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PBL Netherlands Environmental Assessment Agency

Methodology for analysing greenhouse gas emission reduction proposals and national climate policies of major economies

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March 2013

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1 Introduction

This Supplementary Information describes the methodology used to calculate the impact of the major climate and energy policies on emissions for major emitting countries (see Table 1, main text). Before describing the methods in more detail, we first explain the terms Primary energy supply and Target year, as these are used throughout the document.

Primary energy supply. Primary energy supply refers to the direct supply of energy at the source, or supply of crude energy which has not been subjected to any conversion or transformation process[1]. For generating electricity, either combustible sources, such as fossil fuels and biomass, or non-combustible sources, such as wind, solar, and nuclear, can be used. Primary energy supply can be directly measured for combustible sources, but for non-combustible sources it depends on the accounting method. In literature, there are two major accounting methods for determining the primary energy supply of non-combustible sources: the physical energy content method (IEA method) and the substitution method (BP method), see IPCC (2011), Martinot et al. (2007), IEA (2012) for more details. The IEA method counts the electricity produced from the renewables as primary energy supply, while the BP method calculates an equivalent primary energy supply that would have been necessary to produce this electricity in a fossil-fuel power plant. The difference between the methods is the (virtual) energy loss (Martinot et al., 2007). In this study, PBL uses the IEA method, whereas Ecofys uses the method that is assumed in the underlying study.

Target year. Most policies have a target year of 2020. If the target year of a policy is after 2020, the target is linearly interpolated between 2010 and the target year. For example, the renewable mix target for Mexico that holds for 2023 is linearly interpolated between 2023 and 2010. The resulting target for 2020 is used as a starting point for the calculations to assess the effect of the policy. If the target year is before 2020, the target scenario that is constructed is divided into two parts. The first part contains emissions and energy projections until the target year, taking into account the target level. In the second part, we assume a business-as-usual (BAU) trend between the target year and 2020. For example, the effect of the energy intensity target for China that holds for 2015 is calculated by constructing a target scenario that meets the energy intensity target in 2015 and follows energy intensity trends from BAU between 2015 and 2020. The 2020 level of the target scenario can then be compared to BAU energy and emission projections.

2 Renewable targets

Renewable targets aim for a certain amount of renewable energy supply in the target year. There are two types of renewable targets: (i) a *renewable mix target*, which aims for a certain share of renewable energy supply in the total energy mix, and (ii) a *renewable capacity target*, which aims for a certain amount of installed renewable power capacity, specified per type of renewable technology (e.g. solar, wind). A renewable capacity target only covers the electricity sector, but a renewable mix target can cover all sectors.

[1] http://www.iea.org/aboutus/faqs/energyefficiency/

2.1 Renewable mix targets

The effect of renewable mix targets is calculated based on the difference in the share of energy use from renewable resources between the BAU projection and a projection of a scenario in which the renewable target is achieved, using emission factors per unit of primary energy supply. If the target applies to electricity generation, a similar method is used.

A *renewable mix target* aims for a certain share of renewable energy in the target year. The share of renewable energy is either measured in terms of primary energy supply or electricity generation (which is a form of secondary energy supply). The difference between the two is that primary energy supply also includes energy use outside the electricity sector and that it accounts for energy losses in power plants within the electricity sector. Of the countries included in our study, Australia, Brazil, China, EU, India, Indonesia, Mexico, Russia, South Korea, and USA States have renewable mix targets.

The first step in the calculations is to determine the energy mix in the target scenario, in which the renewable target is achieved. If a country does not explicitly specify which non-renewable resources are replaced (e.g. coal, oil, gas) by which renewable resources (e.g. wind, solar), we have assumed that the weight of each renewable energy resource within the renewable mix is the same as in the BAU scenario. This also holds for the non-renewable resources within the non-renewable energy mix. In the second and final step, the emission level after implementation of the target is calculated for each energy carrier using emission factors per unit of primary energy supply. The emission factors for renewables are assumed to be zero. In the calculations we do not consider nuclear energy as a renewable energy source, except if countries have specified this (China, for instance, has defined its renewable target as a non-fossil target, which implies that nuclear energy is included).

There are three differences between the PBL and Ecofys calculations. The first difference is in the accounting method for primary energy supply. The PBL calculations are based on PBL TIMER projections, which are based on the IEA accounting method for primary energy supply. The only difference between the IEA and PBL TIMER accounting method is in the conversion ratio for nuclear energy: IEA assumes a ratio of 33% based on heat loss, whereas the PBL TIMER model assumes a ratio of 100% based on (the absence of) electricity loss. The Ecofys calculations use primary energy supply projections from national plans or the WEO 2011, and thus use the primary energy accounting method underlying these projections. The second difference is in the change in nuclear energy use between the BAU scenario and the target scenario. The PBL calculations assume substitution of nuclear energy by renewable energy, whereas the Ecofys calculations assume that the use of nuclear energy does not change between the two scenarios. Finally, if the target is defined in terms of electricity generation, the PBL calculations first determine the primary energy supply for each energy resource using the appropriate accounting method of primary energy supply before applying emission factors per unit of primary energy supply. The Ecofys calculations directly use emission factors per unit of electricity generation.

2.2 Renewable capacity targets

The effect of renewable capacity targets is calculated by estimating

the reduction in primary energy supply coming from fossil fuel resources compared to BAU developments, by replacing the fossil fuel resources with renewables resources, using emission factors per unit of primary energy supply.

A *renewable capacity target* aims for a certain amount of installed renewable power capacity in a specific year, specified per type of renewable resource (e.g. solar, wind). Brazil, China, India, and South Africa have renewable capacity targets.

In the PBL calculations, we first calculate the additional installed capacity per type of renewable resources compared to BAU projections. The electricity production from this additional renewable capacity is calculated by using load factors per renewable technology from the TIMER model. The load factor is defined as the annual generated electricity divided by the generated electricity that would have been achieved if the power plant would have functioned at maximum capacity for a full year (Blok, 2006). It is assumed that these additional installed renewable capacities replace coal-fired power plants. Then, the reduction in the primary energy supply of coal is calculated by using the efficiency of coal-fired power plants. Finally, the emission reduction is calculated based on the emission factors per unit of primary energy supply of coal.

The Ecofys calculations are based on a slightly different method. This method first determines the new energy mix in the target scenario, based on the electricity generation from the additional renewable capacities, using information on load factors from national studies or Beurskens et al. (2011). This method implies that renewable technologies replace different types of fossil-fuel power plants (whereas PBL calculations assume that only coal-fired plants are replaced – see above). The emission reduction is calculated based on emission factors per unit of electricity generation.

3 Intensity targets

Two types of intensity targets can be distinguished: emission intensity targets and energy intensity targets. The calculations assume that the GDP trend is not affected by meeting the intensity targets.

3.1 Emission intensity targets

***Greenhouse gas emission intensity targets* aim for reductions in emissions per unit of economic output (real GDP), in a specific year, compared to a base year.**

Some countries (e.g. China, India[2]) have an emission intensity target, i.e. reduction in greenhouse gas emissions per unit of GDP. Hence, the effect of intensity targets on the emission level depends on future GDP growth: higher economic growth would imply a higher target emission level. The effect of this target is determined by calculating the emission level corresponding to the emission intensity target, assuming that GDP is not affected by the intensity target. This level can be compared to BAU emission projections to determine the expected emission reductions.

3.2 Energy intensity targets

***Energy intensity targets* aim for reductions in primary energy supply per unit of economic output (real GDP), in a specific year, compared to a base year. The effect of energy intensity targets is calculated based**

[2] India pledged an intensity target, but this is not included in the domestic policies

on GDP projections, BAU trends in primary energy use and emission factors per unit of primary energy supply.

China, Russia, and Ukraine have energy intensity targets. The effect of these targets is determined by first calculating the primary energy supply level in a scenario in which the energy intensity target is achieved, again assuming that GDP is not affected by the target. The emission target level is calculated using emission factors per unit of primary energy supply. This level can be compared to BAU projections to determine the expected emission reductions.

4 Power plant standards

Power plant standards are usually set at the level of best available technology and are stated in terms of CO_2 emissions per unit generated electricity. The effect of power plant standards is estimated by calculating the difference in emissions per unit generated electricity of the new installed or replaced power plants between BAU projection and the projection in which all new plants meet the standards.

Power plant standards set a limit on CO_2 emissions per unit of generated electricity within a certain period. This performance standard is usually based on the best system of emission reduction that has been adequately demonstrated (Lashof et al., 2012); the so-called best available technology (BAT). The USA and Canada have set power plant standards based on natural gas combined-cycle (NGCC) plants or power plants capable of carbon capture storage. Power plant standards can apply for new (USA, Canada) or existing (Australia) fossil fuel power plants.

The effect of power plant standards is estimated by calculating the difference in emissions of the installed or existing power plants in the BAU projection and the projection in which these plants are replaced by new plants that meet or exceed the standards.

In the PBL calculations with the TIMER energy model, existing or new coal fired power plants under the BAU projections are replaced by power plants that satisfy the specified BAT standards. Assuming that the same amount of electricity is generated, the primary energy supply for the new power plants in the target scenario is calculated by applying the efficiencies of the specified BAT power plants. The emission reductions are calculated using emission factors per unit of primary energy supply.

Ecofys calculations are based on the assumption that with the power plant standard no additional coal-fired power plants are built; these are replaced by gas-fired power plants. Therefore, first the expected capacity increase of coal-fired power plants under the BAU projections needs to be determined. Subsequently, the electricity generated by these plants is calculated using an average load factor for coal-fired power plants of 7,500 hours/year[3]. Emissions from the new coal-fired plants are calculated using coal emission factors per unit of generated electricity. For estimating the effect of the standard, we compare these emissions with the emissions that would be emitted if all the additional coal-fired plants were to be replaced by gas-fired power plants.

5 Feed-in-tariff

The impact of feed-in-tariffs on installed renewable capacity is

[3] This can be converted to the load factor as defined in Section 2.2, given that a (non-leap) year has 8760 hours (see Blok (2006))

calculated based on the relationship between the level of the subsidy and growth of installed renewable capacity, estimated from historic data for Germany and Spain, and accounting for barriers such as difficult grid access, missing long-term perspectives and lack of clear regulations. The calculation of the effect on emissions of the resulting installed renewable capacities is the same as for renewable capacity targets.

A *feed-in-tariff* (FIT) is an energy-supply policy focused on supporting the development of new renewable power generation (Cory et al., 2009). The most common FIT policy provides a fixed rate per kilowatt hour (US$/kWh) for the electricity produced for a guaranteed period of time (Blok, 2006). The rate is usually based on the generation cost of each specific technology and is in general higher than expected electricity prices. South Africa and Ukraine introduced feed-in-tariffs.

The impact of feed-in-tariff policies is calculated by first estimating the impact of feed-in-tariffs on the growth of installed renewable capacity, and then by calculating the emission reduction resulting from this growth in the same way as is done for renewable capacity targets.

A calculation tool was developed by Ecofys to estimate the growth of installed renewable capacity resulting from a FIT scheme. The tool includes two main calculation steps. First the FIT is compared with the generation costs found in literature. Based on an analysis of the relationship between the level of the FIT and growth of installed renewable capacity from historic data for Germany and Spain, the annual growth rate is estimated to be equal to

$$g = \frac{\left(\frac{F}{C} - 1\right) - 0.1}{0.9}$$

where

g = annual growth rate of installed capacity

F = Feed-in-tariff of technology (per kWh)

C = Average costs per technology found in literature (per kWh)

This relationship assumes that a policy starts to be effective if the feed-in-tariff is more than 10% above average costs. If this is the case, the annual growth rate of installed capacity is proportional to the level of support above 1.1 times the costs. If the support is twice the costs, the annual growth rate is 100%. Then second, a barrier factor is determined through expert judgement and based on the following considerations that are weighted differently:

- Is grid access 100% assured?
- What is the long-term perspective (20 years)?
- Are clear regulations available for the guaranteed purchase price?

If there are no barriers in place, the annual growth rate is unaffected. Otherwise the resulting barrier factor will multiplied with the growth factor. Then the estimated growth factor will be multiplied with installed capacity values from WEO 2011 for the starting year and extrapolated to 2020.

6 Emission trading system

Emission levels resulting from the implementation of an emission trading system (ETS) are determined by applying the proposed emission caps to emissions of the sectors that

are covered by the ETS, also taking into account implementation barriers. The difference with BAU emissions determines the reductions.

In an *emission trading system* (ETS), allowances to emit GHG emissions are issued or auctioned to companies. Companies are required to hold a number of allowances equivalent to their emissions. In this way an emission cap is set. The national cap is set as a percentage reduction compared to a historical year or BAU level. Australia, the EU, South Korea and USA have set up emission trading systems.

Emission levels resulting from the implementation of an ETS are determined by applying the emission cap to the sectors that are covered under the ETS. The difference with BAU emissions determines the reductions. Based on expert opinion, a barrier factor is introduced to take into account expectations about reaching the target, for example because flaws in measurement, reporting or verification exist or lack of enforcement of the system. It is assumed that the ETS does not affect emissions of sectors not covered under the ETS.

7 Fuel efficiency car standard

The effect of fuel efficiency standards for cars is calculated by two methods. The first is based on replacing cars that do not satisfy the new efficiency standards for cars that do, where the replacement rate is based on the average life time of cars. The other method makes use of the TIMER transport model; the effect on emissions is calculated by running a scenario with improved car standards, taking into account the higher purchase costs for such cars.

A *fuel efficiency car standard* aims to achieve a certain fuel efficiency for new cars within a specific period.

The effect of fuel efficiency standards for cars is calculated by two methods: the Ecofys method, which is based on the replacement rate of cars, and the PBL method, based on the TIMER transport model. Of the analysed countries, the USA and Canada have set fuel efficiency standards.

Ecofys calculations are based on BAU projections for travel distance and emissions from national studies or literature. An assumption is made for the expected life time of cars. This implies an average annual replacement rate for cars. It is assumed that this rate also applies to distance travelled. The calculation starts in the first year of the period that the car standard will come into effect. The car stock in terms of travel distance is decreased by applying the replacement rate, assuming a homogeneous age structure of existing cars. The removed cars are replaced with new cars that are built in that year and satisfy the car standard. The fuel efficiency for these cars follows a linear development until the standard that applies in the final year. These new cars remain in the car stock for a period equal to the expected life time. The emissions of old cars, that are built before the starting year, are calculated with an average emission factor per kilometre that applies in the BAU projections. The emissions for new cars are based on the new car standard. These steps are repeated for all the following years until the final year of the policy period.

The PBL calculations are based on running a target scenario in the TIMER transport model (Girod et al., 2012). Compared to the BAU scenario, two settings are changed (for details, see Deetman et al., 2012). First, the efficiency for gasoline cars and trucks is

set equal to the fuel efficiency standard. Second, the purchase costs of these cars is adjusted, based on costs found in literature. These adjustments lead to different car technologies under the scenario with efficiency standards compared to BAU projections, resulting in different transport emissions. The reduction from implementation of the fuel efficiency standard can be calculated by comparing these emissions to BAU projections.

8 Biofuel targets

The effect of biofuel targets is calculated by two methods. For the first method the PBL TIMER transport model is used. The second method of Ecofys is based on substituting energy use from gasoline or diesel cars by biofuels, using different emission factors from literature.

A *biofuel target* sets a mandatory minimum volume or share of biofuels to be used in the total transportation fuel supply. The effect of biofuel targets is calculated by two methods. The first method of Ecofys is based on substituting energy use from gasoline or diesel cars by biofuels, using different emission factors from literature. For the second method the PBL TIMER transport model is used. Of the countries included in our study, only Indonesia has set biofuel targets.

Ecofys calculations are based on national projections. The additional energy use for biofuels is calculated by comparing the share of biofuels to the transport mix in the BAU projections. It is assumed that the additional biofuels replace gasoline and diesel. The emissions based on gasoline and diesel cars are compared with emissions from biofuels, calculated using IPCC emission factors (IPCC, 2007). Two different emission factor for biofuels are used, first it is assumed that biofuels do not lead to emissions and second that they do lead to indirect emissions, e.g. through land-use change and deforestation.

PBL calculations are based on running a target scenario using the TIMER transport model (Girod et al., 2012). Deetman et al. (2012) presents a more detailed description of the method. A biofuel target specifies the share of biofuels in the fuel mix, in terms of secondary energy use. We assume that the biofuel target is set for passenger cars only. In the biofuel target scenario, the model finds different share of fuels per vehicle type, leading to different emissions compared to BAU projections.

9 Energy efficiency targets

Energy efficiency targets **aim for reductions in primary energy supply or electricity consumption in a specific year, compared to either the level in a historic base year or BAU projections. The effect of energy efficiency targets that aim at reducing primary energy supply is calculated by applying the targeted reduction on historical levels or BAU trends in primary energy supply and emission factors per unit of primary energy supply. If the target applies to electricity generation, a similar method is used, in which first the primary energy supply is calculated using the appropriate accounting method.**

Energy efficiency targets are similar as energy intensity targets, but instead of reduction per unit of GDP, absolute reduction is targeted. Of the countries included in our assessment, the EU is the only one that has set energy efficiency targets. Calculations are similar to those for energy intensity targets (see section 3.2). PBL and Ecofys calculations differ

only for energy efficiency targets defined in terms of electricity consumption, and is the same as difference (iii) as described in section 2.1.

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