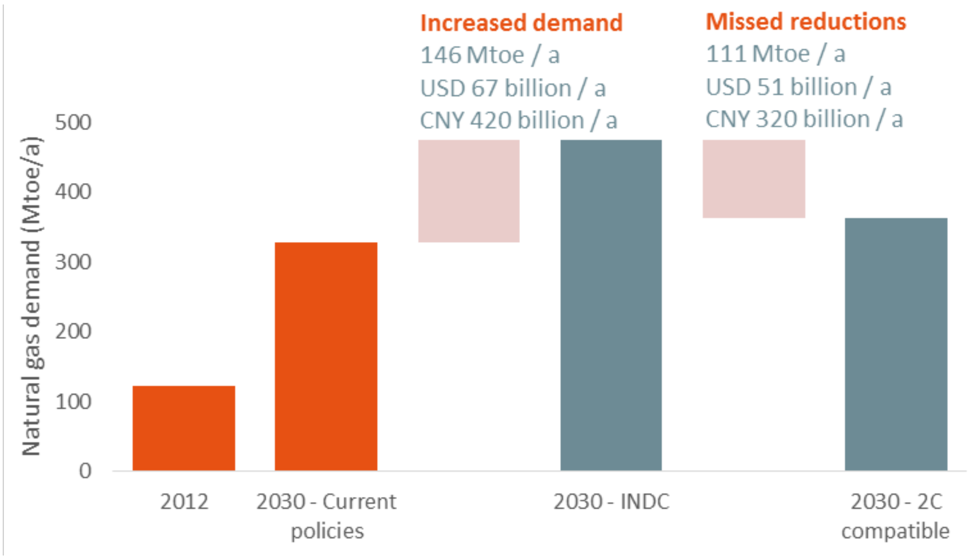

Figure 14: Reduced demand for natural gas in China

4.4.2 Reduced air pollution

As a result of its rapidly expanding economy and industrial developments, China has positioned itself as one of the world's economic powerhouses, and a number of megacities have developed in China since 1990 in response to the rapid urbanisation of the world's most populous country. Such a rapid expansion has been fuelled by tremendous increases in energy consumption, and subsequently to rapid increases in the emissions of air pollutants; the total emission of air pollutants in China was approximately 4 times larger in 2012 than in 1990 (IEA 2014c). Air pollution has become one of the major environmental and social concerns in China, and many Chinese cities report some of the world's highest concentrations of PM. IRENA (2014a) estimates that the health impacts of particulate matter air pollution over 8% of China's GDP. Concerns over air pollution have become a major driver for climate change mitigation policy in the country.

Our illustrative calculations indicate that nearly a third of all cause deaths in China in 2012 could be linked to exposure to excessive concentrations of particulate matter. This study finds that ambient air pollution accounted for in the order of 1.7 million premature deaths in China in 2012. For comparison, the 2010 Global Burden of Disease report in the Lanclet estimated premature deaths from fine particulate matter in China in 2010 to be in the range of approximately 1.1 and 1.4 million (Lozano et al. 2012). Some other studies estimate considerably fewer deaths. Amongst other differences, these figures are highly dependent on assumptions regarding the baseline average exposure to $PM_{2.5}$ in 2012; the availability of reliable and accurate data on $PM_{2.5}$ concentrations in China remains relatively poor, and the data variation between literature sources is considerable. Data from the World Bank's World Development Indicators was taken in order to be consistent with assumptions for the US and the EU, but assuming the average exposures given in some other sources could have reduced the number of calculated deaths in this instance by up to 40%.

Although CO_2 emissions are expected to considerably increase between 2012 and 2030, emissions of local air pollutants will remain relatively constant, or marginally decline according to estimates (IIASA 2012). However, the number of premature deaths in China are still forecast to increase between 2012 and 2030 due to population growth, urbanisation, and an increase in the crude mortality rate due in part to an ageing population. By 2030, the number of annual premature deaths due to $PM_{2.5}$ exposure could reach nearly 3 million. **China's INDC could save in the order of 100,000 premature deaths per year** compared to the current policies scenario. Moreover, if China would strengthen its INDC to meet a **2C compatible trajectory, a further 1.1 million premature deaths could be spared each year by 2030.**

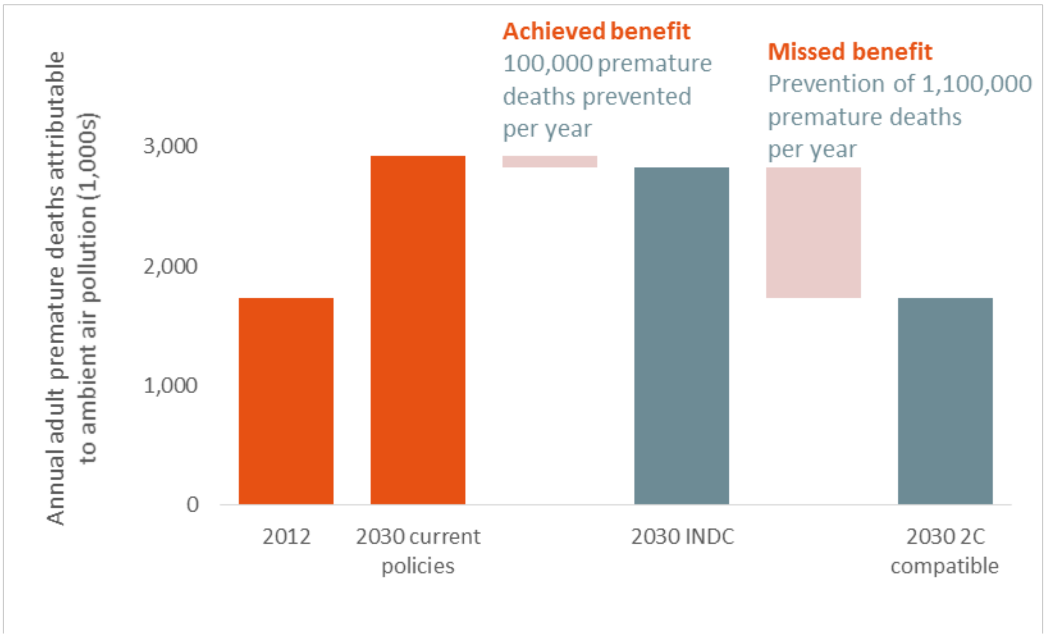

Figure 15: Premature deaths from air pollution in China

4.4.3 Creation of green jobs

Green jobs created in the renewable energy sector

We estimate that China required an estimated 1.5 million full-time equivalent (FTE) jobs in 2012 for the manufacturing, construction, operation and maintenance of domestic solar, wind and hydro electricity installations in 2012. This estimate does not include jobs for China's significant renewable energy technology export industry. According to IRENA (IRENA 2014a), approximately 2.64 million people were employed in the renewables altogether in 2013. Although the current policies trajectory increases the tempo of renewable energy capacity installation marginally, the number of jobs in the sector in China may decrease significantly by 2030 as the employment factor per GW of installed energy for the falls due to the trend of labour de-intensification in the region (Rutovitz & Harris 2012). The anticipated INDC advances substantially on the current policies trajectory with an additional 500,000 jobs by 2030, although this may still entail marginal job losses in the sector between 2012 and 2030. If China were to increase the stringency of their INDC to embark on a 2°C compatible trajectory, a further 1.4 million additional green jobs could be created by 2030, taking the total number of full time equivalent jobs to over 2.6 million.

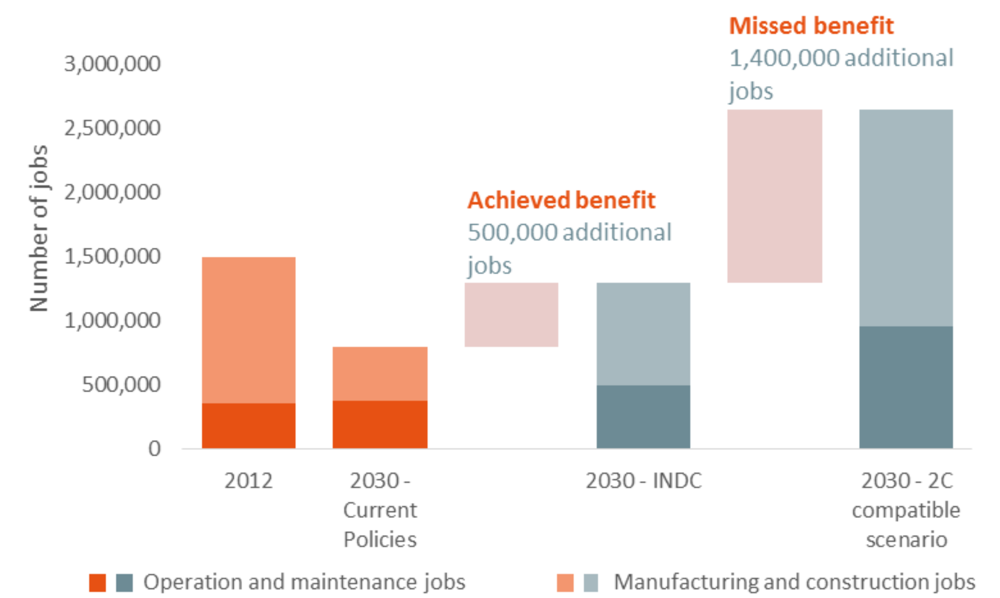

Figure 16: Jobs created in wind, solar and hydro energy in China

Green jobs created through energy efficiency measures

In general, very little information is yet available on the job creation potential of improved energy efficiency. This is also the case for China. Large growth rates in jobs in the renewable energy sector over the last few years have demonstrated how quickly China converts the renewable energy potential into new jobs. Improved energy efficiency has as well an important potential for direct, indirect and induced employment generation in China. The largest users of energy are the industry and transport sector, followed by the buildings sector (IRENA 2014b). Residential energy use, for example, accounts for 86% of the total energy use, with the remainder accounted for in the commercial sector. In this sector, the greatest potential for energy efficiency improvements is in ensuring high energy efficiency standards for new construction (Amecke et al. 2013), which have a large potential for local job creation.

5. Summary

This illustrative study has shown the major co-benefits that have been achieved by the INDCs of the EU the U.S. and China, through the reduction of fossil fuel imports, prevention of premature deaths from air pollution, and the creation of decent green jobs through the renewable energy sector. These achieved co-benefits are summarised in Table 1.

Table 1: Co-benefits achieved by INDCs compared to current policies trajectories

Co-benefit	EU	US	China
Cost savings from reduced fossil fuel imports	USD 33 billion per year saved	Reduced reliance on scarce, domestically produced fuels	Reduce reliance on scarce domestically produced coal by 21%
Premature deaths from excessive ambient exposure to fine particulate matter prevented	6,000 deaths	7,000 deaths	100,000 deaths
Creation of additional green jobs in wind, solar and hydro energy	70,000 jobs	470,000 jobs	500,000 jobs

Despite the major achievements of the INDCs, this study has also shown that the potential co-benefits of strengthening INDCs to meet a 2°C compatible trajectory are many times higher than those already achieved. Table 2 summarises this potential. Figures shown demonstrate the potential co-benefits which are *in addition* to those already achieved by INDCs.

Table 2: Potential co-benefits from strengthening INDCs to meet a 2°C compatible trajectory

Co-benefit	EU	US	China
Cost savings from reduced fossil fuel imports	USD 140 billion per year saved	USD 160 billion per year saved	USD 190 billion per year saved
Premature deaths from excessive ambient exposure to fine particulate matter prevented	40,000 deaths	20,000 deaths	1.1 million deaths
Creation of additional green jobs in the wind, solar and hydro energy	350,000 jobs	180,000 jobs	1.4 million jobs

Recognition of both the achieved and potential co-benefits may increase the willingness of decision makers and influential stakeholders to embark on more ambition climate change mitigation strategies by highlighting the directly tangible synergies between climate change mitigation measures and national development goals. The benefits highlighted in this study – national cost savings, health and job creation – are economy-wide issues that are of key relevance to the development objectives of all imaginable stakeholders. Furthermore, consideration of these co-benefits alongside climate change mitigation policy options are highly likely to decrease the perceived cost of climate change mitigation action. A significant amount of potential and un-implemented mitigation measures in both developing and developed countries is already widely understood to carry negative costs to the financier directly (that is, positive economic returns), and a more thorough consideration of the wider co-benefits accrued externally is likely to substantially increase the mitigation potential that is considered cost-negative for the wider economy. Ultimately, such analysis might demonstrate that climate change mitigation measures which achieve a 2°C compatible trajectory are not only aimed at preserving the well-being of future generations, but may also generate positive economy-wide returns, rather than costs, for the current generation.

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Annex I – Detailed methodologies

Scenarios

Current policies scenario

The current policies scenario simulates the conditions expected in the country should it continue with its current policies, programmes and measures. This scenario is taken from the Climate Action Tracker (CAT 2015), where country specific sources were used, often based upon data from the World Energy Outlook 2014 (IEA 2014c).

INDC pathway

The INDC pathways are taken from the Climate Action Tracker (CAT 2015), where country specific calculations are made, dependant on the type of INDC.

2°C compatible pathway

The 2°C compatible pathway defines a trajectory which a country should take if it is to be consistent with the internationally agreed goal to limit global temperature increase to less than 2°C. For the purpose of this study, a 2°C compatible scenario is defined upon the following simplified general principles:

- The country reaches 100% renewable energy and net-zero emissions for all sectors by the year 2050.
- For energy demand we use the 450ppm scenario of the World Energy Outlook (IEA 2014c). This means it does still increase for some countries, mainly developing countries.
- A linear pathway is followed from the country's current renewable energy shares to 100% in 2050.
- It is assumed that the split between different fossil fuels used for fossil fuel combustion remains constant throughout the phase-out period between now and 2050.

These principles are highly simplified because they neglect the possibilities to achieve a 2°C compatible scenario through other means. For example, countries might continue to increase their emissions in the short term and then reduce them at a faster rate in the future, intermediate shifts to different fuel types (such as a shift from coal to natural gas) might occur before the full phase-out of emissions, or it may become feasible for countries to achieve a 2°C compatible scenario through the use of carbon capture and storage alongside continued fossil fuel combustion. In reality the definition of a 2°C compatible scenario is highly complex; there is no *single* way to develop on a 2°C compatible trajectory, and the approaches that are most attractive are entirely dependent on the economic and political climate of each individual country. For the sake of clarity and comparability the simplified principles described above will be used for all countries.

The precise calculation of the 2°C compatible scenario varies between each co-benefit indicator and is discussed in more detail in the specific methodology section for each respective indicator.

Reduced fossil fuel imports

Defining the indicator and scope

This measurement assesses the cost savings associated with the reduced imports of fossil fuels, due to the reduced demand for these fuels in sectors due to reductions in energy demand and shifts to alternative sources of energy.

For this co-benefit, we consider reduced coal imports for power generation, reduced oil imports for transport, and reduced natural gas demand in all sectors. The selection of these sectors and fuels generally covers the major sources of fossil fuel powered energy consumption, as well as the major sources of potential co-benefit; coal and oil satisfied an estimated 74% of global energy demand in 2013, whilst power accounted for 62% of coal demand and transport for 55% of oil demand. The demand for natural gas worldwide nearly doubled between 1990 and 2012, and is forecast by some scenarios to be the world's greatest source of energy in 2040 (IEA 2014c).

Calculation methodology

Output indicators

Table 3 presents the output indicators that will be produced from this methodology. The indicators shaded in orange are the major output indicators whilst the unshaded rows are the sub-level indicators.

Table 3 Output indicators for reduced fossil fuel imports

Indicator	Scope	Unit
Cost savings from reduced fossil fuel imports achieved (1)	Combined sectors and fuels	USD per year
Potential cost savings from reduced fossil fuel imports missed (2)	Combined sectors and fuels	USD per year
Reduction of oil/coal imports in the transport/power sector achieved (3)	Per sector and fuel type	Mtoe
Potential reduction of oil/coal imports in the transport/power sector missed (4)	Per sector and fuel type	Mtoe

Method of calculation

The production of the output indicators will be based upon a calculation of the differences in energy demand (per sector and fuel type) between the three scenarios: current policies, INDC and 2°C compatible. Table 4 presents the required data inputs for the calculation of the co-benefit in year *x*.

Table 4 Data inputs for the calculation of reduced fossil fuel imports

Indicator	Unit	Source
Sectoral fuel demand in year *x* according to current policies (D_{CP})	Mtoe	World Energy Outlook (IEA 2014c) PRIMES 2013 (European Commission 2013) Climate Action Tracker (CAT 2015) US Annual Energy Outlook 2014 (US EPA 2014)
Sectoral fuel demand in year *x* according to the INDC pathway (D_{INDC})	Mtoe	EU Impact Assessment 2014 (European Commission 2014a) Climate Action Tracker (CAT 2015)
Sectoral fuel demand in year *x* according to 2C compatible pathway (D_{2C})	Mtoe	450 Scenario from the World Energy Outlook (IEA 2014c)
Domestic fuel production (P)	Mtoe	World Energy Outlook (IEA 2014c) PRIMES 2013 (European Commission 2013) US Annual Energy Outlook 2014 (US EPA 2014)
Forecast international price of fuel in year *x*	USD	World Energy Outlook (IEA 2014c)

Figure 17 shows that the sub-level indicators are calculated in the following way, assuming 2030 as the target year of the INDC:

$$Reduction\ of\ imports\ achieved\ in\ 2030 = D_{CP} - D_{INDC}$$

$$Potential\ reduction\ of\ imports\ missed\ in\ 2030 = D_{INDC} - D_{2C}$$

These calculations assume that the domestic fuel production remains lower than the fuel demand in the INDC and 2C scenarios. In countries where this is not the case, the calculation of the reduced imports is rather calculated based on the parameter P (fuel production):

$$Reduction\ of\ imports\ achieved\ in\ 2030 = D_{CP} - P$$

$$Potential\ reduction\ of\ imports\ missed\ in\ 2030 = D_{INDC} - P$$

For countries, which are net exporters of the fuels under consideration, calculations are not made for the reduction of imports.

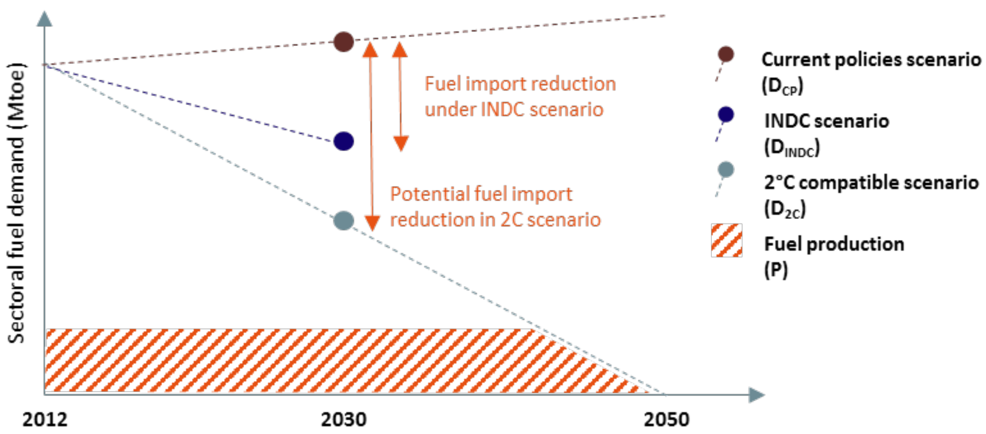

Figure 17 Reduced fossil fuel imports under different scenarios

These sub-level indicators may be converted to the primary output indicator (cost savings) by applying a simple conversion formula based on the international fuel price:

$$Cost\ savings\ from\ reduced\ fossil\ fuel\ imports\ achieved = Reduction\ of\ imports\ achieved \times International\ price\ of\ fuel$$

$$Potential\ cost\ savings\ from\ reduced\ fossil\ fuel\ imports\ missed = Potential\ reduction\ of\ imports\ missed \times International\ price\ of\ fuel$$

Specific assumptions and considerations

The following list provides an overview of the specific assumptions made for the calculation of the co-benefits in the specified sectors for the U.S., China and the EU.

- Financial benefits are based on the WEO forecast fuel prices for 2030 (IEA 2014c). International prices are used for coal and oil, whilst regionally variable prices are available for natural gas.
- Where the fuel demand is met by a combination of local production and imports, it is assumed that imports will be reduced before domestic production when the total demand for fuels is reduced. This assumption may not hold if the marginal cost of oil production are higher than the costs of oil imports. In this case, the economic benefit of reduced demand can be considered even greater than the value given in the results.
- As for the other sectors we assume a transition to 100% renewables by 2050 as the 2°C compatible scenario. For the electricity sector, this is considered by using the growth in electricity consumption under the IEA's WEO 450 scenario (IEA 2014) with a linear reduction of the emissions per kWh from today's level to zero in 2050 or directly the coal consumption in this scenario, whichever is lower. For gas and oil in transport we used the 450 scenario directly as it includes a set of policies that bring about a trajectory of greenhouse-gas emissions from the energy sector that is consistent with the international goal to limit the rise in long-term average global temperature to two degrees Celsius. Under the scenario, the concentration of atmospheric greenhouse gases stabilises by 2100 at a level around 450ppm, after peaking slightly above this level around 2050.
- EU, oil, transport sector, INDC scenario: it is assumed that the change in the amount of oil demand for the transport sector is the same as the change in the total forecast energy consumption of the transport sector, as given in the EU Impact Assessment. This assumes that the relative shares of energy sources in the transport sector remain constant. Realistically, the amount of oil demand is likely to be reduced further as alternative fuels are used in larger quantities, hence the benefits could be even larger.
- US, oil, transport sector, 2°C scenario: The historical data for 2012 between the WEO 450 scenario and the current policies scenario (US Annual Energy Outlook 2014) is inconsistent. For the 2C scenario, the rate of demand change in the WEO data between 2012 and 2030 was applied to the historical data (for 2012) from the US Annual Energy Outlook, in order to determine a value for 2030 that is consistent with the other scenarios.
- US, coal, power sector, INDC scenario: The calculated coal reductions are based upon the 2013 President's Climate Action Plan (Executive Office of the President 2013). The increase is renewable capacity envisaged under this scenario is assumed to be used entirely to offset coal fired power.
- US, coal, power sector, 2°C scenario: The historical data for 2012 between the WEO 450 scenario and the current policies scenario (PRIMES 2013) is inconsistent. For the 2C scenario,

the rate of demand change in the WEO data between 2012 and 2030 was applied to the historical data (for 2012) from the PRIMES model, in order to determine a value for 2030 that is consistent with the other scenarios.

- US, natural gas, INDC scenario: The change in the demand for natural gas that is implied by an INDC with an emissions reduction of 28% is based on the relationship between emission reductions and natural gas demand in the WEO 2014 450 scenario.

Reduced air pollution

Defining the indicator and scope

This methodology assesses the health impacts of decreased outdoor air pollution in urban conurbations, due to the reduced combustion of fossil fuels.

This study considers the health impacts associated with reduced ambient atmospheric concentration of $PM_{2.5}$ in urban and rural populations (using national averages), based upon reduced emissions of primary particulate matter (PM), sulphur dioxide (SO_2), non-nitrogen oxides (NO_x), and ammonia (NH_3), from all sectors.

$PM_{2.5}$ refers to particulate matter with a diameter less than 2.5 µm. $PM_{2.5}$ is the most lethal outdoor air pollutant in urban areas (OECD 2011). Its atmospheric concentration is derived from the emissions of primary particulate matter from fossil fuel combustion processes, as well as from atmospheric reactions between other pollutant gases (secondary particulate matter), namely SO_2, NO_x, and $NH_{3.}$

Concentrations of PM2.5 in any given location can be derived from five distinct sources: natural sources of particulate matter including dust and sea salt; secondary PM from international transboundary emissions; primary and secondary PM from national emissions; primary and secondary PM from urban emissions; and primary PM from street emissions. Natural sources of PM cannot be affected by the domestic policy. The calculation of PM concentrations from international transboundary emissions would require a more in depth version of an air transport model. Therefore, for the U.S., the EU and China, the simplification is made that due to the size of the land masses, most areas are subject to only domestically produced anthropogenic GHG concentrations. As such, policy scenarios are reflected equally in all source components of PM2.5 concentrations, except for the natural source component which remains constant throughout.

This indicator will only reflect the number of premature deaths per year, and as such it considerably underestimates the impacts on human health and the related costs from non-lethal conditions such as chronic and acute bronchitis, or asthma.

Calculation methodology

A large number of studies and models exist which calculate local air pollution and associated health impacts. These methodologies vary considerably with regards to their complexity and accuracy. Indeed, the precise determination of local air pollution is a highly complex exercise that is largely dependent on a very wide range of variables, including local climatic conditions as well as geographical features and urban topographies. For this study, simplified methodologies were combined and adapted to suit the requirements of the output indicators.

Output indicators

Table 5 presents the output indicators that will be produced from this methodology. The indicator shaded in orange is the major output indicator whilst the unshaded row is the sub-level indicator.

Table 5 Output indicators for reduced air pollution

Indicator	Unit
Number of premature deaths saved per year due to reduced $PM_{2.5}$ concentrations.	Deaths per year
	Percentage change
Reduced national average exposure to PM2.5 concentrations due to reduced emissions of greenhouse gases	$\mu g/m^3$

Method of calculation

The calculation of the output indicators will be based upon the differences in the emissions between the three scenarios (current policies, INDC and 2°C compatible), and a selected response factor to calculate $PM_{2.5}$ concentrations and associated deaths. Table 6 presents the required data inputs for the calculation of the co-benefit in year x.

Table 6 Data input for the calculation of reduced air pollution

Indicator	Unit	Source*		
		EU	US	China
Mean annual exposure to $PM_{2.5}$ concentrations in the year 2010 (G_{2012})	$\mu g/m^3$	World Development Indicators (World Bank 2013)		
Estimated national average background concentration of $PM_{2.5}$ from natural sources (G_N)	$\mu g/m^3$	Approximation based on IIASA (2014)	Approximation based on Mueller & Mallard (2011)	Approximation based on Yang et. al. (2011)
Low concentration threshold, under which no additional effect on mortality is observed.	$\mu g/m^3$	Based on California Air Resources Board (2010)		
Population over the age of 30	integer	Health Nutrition and Population Statistics (World Bank 2014)		
Crude death rate	Annual deaths per one thousand population	Bollen (2009)		
Total forecast energy consumption	Mtoe	450 scenario of the World Energy Outlook 2014 (IEA 2014c)		
Total national CO_2 emissions in 2012 (E_{2012})	$MtCO_2$	PRIMES	AEO 2014	WEO 2014
Total national CO_2 emissions in year *x* according to current policies (E_{CP})	$MtCO_2$	PRIMES	AEO 2014	WEO 2014
Total national CO_2 emissions in year *x* according to the INDC pathway (E_{INDC})	$MtCO_2$	PRIMES; EU Impact Assessment	CAT	CAT
Total national CO_2 emissions in year *x* according to the 2°C	$MtCO_2$	See section "*definition of 2°C compatible scenario*", below.		

compatible pathway (E_{2C})		
Relationship between the reduction of the emissions of CO2 and the emissions of air pollutants (for each specific country and scenario).	Factor	IIASA (IIASA 2012) and WEO 2012

* PRIMES – EU Trends to 2050 (European Commission 2013); AEO – US Annual Energy Outlook 2014 (US EPA 2014); WEO – IEA World Energy Outlook 2014 (IEA 2014c); CAT – Climate Action Tracker (CAT 2015)

Estimated emissions of SO_2 and NOx will be used as a proxy for the emissions of all the major air pollutants under consideration: primary PM, SO_2, NO_x, and NH_3. This simplification recognises that emissions of SO_2 and NOx are highly influential to the production of secondary particulate matter, and assumes that the emissions of other air pollutants are reduced proportionally to SO_2 and NOx. A number of studies have applied such simplifications that assume uniform reductions of all these gases for the calculation of local outdoor air pollution, most notably the OECD 2050 Environmental Outlook (OECD 2011). Detailed data for SO_2 and NOx emissions is not available under all scenarios. Instead, the relationships between CO2 emission projections and SO_2/NOx projections were analysed for each individual country to produce an indicative factor that allows for the estimation of air pollutant emissions based upon CO2 emissions, the data for which is readily available and more easily modelled under various scenarios.

In a first step, the urban atmospheric concentration of $PM_{2.5}$ is calculated:

$$Mean\ exposure\ to\ PM2.5\ concentrations\ in\ year\ x = \Delta E\ (G_{2012} - G_N)\ +\ G_N$$

ΔE represents the change in emissions of air pollutants that contribute to PM2.5 concentrations, as a ratio of emissions in the calculation year and the base year, 2012. This formula is based on a simplification that assumes a linear decrease of $PM_{2.5}$ concentrations in line with reduced CO_2 emissions. This assumption is consistent with Bollen (2009).

Estimated background levels of $PM_{2.5}$ that are not attributable to anthropogenic emissions of pollutants (G_N) are taken into consideration. Figure 18 shows how under the 2°C compatible scenario (which assumes a reduction to zero CO2 emissions from energy by 2050), the atmospheric concentration of $PM_{2.5}$ reduces in linear fashion from its value in 2012 to the value of the background concentration in 2050. Other factors that determine the atmospheric concentration of $PM_{2.5}$, such as weather conditions and geographical features, are assumed to remain constant.

Figure 18 also shows how the difference in the atmospheric concentration of $PM_{2.5}$ between the different scenarios can be determined.

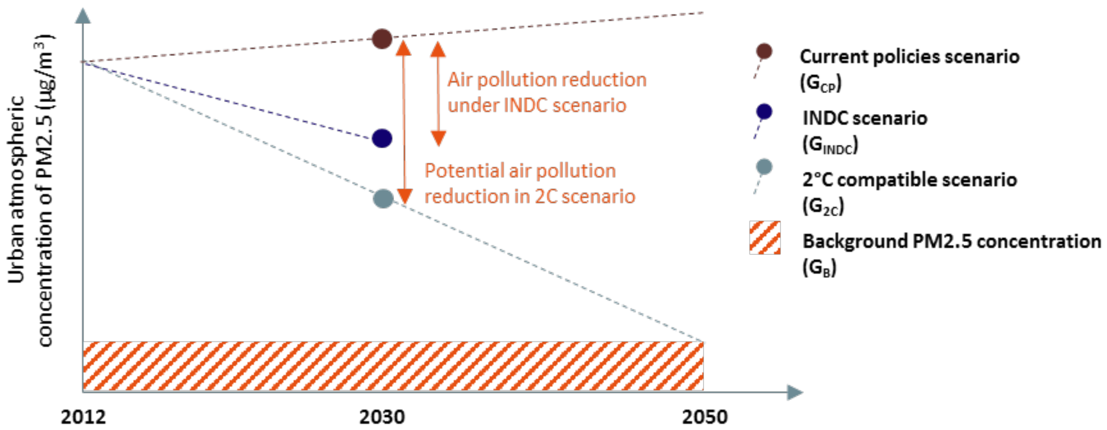

Figure 18 Reduced air pollution under different scenarios

In a second step, the reduction of premature mortality can be calculated depending on the change of atmospheric concentration of $PM_{2.5}$ between scenarios (Bollen 2009; Fang et al. 2013; Public Health England 2014):

$$\text{Premature deaths from particulate air pollution} = \text{Attributable factor (AF)} \times \text{Crude mortality rate} \times \text{Population}$$

$$\text{Attributable factor} = \frac{\beta^{G} - 1}{\beta^{G}}$$

The attributable factor calculates the percentage of deaths which may be attributed to excessive $PM_{2.5}$ concentrations. In this equation, G is the concentration of the pollutant, as demonstrated by Figure 18, given in units of 10 μg/m^3. β refers to the estimated factor of the log-linear relationship between the concentration of any given pollutant and the resulting mortality rate (concentration-response factor). Krewski et al. (2009) finds a 5.9% risk increase of premature mortality from all causes for every $PM_{2.5}$ concentration increase of 10 μg/m^3. Therefore, the value 1.059 is used for the concentration response factor β, as per Fang et al. (2013) and Bollen (2009). It is common practice when calculating premature deaths from $PM_{2.5}$ concentrations to consider only the population over 30 years of age (Public Health England 2014).

This study does not use of a low concentration threshold (LCT). The use of an LCT assumes that below a certain level of PM2.5 concentration, there is no effect on mortality. There is no general consensus on whether the use of an LCT is appropriate or not, due to the lack of empirical evidence that such a threshold does or does not exist. The use of an LCT of 5.8 μg/m^3 in this study would only marginally change the results for China, but it would reduce the number of calculated deaths in the EU and the U.S. in 2012 by around 40%.

Defining the 2°C compatible scenario

The 2C compatible pathway for this indicator is based upon 100% renewables by 2050. It is estimated by using the projections for total fuel demand from the WEO 450 scenario, which incorporates polices including EE measures that reduce energy consumption in line with the international 2C goal, multiplied by a decreasing emissions intensity. We assume a decrease to zero emissions intensity of the energy sector in all countries by 2050. It is further assumed that all countries reach this specific target in 2050 and not before. The emissions intensity of energy is calculated for 2012 based on historical demand and emissions data from WEO (IEA 2014c) and the Climate Action Tracker (CAT 2015).

Specific assumptions and considerations

The following list provides an overview of the specific assumptions made and noteworthy considerations for the calculation of premature deaths from air pollution for the U.S., China and the EU.

- Average $PM2_{.5}$ concentrations are assumed to be linearly related to air pollutant emissions, such that a halving of emissions causes a halving of the anthropogenic component of PM2.5 concentrations.
- It is assumed that reductions in suplur dioxide (SO_2) and nitrogen oxides (NOx) are accompanied by reductions of the same scale in primary PM and ammonia (NH3).
- It is assumed that the relationship between projected emissions of CO_2, SO_2 and NOx under various scenarios according to IIASA can be extrapolated to estimate SO_2 and NOx emissions according to modelled CO_2 emissions under different scenarios.
- It is assumed that the premature death response rate is linearly related to the concentration of PM2.5 ((Fang et al. 2013; Bollen 2009; Public Health England 2014))
- The 2°C compatible pathway assumes a decrease to zero emissions intensity of the energy sector in all countries by 2050. It is further assumed that all countries reach this specific target in 2050 and not before. Trends for overall fuel demand are taken from the WEO 450 scenario, which incorporates polices including EE measures that reduce energy consumption in line with the international 2C goal.
- Comprehensive and reliable data for average ambient $PM_{2.5}$ concentrations is not available in all areas. Furthermore, the spatial and temporal variations of PM concentrations are so large in some territories, particularly in China, that the mean data should be treated with caution regarding its precision.
- As explained in the methodology, this study assumes no low concentration threshold (LCT).There is a lack of empirical evidence for or against the use of a LCT.
- The selection of natural background PM2.5 concentrations is based on the literature, and approximate values are estimated based upon the likely range given within the literature sources reviewed. The precision of this input data cannot be guaranteed due to the generally limited availability of such data in all countries, but adjustments made to this input variable within the identified ranges produce only marginal changes in the final results.

Green jobs from renewable energy

Defining the indicator and scope

This section outlines a methodology to determine the impact on employment from the installation of wind, solar and hydro renewable electricity capacity. We use the employment factor approach to quantify direct job creation during two phases of the life cycle, a) manufacturing, construction and installation (MCI) and b) operation and maintenance (O&M). Jobs more broadly related to renewable energy through other phases of the cycle, including research, technological development, consultation, project development, and project evaluation, are not included in the scope of this study. Furthermore, this study only determines the impact on employment of the domestically installed capacity; jobs created through renewables export industry are not included.

This approach is a first approximation of the effect on green jobs. The focus is only on the creation of 'decent green jobs'. For the purpose of this study, we adopt a definition of green jobs provided by ILO (2013a):

Green jobs are decent jobs that contribute to preserving and restoring the environment, be they in traditional sectors such as manufacturing and construction, or in new, emerging green sectors such as renewable energy and energy efficiency. Green jobs reduce consumption of energy and raw materials; limit greenhouse gas emissions; minimize waste and pollution; protect and restore ecosystems; and enable enterprises and communities to adapt to climate change.

Accordingly, the methodology does not take into account that jobs may be lost elsewhere through reduced use of fossil fuels or shift of economic activity towards renewables away from other potential activities.

Calculation methodology

According to the International Renewable Energy Agency (IRENA 2014a) mayor gaps remain in the generation of data on employment in the renewable energy sector. The main reason for this is that due to the cross-cutting nature of the sector, information is difficult to capture in standard national statistics. To date, only a few countries are collecting relevant data on renewable energy jobs. Relatively detailed data is available only for the United States and several European countries. Better harmonisation of data reporting categories is necessary to improve the quality and comparability of employment data.

In most cases, employment figures are derived from various sources, using heterogeneous methods, assumptions and time frames, which makes comparison of data difficult. One way around this is to use sensitivity analysis to test key data sources and assumptions.

Output indicators

Table 7 presents the output indicators that will be produced from this methodology.

Table 7 Output indicators for reduced air pollution

Indicator	Unit
Jobs for the construction and installation of hydro, wind and solar electricity installations.	Integer Percentage change
Jobs for the maintenance and operation of hydro, wind and solar electricity installations.	Integer

Method of calculation

To evaluate the impact of an increase in renewable energy and energy efficiency measures on job creation, we follow (IRENA 2014a) and apply the employment factor approach. The method is the least resource-intensive method for assessing direct job creation and is based on data for:

- Installed capacities for specific renewable electricity technologies
- Employment factors per unit of installed capacity

Employment factors indicate the number of full-time equivalent (FTE) jobs created per unit of installed capacity. The employment factors are derived in the literature from the following simplified calculation:

Renewable energy

$$Employment\ factor_{RE} = Jobs\ created_{RE}\ /Installed\ capacity\ (MW)$$

A secondary literature review was carried out to collect employment factors from the most relevant sources on this topic. This allows us to get an idea on data ranges and the uncertainty of results.

For the estimation of job creation in renewable energy deployment, the employment factor approach uses different factors for different phases of the life cycle. We consider two phases: a) manufacturing, construction and installation (MCI) and b) operation and maintenance (O&M). These two phases are considered in most of the available secondary literature on employment generation in the renewable energy sector. Table 8 presents employment factors for the OECD and the US. According to Rutovitz & Harris (2012), a regional multiplication factor of 2.6 on the OECD figures is required for China before 2015, and approximately 1.3 in 2030.

Table 8 Employment factors for the renewable energy sector from various studies

Technology	MCI (Jobs per newly installed MW)	O &M (Jobs per MW)	Region	Year of estimation
Wind, onshore	8.6	0.2	OECD countries (Average values)	Various (2006-2011)
	12.1	0.1	US	2010
Wind, offshore	18.1	0.2	OECD countries (Average values)	2010
Solar PV	17.9	0.3	OECD countries (Average values)	Various (2007-2011)
	20.0	0.2	US	2011
Hydro, large	7.5	0.3	OECD countries (Average values)	Various
Hydro, small	20.5	2.4	OECD countries (Average values)	Various
Geothermal	10.7	0.4	OECD countries (Average values)	Various

Source: (Rutovitz & Harris 2012)

To estimate the total number of direct jobs under the current policies, INDC and 2°C compatible scenarios, employment factors are multiplied by the calculated renewable energy capacity for each technology type (onshore wind, offshore wind, solar PV, small hydro, and large hydro).

Table 9 presents the required data inputs for the calculation of the co-benefit in any given year.

Table 9 Data input to calculate employment generation

Indicator	Unit	Source*		
		EU	US	China
Total installed capacity per technology (current policies)	MW	PRIMES, EU Impact Assessment	AEO 2014	WEO 2014
Total installed capacity per technology (INDC scenario)	MW	PRIMES, EU Impact Assessment	Own calculation	CAT
Total installed capacity per technology (2C compatible scenario)	MW	See *defining the 2C compatible scenario*, below.		
Domestic power demand	MWh	PRIMES, EU Impact Assessment	AEO 2014	Extrapolation from WEO 2014
Capacity factors of renewable technologies	Annual MWh per MW installed capacity	Derived from PRIMES (European Commission 2013)		
Employment factor per technology and activity	Jobs created per installed capacity (MW) (split by MCI and O&M)	Rutovitz & Harris (2012)		

* PRIMES – EU Trends to 2050 (European Commission 2013); AEO – US Annual Energy Outlook 2014 (US EPA 2014); WEO – *: IEA World Energy Outlook 2014 (IEA 2014c); CAT – Climate Action Tracker (CAT 2015)

Figure 19 shows how the difference between the number of jobs under each scenario will be determined.

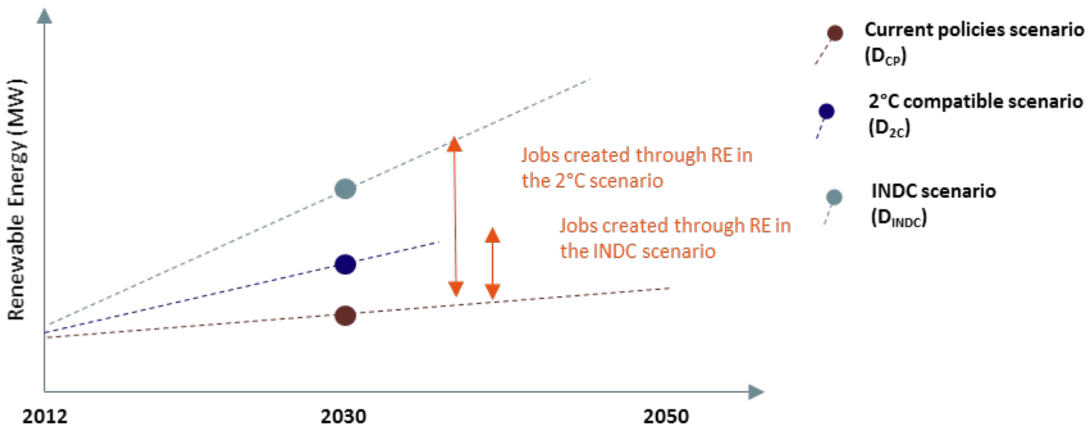

Figure 19: Green jobs created under different scenarios

Defining the 2°C compatible scenario

The 2°C compatible pathway for this indicator is based upon a linear development from today's installed renewable capacity to 100% renewables in the electricity sector by 2050. The total capacity of each renewable energy technology required in 2050 is calculated according to the total forecast electricity demand in 2050, divided by the assumed capacity factors of each renewable energy technology. The proportional split of each technology is based upon the proportional split calculated for 2030 in the INDC scenario. The capacity factors for each technology are taken from those implied by the 2050 reference scenario for the EU (European Commission 2013).

Specific assumptions and considerations

- The data for 2030 under the US current policies scenario is taken as the midpoint between the 2025 and 2035 data in the US Annual Energy Outlook.
- The US INDC scenario is modelled based upon the 2013 President's Climate Action Plan (Executive Office of the President 2013). The plan entails a doubling of renewable capacity between 2012 and 2020, and the rate of renewables installation during this period was extrapolated to 2030.
- The 2C compatible scenario assumes that all countries arrive at 100% renewables in the electricity sector in 2050 exactly, and not before.
- It is assumed that the proportional split of renewables in the electricity energy system in 2050 (under a 100% renewable energy system) will be equal to the proportional split of renewables in 2030, according to the INDC scenario. This assumption overlooks the possibility that specific types of renewables may reach the limit of their resource potentials, requiring a larger share from other types of renewables in a 100% renewable system.
- It is assumed as a simplification, that a 70:30 split will exist between onshore and offshore wind generation in 2050 for all countries. This split is in line with the global forecast of the IEA Wind Roadmap (IEA 2013).
- It is assumed as a simplification, that a 09:91 split will exist between small and large hydro generation in 2050 for all countries. This split is in line with the current global trend (REN21 2014).
- Capacity factors for renewable technologies in 2050 are taken from the implied forecast capacity factors in the PRIMES model (European Commission 2013). In this model, the amount of energy generated per unit capacity of renewables is larger in 2050 than in 2010, due largely to technological advances and the more advantageous placements of installations. Through this methodology, the total generation capacity required in each country under the 100% scenario is calculated to be around one third larger than in the reference scenarios.
- A multiplication factor of 1.3 is applied to the employment factor of the OECD for China in 2030. This is an extrapolation of the data from Rutovitz & Harris (2012), which indicates a factor of 1.9 in 2020 and 1.0 in 2035.