*Contract N°: IEE/11/845/SI2.616378*

# *Bringing Europe and Third countries closer together through renewable Energies*

# *BETTER*

# *Integrative assessment of RES cooperation with Third countries (D6.4)*

Co-funded by the Intelligent Energy Europe
Programme of the European Union

*Project Coordinator:* ***CIEMAT***

*Work Package* ***6*** *Leader Organization:* ***TU Wien***

*Task Leader Organization:* ***TU Wien***

***March 2015***

Co-funded by the Intelligent Energy Europe
Programme of the European Union

Contract N°: IEE/11/845/SI2.616378

Project Acronym: BETTER

# Bringing Europe and Third countries closer together through renewable Energies

# *Integrative Assessment of RES cooperation with Third countries* ***(D6.4)***

*March 2015*

*Project Coordinator:* ***CIEMAT***

*Work Package* ***6*** *Leader Organization:* ***TU Wien***

*Authors:*

***Gustav Resch, Marijke Welisch, André Ortner, Gerhard Totschnig***
***(TU Wien, Energy Economics Group)***

***Andreas Türk, Daniel Steiner***
***(Joanneum Research)***

# PREFACE

BETTER intends to address RES cooperation between the EU and Third countries. The RES Directive allows Member States to cooperate with Third countries to achieve their 2020 RES targets in a more cost efficient way. The core objective of BETTER is to assess, through case studies, stakeholders involvement and integrated analysis, to what extent this cooperation *can help Europe achieve its RES targets in 2020 and beyond, trigger the deployment of RES electricity projects in Third countries and create win-win circumstances for all involved parties*.

The case studies focusing on **North Africa, the Western Balkans and Turkey** will investigate the technical, socio-economic and environmental aspects of RES cooperation. Additionally, an integrated assessment will be undertaken from the “EU plus Third countries” perspective, including a quantitative cost-benefit evaluation of feasible policy approaches as well as strategic power system analyses. Impacts on the achievement of EU climate targets, energy security, and macro-economic aspects will be also analysed.

The strong involvement of all relevant stakeholders will enable a more thorough understanding of the variables at play, an identification and prioritisation of necessary policy prerequisites. The dissemination strategy lays a special emphasis on reaching European-wide actors and stakeholders, well, beyond the target area region.

# PROJECT PARTNERS

| N° | Participant name | Short Name | Country code |
|---|---|---|---|
| **CO1** | Centro de Investigaciones Energéticas, Tecnológicas y Medioambientales | CIEMAT | ES |
| **CB2** | German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.) | DLR | DE |
| **CB3** | Energy Research Centre of the Netherlands | ECN | NL |
| **CB4** | JOANNEUM RESEARCH Forschungsgesellschaft mbH | JR | AT |
| **CB5** | National Technical University of Athens | NTUA | GR |
| **CB6** | Observatoire Mediterranéen de l’Energie | OME | FR |
| **CB7** | Potsdam Institute for Climate Impact Research | PIK | DE |
| **CB8** | Vienna University of Technology | TUWIEN | AT |
| **CB9** | United Nations Development Program | UNDP | HR |

# Contents

# Figures, Tables and Boxes

*Figures:*

## *Tables:*

*Boxes:*

# 1 Introduction

The following report provides estimations of feasible renewable energy source (RES) deployment, and in particular for development of electricity from renewable energy sources (RES-E) in Turkey, the Western Balkans and North Africa. From these results the potential for cooperation in renewables production between the countries and the European Union (EU) is assessed and evaluated, in a short- (2020), mid- (2030) and long-term (up to 2040) perspective.

## 1.1 Policy context / objectives of this report

Article 9 of EU Directive 2009/28/EC – the Directive on the promotion of the use of energy from renewable sources (RES Directive) – regulates the cooperation of EU Member States and Third countries in the respect that the Member States can enter joint projects with Third countries "regarding the production of electricity from renewable energy sources" (EU, 2009). Specifically this allows EU Member States to produce a certain share of the renewable energy to reach their national RE-target in another country. Especially for countries that are currently behind their targets, importing RES-(E) with a high resource quality could be beneficial. Cooperation on renewables in general can also contribute to the promotion and further development of low carbon technologies for the EU and its neighbouring countries – and thus be an important step towards a sustainable energy system in the long term.

The framework for this assessment is provided by the Intelligent Energy Europe project BETTER. This project intends to address RES cooperation between the EU and its neighbours in several dimensions. The starting point is given through the cooperation mechanisms provided by the RES Directive as discussed above. The assessment undertaken within the BETTER project focusses on the short-term (2020) period for cooperation potentials as well as on medium (2030) and long-term prospects (up to 2040). While short-term improvement already provides a valuable contribution to European energy and climate goals, implementing successful cooperation mechanisms now and strengthening ties in an overall integrated EU and Third countries energy network is crucial to achieve long-term environmental sustainability.

> *This report* focuses on the quantitative assessments undertaken on the extent to which RES cooperation can create mutual benefits, identifying costs and benefits for both sides but in particular with respect to RES target achievement (2020, 2030 and beyond) at EU level. Prospects for RES generation in Turkey, North Africa, the Western Balkans and the EU are calculated under various policy pathways, reflecting the uncertainty on the way forward – e.g. concerning the ambition level of future RES targets and RES developments at EU level and in the assessed neighbouring regions / countries as well as with regard to RES cooperation. Thus, this overarching integrative assessment paints a big picture scenario and provides valuable policy implications for future cooperation between the EU28 Member States and their neighbouring countries. Furthermore, co-effects are shown that could occur from the different levels of RES deployment.

Previous studies primarily focused on the cooperation between Europe and the MENA region (Middle East and North Africa). The assessment underlying this paper is the first of its kind to our knowledge that opens up the geographical spread. It introduces further possible cooperation partners, namely Turkey and the West Balkans aside of the North African region. A brief literature review as provided subsequently in Box 1 shows the current state of research in a concise way and mainly aims at presenting findings on cooperation potentials.

**Box 1: Literature review: a brief recap of recent studies on RES cooperation between the EU and its neighbours**

One important study to be named in this context is “Desert Power: Getting Started” – it has been executed by the Desertec Industry Initiative (Dii) and evaluates the possibilities for expanding solar and wind power in the MENA region for local use as well as for export to Europe (Dii, 2013). Specifically, the study addresses the regulatory framework, transmission regulation, wind and solar potentials and their generation cost as well as other coinciding effects. The quantitative part of the analysis focuses on the techno-economic optimisation of the power system with a simulation of solar and wind technology diffusion. The report highlights, that cooperation in renewables would be beneficial in various respects and provides short-, medium and long-term policy recommendations. In the short term, promotion should take place, according to the research consortium whereas in the medium and long term intensified international co-operation and convergence are envisaged.

The quantitative assessment of the transition to a sustainable and integrated power system for the EU and the MENA region was performed using Fraunhofer ISI’s PowerACE and TU Wien’s Green-X model. The results show substantial possible imports of renewable electricity from MENA to the EU from 2030 on. This would only be a small relative share of the total RES-E produced, as local demand is also bound to increase considerably. In the broad sense, this means that both regional benefits as well as export potential could be achieved by cooperation in renewables in the EUMENA context. The results of their bottom-up analysis show a scenario of potentially 86.7 TWh to be produced in the MENA region in 2021. This amount increases to 301.4 TWh in 2030 and 1743.2 TWh in 2050, respectively, opening up enormous scope for export potential. The potential is made up by solar energy to a large extent: in 2021, nearly half the potential consists of photovoltaics (PV) and concentrated solar power (CSP), in 2030 and 2050, the technologies still make up 37 and 33 % of the mix respectively.

The technical dimension is crucial for this potential to be realised: the study states that for this cooperation to be put into action, building and extending grids is essential. By absolute numbers, this means that for 2050, the available potential of solar and wind energy with levelised cost of energy (LCOE) below 50€/MWh could reach 35,000 TWh/a in the MENA region. This represents four times the electricity demand of 2050 in EUMENA - shares could thus be used domestically and imported by EU Member States.

Further interesting results stem from a study by DLR (Deutsches Institut für Luft und Raumfahrt) from 2009 on “Potential, Infrastructure and Cost of Solar Electricity Import Corridors from MENA to Europe”. This study is a result of the EU project “Risk of Energy Availability: Common Corridors for Europe Supply Security (REACCESS)”. It focuses on Concentrated Solar Power (CSP) potentials and concludes that a total overall CSP potential of 537,680 TWh/a could be achieved in the MENA region for the year 2050, offering a large potential for export, given political and technical barriers were mitigated (DLR, 2009).

Another article by Trieb et al. (2012), describes the approach and results of an analysis of possible solar electricity import corridors from MENA to Europe including Turkey. The study is also based on the technical assessment of solar energy potentials in the MENA countries. The authors estimate that a total technical solar power generation potential of 538,000 TWh/a implies that less than 0.2% of the land suitable for CSP plants would be enough to supply 15% of the electricity demand expected in Europe in the year 2050.

The European Commission (EC) has assessed the future of RES deployment from the EU perspective, focusing on fulfilment of targets for 2020 and beyond as well as potential shortfalls within the EU and its Member States. The Commission’s renewable energy progress report from 2013 shows, that the legally binding renewable energy targets led the overall share of RES to grow strongly. The data analysis for the EU as a whole shows positive results towards achieving the 2020 targets. Some Member States nevertheless need to undertake additional efforts. Failure to comply with national plans seems to be evident for certain technologies and at the aggregated level by country (European Commission, 2013a).

The impact assessment by the European Commission for a policy framework on climate and energy in the period from 2020 up to 2030 complements this report with the medium time perspective: This analysis builds on results by the PRIMES model[1] (European Commission, 2014), which was implemented to evaluate progress in reaching EU RES targets. “A large number of scenarios combining targets and ambition levels have been analysed” for this study and in contrasting them, the following results have been derived for RES implementation in the EU context. Depending on the scenario taken as a basis, an overall renewables share in the range between 24.4% up to 34.5% in gross final energy consumption appears feasible. This largely depends on the policy framework implemented, i.e. “enabling conditions” (European Commission, 2014).

The longer term perspective up to 2050 has been assessed in the EC’s Energy Roadmap 2050 (European Commission for Energy, 2011). As a “broad policy document without having the ambition of defining individual policy measures,” the analysis presents an extensive picture and contrasts different possible scenarios and their respective challenges and barriers without proposing solutions to all of them. The model results again draw on PRIMES among other modelling tools. The roadmap presents an increased RES share as one of the central pillars of the European Decarbonisation Strategy and estimates scenarios containing at least 55% and up to 75% of RES share in gross final energy consumption by 2050.

## 1.2 Structure of this report

This report is structured as follows:

- The method of approach and related key assumptions applied in the assessment of RES cooperation between the EU and its assessed neighbouring regions (North Africa, Western Balkans and Turkey) is introduced in chapter 2 of this report.
- Next to that, chapter 3 presents the outcomes of the model-based assessment of prospects for RES cooperation. As a first element in that within section 3.1 a quantitative outlook on future RES developments in the enlarged geographical context is undertaken, indicating RES deployment at various levels is prepared. Next to that, prospects for RES cooperation are identified in section 3.2, indicating RES exchange between regions as well as the corresponding monetary transfer. Section 3.3 complements the energy-related survey through taking a closer look at the corresponding economic impacts: possible savings in terms of costs, in particular with respect to RES support, are provided, and information on costs, expenditures and benefits is presented for each assessed region. Finally, section 3.4 is dedicated to the complementary power-system analysis.
- Complementary to the model-based assessment, possible co-effects of a geographically enhanced RES cooperation are analysed in chapter 4 of this report, discussing environmental impacts, expectable changes at a macro level related to job creation and GDP as well as impacts on supply security.
- Chapter 5 is then dedicated to compare the results gained with other studies, focussing on RES developments in North Africa and past assessment of RES exchange with Europe.
- Finally, conclusions are drawn and documented in chapter 6.

[1] The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand.

# 2 Method of Approach and Key Assumptions

This section is dedicated to illustrate the method of approach applied and the key assumptions taken for the model-based assessment of RES cooperation between the EU and its neighbours from an integrated perspective. Before details on modelling are discussed a theoretical introduction is provided, showing the principle concept of cross-country cooperation. This concept is valid for renewables in particular but can be applied to other forms of (energy-related) cooperation.

## 2.1 Theory: The principle concept of Cooperation

Energy policy interventions, and in particular support incentives that aim to achieve certain policy targets, should be designed for being effective and (economically) efficient. *Effectiveness* relates to target achievement and *efficiency* means that the target should be achieved at minimal costs. The European Commission (EC) has defined country-specific targets in Directive 2009/28/EC for the RES share of its gross final consumption for 2020. The targets have been defined by making use of a specific burden-sharing approach, which did not consider national deployment costs and available potentials of renewable energy. However, on the one hand costs and potentials significantly vary among Member States and on the other hand it is the aim of the EU to achieve the total RES share in a cost-efficient way. From this perspective it becomes clear that RES should be installed in places with the cheapest available potentials until the EU-wide target is achieved.

Member States should thus negotiate on buying or selling surplus RES generation, leading their national RES shares to deviate from their target - in a way that each surplus is balanced by a corresponding deficit. Figure 1 shows the general concept of how RES cooperation between countries can benefit both partners, for the example of two countries with distinct RES deployment costs. Specifically it can be seen, how the gain in total welfare depends on the potentials (x) that exist in the different countries and on the respective costs (c) for RES deployment. How this welfare is distributed then depends on negotiations (implied by the red line).

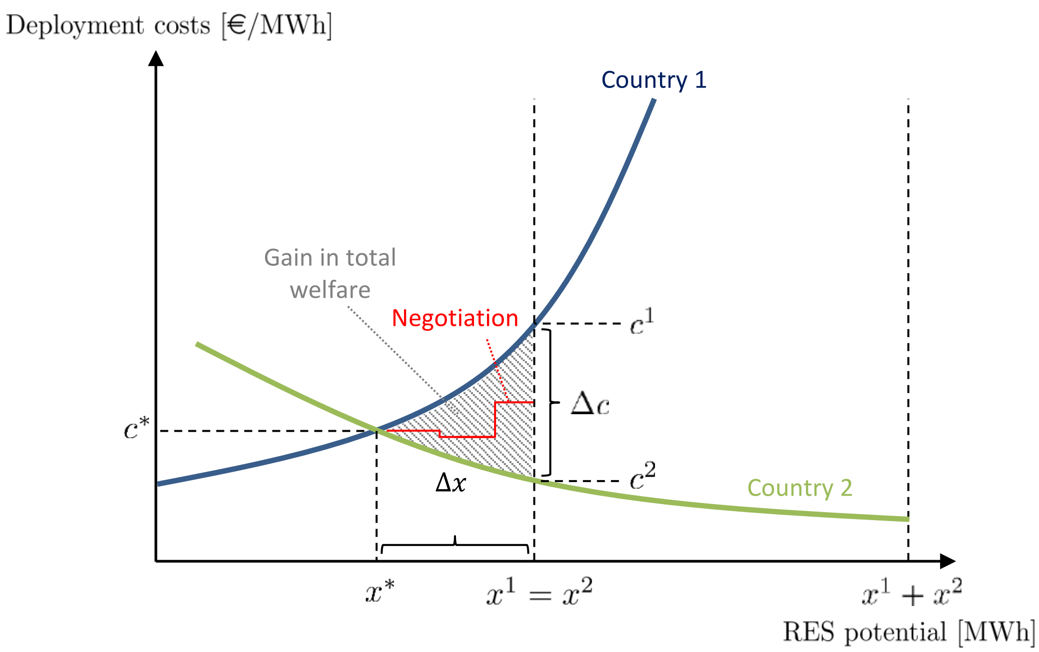



**Figure 1: General concept of RES cooperation between countries**

The cost curve of country 2 has been mirrored along the x-axis (cost) and shifted along the y-axis (potential) in a way that the starting point is positioned at the sum of both country targets (x1+x2). By doing so the point at which both countries would reach their target exactly overlaps. The target of country 1 counts from the left side and the target of country 2 from the right side of the graph. For this example the targets of both countries were assumed to be equal (x1 = x2), however the slopes of the cost curves have been set differently. At the point x1 = x2 both countries would reach their target. It can be seen that in this case because of the different slopes of the deployment cost curves a cost difference occurs. If the countries were to negotiate, it would be beneficial for country 1 to deploy less renewables and to give a certain share of its thus additionally available monetary resources to country 2, which would in turn deploy more. This can be continued up to point x*, where the marginal deployment costs of both countries are equal. The area between the cost curves depicts the total gain in welfare. How this welfare is then distributed among the partners is subject to negotiation and among others depends on the additional country-specific costs and benefits associated with RES deployment, which are not incorporated in the deployment cost curves.

This theoretical concept shows how a case for RES cooperation occurs through differences in cost structures and available potentials between countries. Additional deployment of RES in one country can be beneficially (partly) exported and add on to the RES share of the other country via cooperation. The concept has been demonstrated via a static approach and only for two countries. In practice, on the one hand one would have to consider dynamic effects (e.g. cost reductions of the deployment cost over time and maximum diffusion rates of deployment) as they play a crucial role in the cost-efficient and effective target achievement pathway of a certain country. On the other hand all involved countries would have to enter into bi- or multilateral, sequential or parallel negotiations, respectively. All these aspects significantly complicate the above described concept and need to be considered when looking into practical implementations of RES cooperation.

## 2.2 Method of approach for the model-based assessment of RES cooperation

The methodology of the *integrated assessment* in the BETTER project consists of different dimensions: While grid and transmission needs or constraints, respectively, together with the physical integration possibilities are evaluated from a technical perspective in a **power-system analysis**, done by use of TU Wien's HiREPS model, the complementary techno-economic and policy dimensions are represented by the feasibility studies taking into account different policy pathways. Concretely for the latter part a comprehensive scenario-based assessment of prospects for RES cooperation from the integrated (top-down) perspective was executed by application of TU Wien's Green-X model. This **techno-economic policy analysis** acts as key basis for our overall evaluation of prospects for RES cooperation in the enlarged geographical context (EU plus Third countries). It allows for identifying monetary savings associated with enhanced RES cooperation as well as resulting changes in costs, expenditures and benefits by region that come alongside the changes in installed RES capacities and generation across the assessed regions.

Moreover, the comprehensive model-based analysis as sketched above, and for which the approach and assumptions are discussed subsequently, is complemented by an **assessment of co-effects** such as impacts on the achievement of EU climate targets, energy security, air pollution, costs of long-term fossil energy lock in, and macro-economic aspects (job creation). This work is done in a detailed quantitative manner, complemented by qualitative analysis and interpretation and represented in section 4 of this report.

Please note further that the top-down integrated assessment of RES cooperation in the enlarged geographical context (EU plus Third countries) as discussed within this report builds on detailed analyses done in a bottom-up manner for each case region (i.e. North Africa, Western Balkans and Turkey). During the case study works in the BETTER project regional prospects for future RES developments in general, and for RES cooperation with the EU in particular, have been assessed from the perspective of the targeted EU neighbouring country/region.[2]

In the following, the modelling system used for the assessment is introduced, offering a brief characterisation of both models (i.e. Green-X and HiREPs) and of their interplay. Then we introduce the scenarios that are assessed and presented in subsequent sections of this report. Finally key input parameter and assumptions are presented.

### 2.2.1 The BETTER modelling system: Green-X and HiREPS

The modelling system for the assessment of prospects for RES cooperation between the EU and its neighbours consists of two distinct models with complementary skills and strengths: Green-X, used in the techno-economic policy analysis of various RES cooperation scenarios, and HiREPS, applied in the power-system analysis to validate the possibilities, constraints and prerequisites related to physical RES integration. Below both models are described and subsequently their interplay applied within this assessment is shown.

***Green-X***

TU Wien's Green-X is a specialised energy system model focussing on renewable energy technologies that offers:

- a thorough assessment of impacts stemming from various forms of energy policy interventions, offering a detailed representation of key characteristics of different energy policy instruments as input to modelling, complemented by a detailed assessment of their impacts, and

[2] These bottom-up views on prospects for RES cooperation can be found in the BETTER case study reports, i.e. for Turkey in Ortner et al. (2015), for the Western Balkans in Türk et al. (2015), and for North Africa in Trieb (2015), respectively.

- a detailed description renewable energy technologies, characterised by their resource potentials and related technology and feedstock cost, in Europe and in the analysed neighbouring countries.

Green-X aims at indicating consequences of RES policy choices in a real-world energy policy context. In principle, the model allows for conducting in-depth analyses of future RES deployment and corresponding costs, expenditures and benefits arising from the preconditioned policy choices on country, sector and technology level on a yearly basis, in the time span up to 2050[3].

**Box 2: Brief characterisation of the Green-X model**

The model Green-X has been developed by the Energy Economics Group (EEG) at TU Wien under the EU research project "Green-X–Deriving optimal promotion strategies for increasing the share of RES-E in a dynamic European electricity market" (Contract No. ENG2-CT-2002-00607). Initially focussed on the electricity sector, this modelling tool, and its database on renewable energy (RES) potentials and costs, has been extended to incorporate renewable energy technologies within all energy sectors.

Green-X covers the EU-28, the Contracting Parties of the Energy Community (West Balkans, Ukraine, Moldova) and selected other EU neighbours (Turkey, North African countries). It allows the investigation of the future deployment of RES as well as the accompanying cost (including capital expenditures, additional generation cost of RES compared to conventional options, consumer expenditures due to applied supporting policies) and benefits (for instance, avoidance of fossil fuels and corresponding carbon emission savings). Results are calculated at both a country- and technology-level on a yearly basis. The time-horizon allows for in-depth assessments up to 2050. The Green-X model develops nationally specific dynamic cost-resource curves for all key RES technologies, including for renewable electricity, biogas, biomass, biowaste, wind on- and offshore, hydropower large- and small-scale, solar thermal electricity, photovoltaic, tidal stream and wave power, geothermal electricity; for renewable heat, biomass, sub-divided into log wood, wood chips, pellets, grid-connected heat, geothermal grid-connected heat, heat pumps and solar thermal heat; and, for renewable transport fuels, first generation biofuels (biodiesel and bioethanol), second generation biofuels (lignocellulosic bioethanol, biomass to liquid), as well as the impact of biofuel imports. Besides the formal description of RES potentials and costs, Green-X provides a detailed representation of dynamic aspects such as technological learning and technology diffusion.

Through its in-depth energy policy representation, the Green-X model allows an assessment of the impact of applying (combinations of) different energy policy instruments (for instance, quota obligations based on tradable green certificates / guarantees of origin, (premium) feed-in tariffs, tax incentives, investment incentives, impact of emission trading on reference energy prices) at both country or European level in a dynamic framework. Sensitivity investigations on key input parameters such as non-economic barriers (influencing the technology diffusion), conventional energy prices, energy demand developments or technological progress (technological learning) typically complement a policy assessment.

Within the Green-X model, the allocation of biomass feedstock to feasible technologies and sectors is fully internalised into the overall calculation procedure. For each feedstock category, technology options (and their corresponding demands) are ranked based on the feasible revenue streams as available to a possible investor under the conditioned, scenario-specific energy policy framework that may change on a yearly basis. Recently, a module for intra-European trade of biomass feedstock has been added to Green-X that operates on the same principle as outlined above but at a European rather than at a purely national level. Thus, associated transport costs and GHG emissions reflect the outcomes of a detailed logistic model. Consequently, competition on biomass supply and demand arising within a country from the conditioned

[3] Within this analysis of future prospects for RES cooperation between the EU and its neighbours the time span of scenario works has been limited to 2040 because of limits in computing times and robustness concerns.

support incentives for heat and electricity as well as between countries can be reflected. In other words, the supporting framework at MS level may have a significant impact on the resulting biomass allocation and use as well as associated trade.

Moreover, Green-X was extended throughout 2011 to allow an endogenous modelling of sustainability regulations for the energetic use of biomass. This comprises specifically the application of GHG constraints that exclude technology/feedstock combinations not complying with conditioned thresholds. The model allows flexibility in applying such limitations, that is to say, the user can select which technology clusters and feedstock categories are affected by the regulation both at national and EU level, and, additionally, applied parameters may change over time.

## ***HiREPS***

HiREPS is a power system simulation and optimisation model that allows for detailed assessments of the physical integration constraints of the power system. Thanks to a suitable grid representation also related limitations and / or requirements can be assessed. Below Box 3 offers a brief characterisation of the model.

**Box 3: Brief characterisation of the HiREPS model**

The HiREPS (High Resolution Power System) model is a dynamic power system simulation and optimization model suitable for assessing the technical feasibility of integrating high shares of (variable) renewables into the power system.

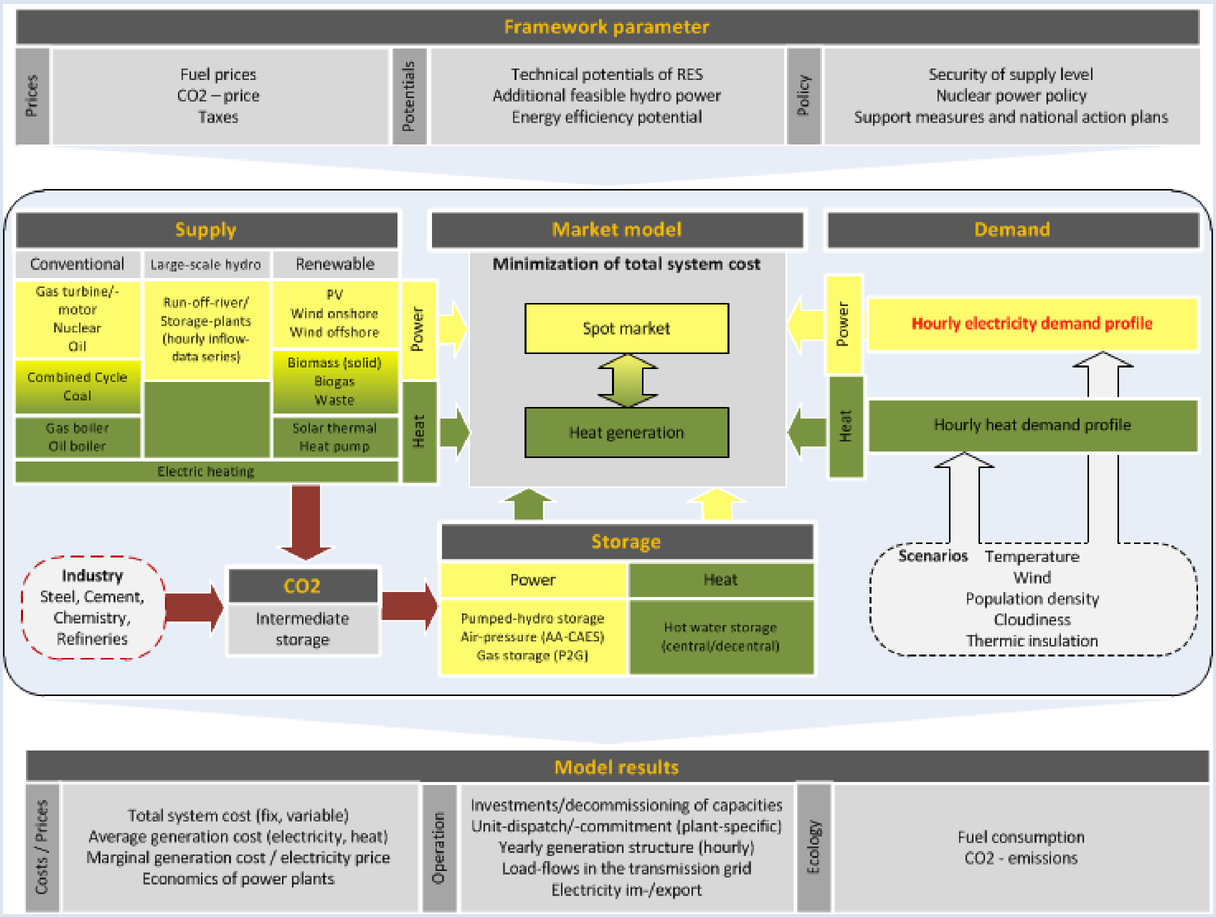



**Figure 2: Schematic overview of the HiREPS model**

In general, critical aspects of electricity generation from (variable) renewables are:

- Hourly and spatial variability of RES electricity generation
- Thermal limits of the electricity grid including Kirchhoff´s law
- Technical constraints of thermal and hydro power plants
- Detailed representation of hydro-electric generation including multi-reservoir systems

Within the course of the BETTER project the geographical coverage of the model has been extended. The advanced version allows for a power system analysis of the whole EU-MENA region, including in addition Turkey and Western Balkan countries.

A typical application case of the model is to calculate for an assumed distribution of wind turbines, solar photovoltaic and solar thermal power plants the local renewable power generation across the assessed region (e.g. in the case of the integrated assessment done in BETTER this comprises the EU28 and all researched neighbouring regions) as well as the simulation of thermal power plants, hydropower, future power prices and transmission grid limitations.

A schematic overview of HiREPS is given in Figure 2, indicating key input (framework) parameter, the core elements of the modelling core (incl. modules related to supply, demand, storage and CO2 and their market-based interplay) and typical model results.

## ***Model coupling in the integrated assessment***

As stated above, the approach used for the integrated model-based assessment in the BETTER project combines different dimensions:

- A comprehensive scenario-based assessment of prospects for RES cooperation from the integrated (top-down) perspective is undertaken with TU Wien's Green-X model. This **techno-economic policy analysis** acts as key basis for our overall evaluation of prospects for RES cooperation in the enlarged geographical context (EU plus Third countries). It allows for identifying monetary savings associated with enhanced RES cooperation as well as resulting changes in costs, expenditures and benefits by region that come alongside with the changes in installed RES capacities and generation across the assessed regions. With Green-X the overall modelling of future RES developments in the EU and its neighbours is done for all energy sectors (i.e. electricity, heating & cooling and biofuels in transport) whereas our detailed assessment of enhanced cross-border RES cooperation is limited to the electricity sector.
- Complementary to above and specifically for the electricity sector, grid and transmission needs or constraints, respectively, together with the physical integration possibilities are evaluated from a technical perspective in a **power-system analysis**, done by use of TU Wien's HiREPS model.

Figure 3 gives an overview on the interplay of both models. Both models are operated with the same set of general input parameters, however in different spatial and temporal resolution. Green-X delivers a first picture of renewables deployment and related costs, expenditures and benefits by country on a yearly basis (2010 to 2040). The output of Green-X in terms of country- and technology-specific RES capacities and generation in the electricity sector for selected years (2030, 2040) serves as input for the power-system analysis done with HiREPS. Subsequently, the HiREPS model analyses the interplay between supply, demand and storage in the electricity sector on an hourly basis for the given years. The output of HiREPS is then fed back into the RES investment model Green-X. In particular the feedback comprises the amount of RES that can be integrated into the grids, the electricity prices and corresponding market revenues (i.e. market values of the produced electricity of variable and dispatchable RES-E) of all assessed RES-E technologies for each assessed country.

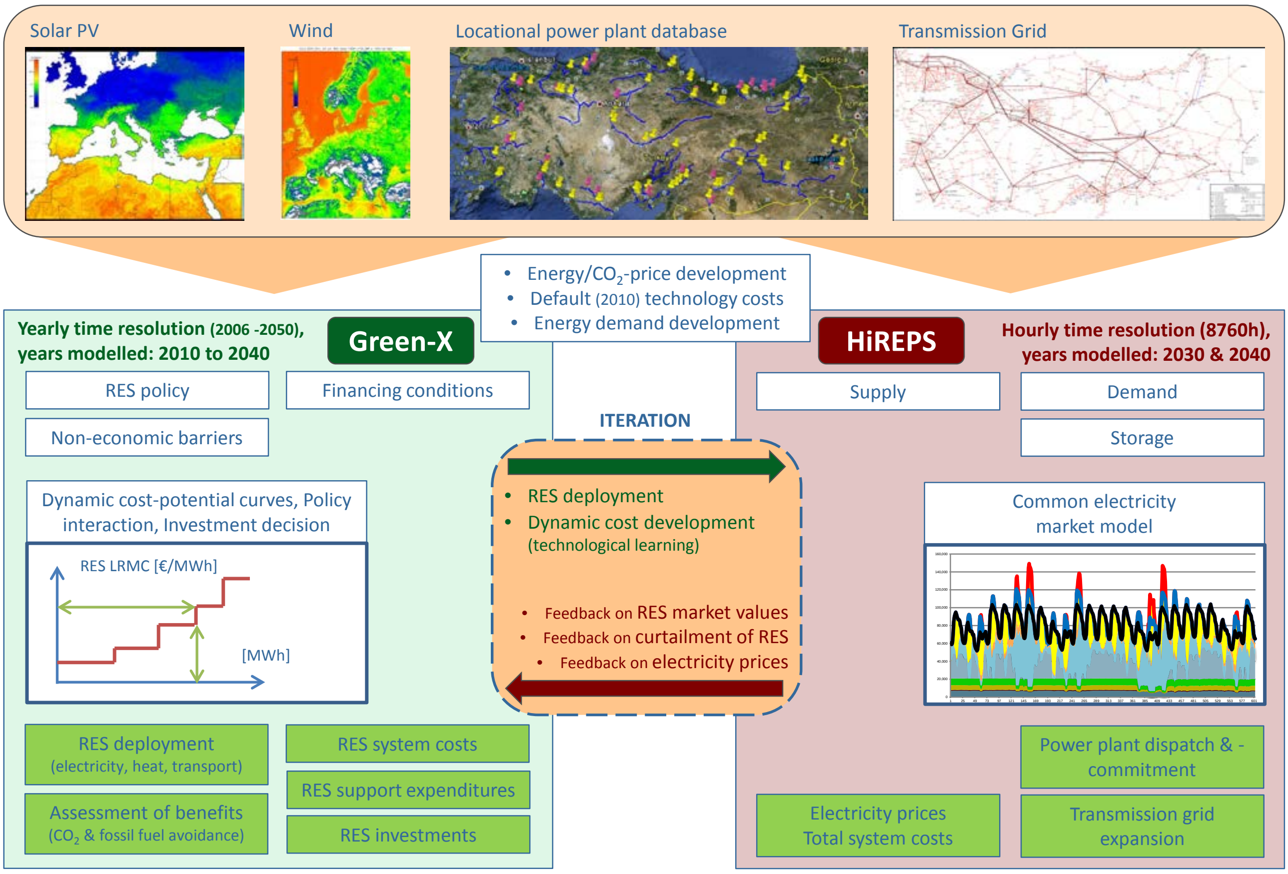



**Figure 3: Model coupling between Green-X (left) and HiREPS (right) in the integrated assessment of the BETTER project**

### 2.2.2 Scenario definition: Overview on assessed cases

The *integrated assessment* serves as an overarching top-down framework to identify opportunities for RES cooperation considering supply and demand for doing so across the whole enlarged geographical region. Large-scale cooperation scenarios are assessed in the mid- (2030) and long-term (2040) perspective, geographically including the 28 EU Member States as well as the Western Balkan region, Turkey and North Africa as additional cooperation partners.

The top-down integrated assessment of RES cooperation in the enlarged geographical context (EU plus Third countries) for which assessed scenarios are introduced subsequently builds on detailed analyses done in a bottom-up manner for each case region (i.e. North Africa, Western Balkans and Turkey). [4] Of interest, a model-based bottom-up assessment using Green-X (and partly HiREPS) has been conducted for Western Balkans and Turkey, cf. Box 4.

**Box 4: Overview on complementary bottom-up scenarios analysed for Western Balkans and Turkey**

The scenarios analysed in the *bottom-up assessment*, for Turkey and the Western Balkans, combine two different characteristics: different ambition levels for RES deployment in 2030 in particular and different support policies for renewables from 2020 onwards. With respect to the underlying policy concepts the following assumptions are taken for the assessed policy paths:

[4] The bottom-up assessments on prospects for RES cooperation are discussed in the BETTER case study reports, i.e. for Turkey in Ortner et al. (2015), for the Western Balkans in Türk et al. (2015), and for North Africa in Trieb (2015), respectively.

- The *"Business as Usual (BAU)"* scenario, as the name implies, represents unchanged national policies and efforts for implementation of RES: the current policy path will be followed. The scenario can be varied by whether different (non-economic) barriers remain in the countries or if they are mitigated over time.
- Alternative policy paths follow the concept of *"Strengthened National Policies (SNP)"* where a continuation of the current policy framework with national RES targets (for 2030 and beyond) is assumed. In general this implies for each country to use national support schemes to meet its own target, complemented by RES cooperation between Member States (and with the EU's neighbours) in the case of insufficient or comparatively expensive domestic renewable sources. Within the bottom-up assessment conducted for Turkey and the Western Balkans two distinct scenarios were assessed, assuming that either moderate or generous (i.e. high) support is offered to the applicable renewable energy technologies in the electricity sector and in heating and cooling. Thereby the assumption is taken that support levels differ by technology and change over time, reflecting expected technological progress.

Building on BAU and SNP, eight possible future scenarios were obtained. The scenarios basically differ in their ambition level for financial support, the assumed demand development and the presence of non-cost-barriers that jeopardise the development of RES. Generally, the bottom-up assessment serves to open up a corridor of feasible future RES developments by targeted EU neighbouring region, aiming to provide a first indication of feasible RES cooperation potentials from an export country perspective and focusing hereby on the short (2020) and mid-term (2030) perspective.

## ***Overview on assessed key cases***

An overview on assessed *key scenarios of the integrated assessment* is given in Figure 4. For this policy-related techno-economic assessment the Green-X model has been applied. As described in section 2.2.1 in further detail, the Green-X modelling of future RES deployment and related costs and benefits by country serves as basis for the complementary power-system analysis using the HiREPS model. For practical reasons, due to limitations in computing times, the power-system analysis has however been limited to the cases of strong and weak RES deployment. Thus, the level of ambition concerning future RES expansion, in particular the envisaged 2030 RES target at EU and Energy Community level, stands in focus of the overall assessment, complemented by sensitivity analyses related to specifics of the targeted regions on their ways forward.

As noted in Figure 4 and illustrated graphically in Figure 5, for the ambition level related to the future RES expansion three distinct RES pathways were assumed for 2030 (and beyond), one following a *strong RES target* for 2030 (i.e. 32.5% as RES share in gross final energy demand at EU level), one aiming for a *moderate 2030 RES target* (i.e. 30.0%), and one reflecting the current policy thinking, aiming for a 2030 RES share of 27% (i.e. named subsequently as *weak RES target*). Then, different policy cases were assessed for achieving these targets, all assuming full RES cooperation within certain system boundaries. The following key scenarios were thus distinguishable:

- EU only (reference) cases: RES cooperation only within the EU, domestic RES target fulfilment within neighbouring countries.
- EU plus (default cases): these scenarios assume full RES cooperation across the EU as well as all three case regions (North Africa, Western Balkans and Turkey)

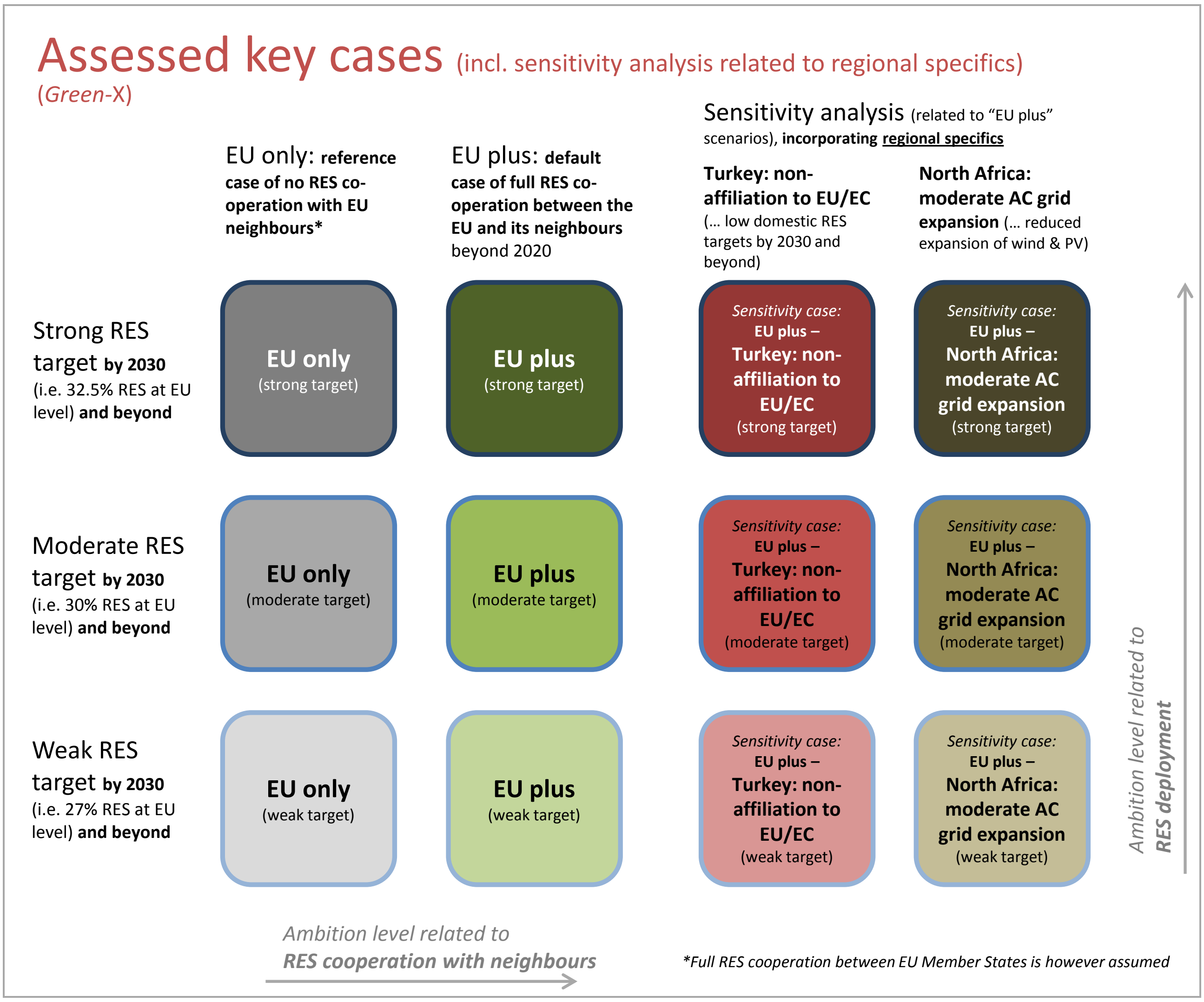



**Figure 4: Overview on assessed key scenarios (key scenarios plus sensitivity cases related to regional specifics) (Green-X (and partly HiREPS) modelling)**

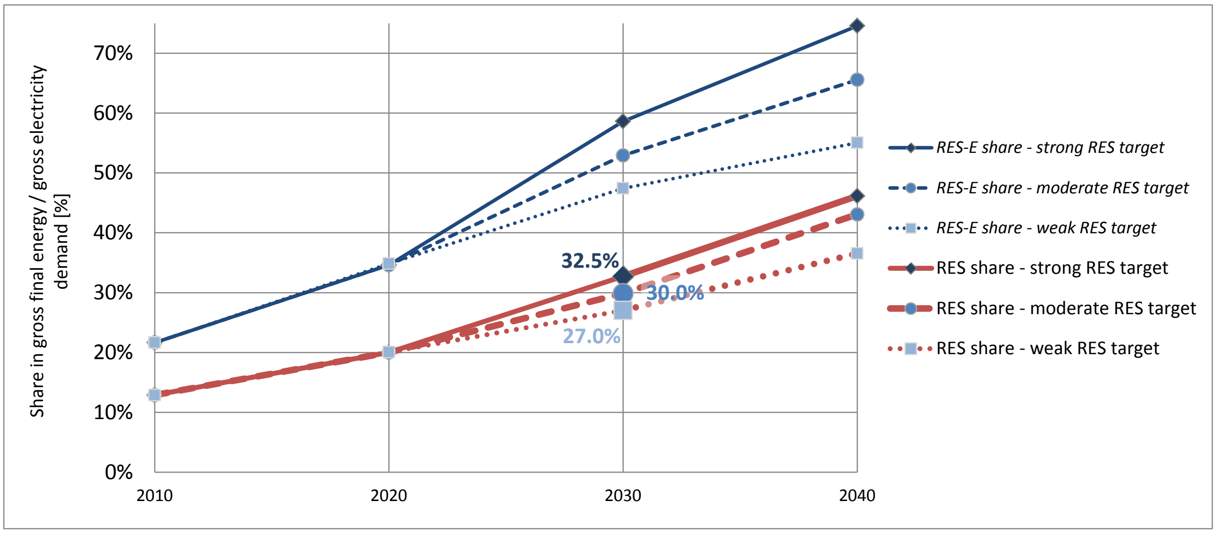



**Figure 5: The assumed ambition level related to future RES deployment by 2030 and beyond at EU level**

To fully understand the use of policy instruments and RES targets in this model-based analysis, the following aspects have to be kept in mind:

- Assessment of RES cooperation limited to the electricity sector: The overall modelling of future RES developments in the EU and its neighbours is done for all energy sectors (i.e. electricity, heating & cooling and biofuels in transport)[5] but our detailed assessment of cross-border RES cooperation in the mid- (2030) to long-term (2040) is limited to the electricity sector.
- Quota system with tradable green certificates assumed as common support instrument to better assess prospects for RES cooperation: A (harmonised and uniform) RES-E trading regime is used in modelling to identify the opportunities and benefits related to RES cooperation. More precisely, a support scheme harmonised across all assessed countries is assumed for RES in the electricity sector that does not differentiate between different technologies. In this case the marginal technology to meet the given RES-targets sets the price for the overall portfolio of RES technologies in the electricity sector. The policy costs occurring in the quota system can be calculated as the certificate price multiplied by the RES generation under the quota system. These costs are then distributed in a harmonised way across all countries so that each type of consumer pays the same (virtual) surcharge per unit of (renewable) electricity consumed.
- EU-wide green certificate trading used as reference ("EU only" cases): First, the EU only (reference) cases are created, in which RES-E trade is assumed to take place among the EU Member States and within the EU boundaries only. Sector-specific targets (for RES-E within the trading regime, and for biofuels in transport where physical trade is common practice already today to meet national blending obligations) and financial incentives for RES in heating and cooling are modified in accordance with the envisaged ambitions level – i.e. until targeted volumes of overall RES deployment (i.e. overall 2030 RES shares in gross final energy demand) are met at EU level.
- Full RES cooperation scenarios assume the establishment of a green certificate trading regime in all assessed countries (EU plus Third countries – i.e. "EU plus" cases): For all further scenarios that include cooperation between the EU and the analysed neighbouring countries, similar RES-E targets to those at EU level (i.e. related to the RES expansion, in particular renewable electricity installations beyond 2020 that are allowed to participate in the RES-E trading regime) are assumed to be applied in the Energy Community (EC), and in particular in our analysed EC Contracting Parties (i.e. the Western Balkans). Virtual exchange is then the default (EU plus) form of cooperation between and within the EU and the EC. In contrast to that, a physical exchange of the produced renewable electricity is conditioned for RES-E cooperation between the EU and North Africa.
- Sensitivity case for Turkey related to the non-affiliation to the EU/EC: For Turkey a sensitivity variant assesses the impact of whether accession to the Energy Community or respectively the EU takes place or not – as default the assumption is taken that Turkey will join and consequently apply a similar policy concept and ambition level for RES. In the sensitivity variant of Turkey not joining the assumption is taken that only a low target is followed by Turkey related to its mid- to long-term ambition concerning domestic RES use. This leaves room for further RES-E exports to the EU. In contrast to default (EU plus) within the EU/EC, under these circumstances physical renewable electricity export is then however assumed to be a necessity.
- Sensitivity case for North Africa with respect to a moderate (AC[6]) grid expansion: A different approach is followed for the North African countries. Domestic RES use is aligned with DLR's bottom-up assessment. Concentrated solar thermal power (CSP) and wind power as well as centralised large-scale photovoltaic

[5] Please note that for assessed North African countries (i.e. Algeria, Egypt, Libya, Morocco and Tunisia) also the modelling is constraint to the electricity sector due to data availability. This coincides well with real-world limitations of RES cooperation between the EU and North Africa, where only electricity exchange may represent a viable opportunity in practice.
[6] AC stands for "Alternating Current".

(PV) plants not used domestically are then allowed, model wise, to participate in the EU/EC RES trading regime. Within the sensitivity assessment a closer look is taken at the technical concept used to transfer the surplus in renewable electricity from North Africa to Europe. In the sensitivity case DLR's preferred concept of transferring electricity from CSP via High Voltage Direct Current (HVDC) lines to centres of Europe is followed. This implies consequently a less strong expansion of the "conventional" transmission and distribution grid in North Africa as well as to Southern Europe, and may therefore lead to a delayed expansion of wind and PV (that appear less viable for HVDC transfer due to their variability).

Large parts of grid expansion costs borne by RES producers in the case of physical exchange: The complementary power-system analysis gives a rough indication about the infrastructure requirements and corresponding costs to import identified RES electricity volumes to the EU. In Green-X modelling the assumption is taken that large parts of these costs have to be borne by the respective RES producers. In practice that means that in all default scenarios we assume that North African[7] RES producers aiming for the export market (i.e. RES cooperation with the EU/EC) in future years have to cover the largest part of the identified grid expansion costs – as default we estimate that as a rule of thumb two thirds of the identified grid expansion costs are borne by the RES producers whereas the remainder (of one third of the total is socialised). For details on the outcomes of the grid assessment we refer to section 3.4.3 of this report. Furthermore, please note that light is shed on these aspects also in a complementary sensitivity assessment as introduced below and for which outcomes are presented in section 3.5.

***Overview on assessed cases in a complementary sensitivity analysis***

Since modelling exercises are subject to the quality and correctness of the assumptions and input data two complementary sensitivity analyses have been performed: As shown in Figure 6, one sensitivity assessment is related to the assumptions on grid costs in the case of physical electricity transfer from North Africa to the European Union whereas the other serves to assess the importance of each case region related to RES cooperation, assuming, in contrast to default, a limitation of RES cooperation to only one neighbouring region/country.

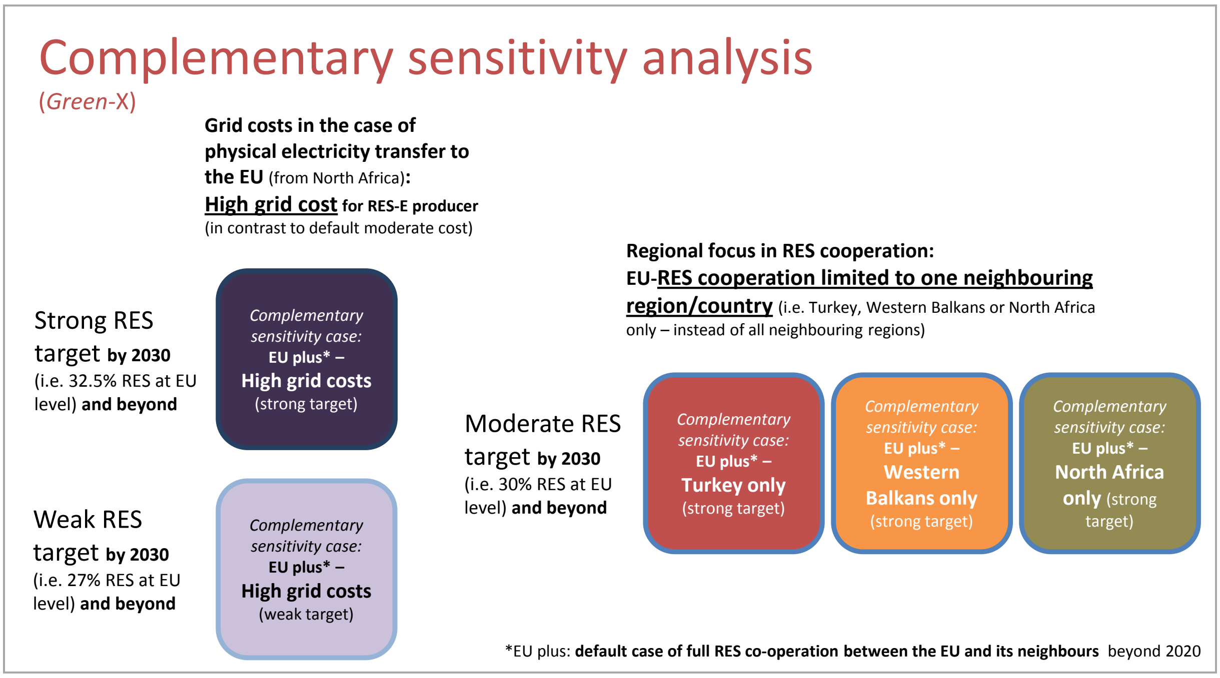



**Figure 6: Overview on assessed cases in the complementary sensitivity analysis (Green-X modelling)**

[7] In the sensitivity variant on regional specifics of Turkey that obligation affects also Turkish RES producers.

### 2.2.3 Overview of key parameters

In order to ensure maximum consistency with existing EU scenarios and projections various input parameters of the renewable scenarios conducted with Green-X and HiREPS are derived from PRIMES modelling, specifically concerning the Integrated Assessment and the data used therein for EU countries. More precisely, the PRIMES scenario used is the PRIMES *reference scenario* as of 2013 (EC, 2013b). The main data source for RES-specific parameters is the Green-X database – this concerns for example information on the status quo of RES deployment, future RES potentials and related costs as well as other country-specific parameter concerning non-economic barriers that limit an accelerated uptake of RES. Moreover, the policy framework for RES is specifically defined for this assessment. Energy demand developments for Turkey, Western Balkans and North Africa as well as assumptions on the conventional supply portfolio and on related reference conversion efficiencies and carbon intensities have been derived within this project as part of the bottom-up case study works by region while for EU countries the PRIMES reference scenario serves as basis.

Table 1 provides a concise overview on which parameters are based on PRIMES, on the Green-X database and which have been defined for this assessment.

**Table 1: Main input sources for scenario parameters in the integrated assessment of the BETTER project**

| Based on PRIMES | Based on Green-X database | Defined for this assessment |
|---|---|---|
| Primary energy prices | RES cost (investment, fuel, O&M) | Reference electricity prices |
| Energy demand by sector (EU countries) | RES potential | Energy demand by sector (neighbouring countries) |
| Conventional supply portfolio: conversion efficiencies and $CO_2$ intensities by sector (EU countries) | Biomass trade specification | Conventional supply portfolio: conversion efficiencies and CO2 intensities by sector (neighbouring countries) |
| | Technology diffusion / Non-economic barriers | Grid-related parameter including costs |
| | Learning rates | RES policy framework |

Below we discuss general parameter like energy demand or energy prices in further detail whereas specific input parameter for the techno-economic policy assessment done with Green-X or for the (technical) power-systems analysis undertaken by use of HiREPS are outlined in subsequent sections (subsection 2.2.4 (Green-X) and subsection 2.2.5 (HiREPS)). Moreover, details on the Green-X database on potentials and costs can be found in section 2.3 of this report.

***Energy demand***

Figure 7 depicts the projected energy demand development at EU 28 level according to the PRIMES reference scenario and for each assessed neighbouring region / country in accordance with the bottom-up assessment done by case study (cf. Trieb (2015) for North Africa, Türk et al. (2015) for Western Balkans and Ortner et al. (2015) for Turkey. More precisely, Figure 7 shows the assumed future development of gross final energy demand (left) and of gross electricity demand (right).

A comparison to alternative PRIMES demand projections at EU 28 levels shows the following trends: The *PRIMES reference case* as of 2013 (EC, 2013b) draws a modified picture of future demand patterns compared to previous baseline and reference cases. The impacts of the global financial crisis are reflected, leading to a reduction of overall gross final energy demand when comparing 2010 and 2005. In the years until 2020 a decline is observable, as a consequence of increased energy efficiency combined with a continuous stagnation of economic activities. In the subsequent decade until 2030, according to the *PRIMES reference case* gross final energy demand is expected to decline further, but at a moderate level whereas in the final years up to 2040 a slight increase is expected. On average across the whole assessment period (2010 to 2040) a slight decrease (at 0.1% annually) is expected at EU28 level whereas in Western Balkans a moderate growth (by 1.2% on average annually) and in Turkey a strong growth (at 2.4% annually) is assumed.

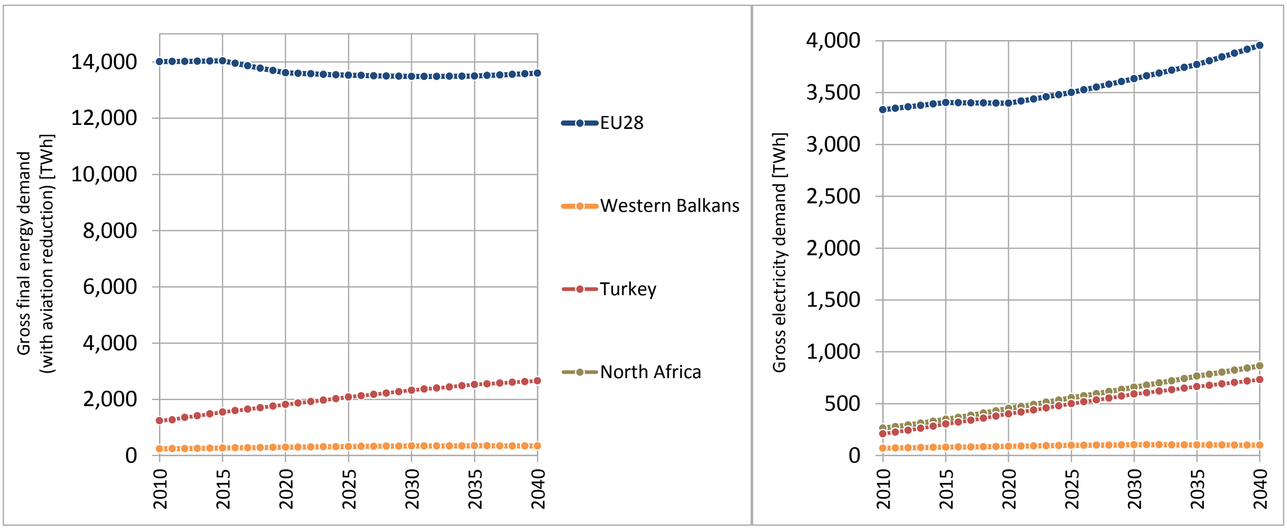



**Figure 7: Comparison of projected energy demand development at EU28 level and by neighbouring country/region– gross electricity demand (left) and gross final energy demand (right).**

Source: PRIMES reference scenario (EC, 2013) and own BETTER assessments

For the electricity sector, demand growth is generally more pronounced, even at a European level. The PRIMES reference case assumes for the EU28 a moderate increase (i.e. 0.6% average annual growth) because of cross-sector substitutions: electricity is expected to make a stronger contribution to meeting the demand for heating & cooling in the future, and similar substitution effects are assumed for the transport sector as well. Similar to overall gross final energy demand, stronger growth trends are expected in the neighbouring regions. For Western Balkans the assumed average annual increase amounts to 1.1%, for North Africa to 4.0% and for Turkey to 4.2%.

## ***Fossil fuel and carbon prices***

The country- and sector-specific reference energy prices used in this analysis are based on the primary energy price assumptions applied in the latest PRIMES reference scenario that has also served as a basis for the Impact Assessment accompanying the Communication from the European Commission "A policy framework for climate and energy in the period from 2020 to 2030" (COM(2014) 15 final). As shown in Figure 8 (left) generally only one price trend is considered – i.e. a default case of moderate energy prices that reflects the price trends of the *PRIMES reference case*. Compared to energy prices as observed today (2015), with the exception of coal (where assumed price trends have to be judged as high) price assumptions appear generally reasonable.

The $CO_2$ price underlying in the scenarios presented in this report is also based on recent PRIMES modelling, see Figure 8 (right). In modelling it is assumed that $CO_2$ pricing affects conventional supply in the EU28, and post 2020 also in Contracting Parties of the Energy Community (currently limited Western Balkans but in future probably including Turkey). Actual market prices for EU Allowances have fluctuated between 6 and 30 €/t since 2005 but remained on a low level with averages around 7 €/t in the first quarter of 2015. In the model, it is assumed that $CO_2$ prices are directly passed through to electricity prices as well as to prices for grid-connected heat supply.

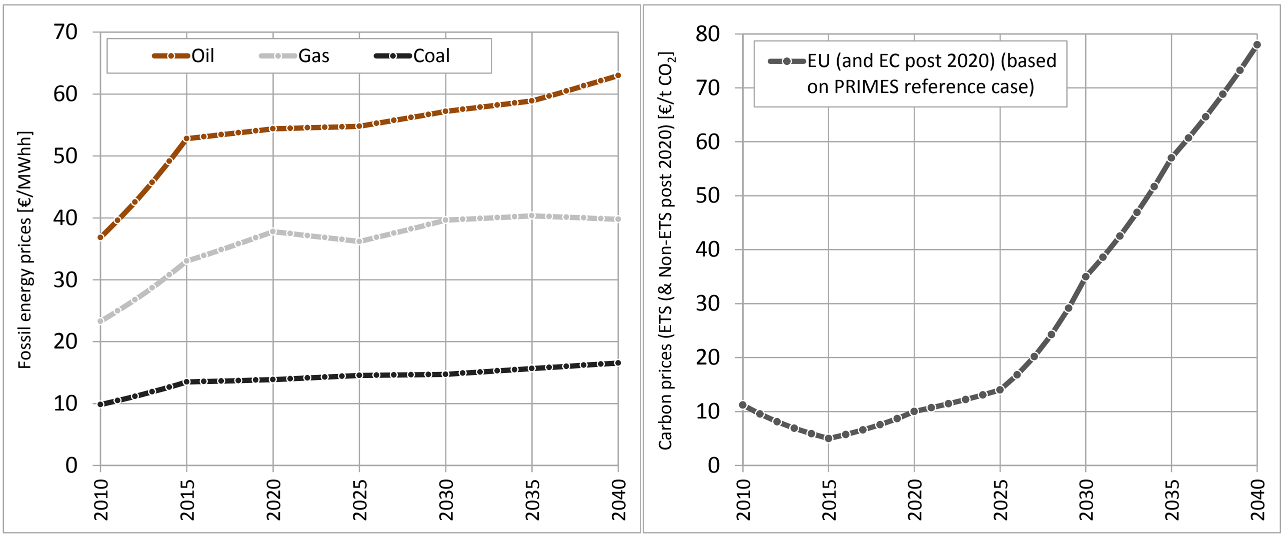



**Figure 8: Assumptions on prices for fossil fuels (left) and $CO_2$ emissions (right)**

Source: PRIMES scenarios (EC, 2013)

### 2.2.4 Key input parameter for the techno-economic policy assessment (Green-X)

Below we illustrate key input parameters for the techno-economic policy assessment related to prospects for RES cooperation, done by use of TU Wien's Green-X model. This comprises financing parameter, general assumptions related to RES support incentives and the conventional supply portfolio, of relevance for the assessment of benefits like fossil fuel and $CO_2$ emission avoidance.

***Financing parameter: Interest rate / weighted average cost of capital - the role of (investor's) risk***

Attention is dedicated in the model-based assessment to incorporate the impact of investor's risk on RES deployment and corresponding (capital / support) expenditures. In contrast to detailed bottom-up analysis of illustrative financing cases as conducted by case region within this project or for example in the RE-Shaping study for EU countries (see Rathmann et al. (2011)), Green-X modelling aims to provide the aggregated view at country or regional level with less details on individual direct financing instruments. More precisely, debt and equity conditions as resulting from particular financing instruments are incorporated by applying different weighted average cost of capital (WACC) levels.[8]

Determining the necessary rate of return is based on the weighted average cost of capital (WACC) methodology. WACC is often used as an estimate of the internal discount rate of a project or the overall rate of return desired by all investors (equity and debt providers). This means that the WACC formula[9] determines the required rate of return on a company's total asset base and is determined by the Capital Asset Pricing Model (CAPM) and the return on debt. Formally, the pre-tax cost of capital is given by:

$$WACC^{pre\text{-}tax} = g_d \bullet r_d + g_e \bullet r_e = g_d \bullet [r_{fd} + r_{pd}] \bullet (1 - r_{td}) / (1 - r_{tc}) + g_e \bullet [r_{fe} + \beta \bullet r_{pe}] / (1 - r_{tc})$$

[8] Note that the impact of proactive risk mitigation on the required cost and expenditures for achieving the Member States 2020 RES targets has been illustrated in a recent study named "Financing Renewable Energy in the European Energy Market" (de Jager et al., 2011). This study was done on behalf of the European Commission, DG ENER, and conducted by a consortium led by Ecofys.

[9] The WACC represents the necessary rate a prospective investor requires for investment in a new plant.

Table 2: Example of value setting for WACC calculation

| *WACC methodology* | Abbreviation/ Calculation | *Default* risk assessment | | *High* risk assessment | |
|---|---|---|---|---|---|
| | | Debt (d) | Equity (e) | Debt (d) | Equity (e) |
| Share equity / debt | g | 70.0% | 30.0% | 67.5% | 32.5% |
| Nominal risk free rate | $r_n$ | 4.1% | 4.1% | 4.1% | 4.1% |
| Inflation rate | $i$ | 2.1% | 2.1% | 2.1% | 2.1% |
| Real risk free rate | $r_f = r_n - i$ | 2.0% | 2.0% | 2.0% | 2.0% |
| Expected market rate of return | $r_m$ | 4.3% | 7.3% | 5.4% | 9.0% |
| Risk premium | $r_p = r_m - r_f$ | 2.3% | 5.3% | 3.4% | 7.0% |
| Equity beta | $b$ | | 1.6 | | 1.6 |
| Tax rate (tax deduction) | $r_{td}$ | 30.0% | | 30.0% | |
| Tax rate (corporate income tax) | $r_{tc}$ | | 30.0% | | 30.0% |
| Post-tax cost | $r_{pt}$ | 3.0% | 10.5% | 3.8% | 13.2% |
| Pre-tax cost | $r = r_{pt} / (1-r_{tc})$ | 4.3% | 15.0% | 5.4% | 18.9% |
| **Weighted average cost of capital (pre-tax)** | | **7.5%** | | **9.8%** | |
| *Weighted average cost of capital (post-tax)* | | *5.3%* | | *6.8%* | |

Table 3: Policy risk: Instrument-specific risk factor

| *Policy risk: Instrument-specific risk factor (i.e. multiplier of default WACC)* | |
|---|---|
| FIT (feed-in tariff) | 1.00 |
| FIP (feed-in premium) | 1.10 |
| **QUO (quota system with uniform tradable green certificates (TGC))** | **1.20** |
| ETS only (Emission Trading Scheme only - no dedicated RES support) | 1.30 |
| TEN (tenders for selected RES-E technologies) | 1.15 |

Table 2 explains the determination of the WACC exemplarily for two differing cases – a default and a high risk assessment. Within the model-based analysis, a range of settings is applied to reflect investor's risk appropriate. Thereby, risk refers to three different issues:

- A *'policy risk'* related to uncertainty on future earnings caused by the support scheme itself – e.g. referring to the uncertain development of certificate prices within a RES trading system and / or uncertainty related to earnings from selling electricity on the spot market. As shown in Table 2, with respect to policy risk the range of settings used in the analysis varies from 7.5% (default risk) up to 9.8% (high risk). The different values are based on a different risk assessment, a standard risk level and a set of risk levels characterised by a higher expected / required market rate of return. 7.5 % is used as the default value for stable planning conditions as given, e.g. under advanced fixed feed-in tariffs. The higher value is applied in scenarios with less stable planning conditions, i.e. in the cases where support schemes cause a higher risk for investors as associated e.g. with RES trading (and related uncertainty on future earnings on the certificate market). The highest risk setting is used for the case of having no dedicated RES support – where in consequence the (European) Emission Trading Scheme (ETS) serves as only policy initiative for supporting low carbon energy technologies. An overview on the general settings used within Green-X by type of policy instrument or pathway, respectively, is given in Table 3 above. Since the key RES policy instrument used in this assessment (of prospects for RES cooperation) is a quota scheme

(QUO) for renewables in the electricity sector with accompanying green certificate trading as default a high policy risk factor in size of 1.2 is used.

- A *'technology risk'* referring to uncertainty on future energy production due to unexpected production breaks, technical problems etc... Such deficits may cause (unexpected) additional operational and maintenance cost or require substantial reinvestments which (after a phase out of operational guarantees) typically have to be borne by the investors themselves. In the case of biomass this also includes risk associated with the future development of feedstock prices. Table 4 (below) illustrates the default assumptions applied to consider investor's technology risk. The expressed technology-specific risk factors are used as multiplier of the default WACC figure. Ranges as indicated for several RES categories arise from the fact that risk profiles are expected to change over time as well as that a certain RES category includes a range of technologies (and for instance also a range of different feedstock in the case of biomass) and unit sizes. The lower boundary as applicable for PV or for several RES heat options indicates also a differing risk profiling of small-scale investors that partly tend to show a certain "willingness to invest", requiring a lower rate of return than commercial investors.

**Table 4: Technology-specific risk factor**

| *Technology-specific risk factor (i.e. multiplier of default WACC)* | | | |
|---|---|---|---|
| *RES-electricity* | | *RES-heat* | |
| Biogas | 1.00-1.05 | Biogas (grid) | 1.05 |
| Solid biomass | 1.05 | Solid biomass (grid) | 1.05 |
| Biowaste | 1.05 | Biowaste (grid) | 1.05 |
| Geothermal electricity | 1.1 | Geothermal heat (grid) | 1.05 |
| Hydro large-scale | 0.95 | Solid biomass (non-grid) | 0.90-0.95 |
| Hydro small-scale | 0.95 | Solar thermal heat. & water | 0.41-0.90 |
| Photovoltaics | 0.85-0.90 | Heat pumps | 0.68-0.90 |
| Solar thermal electricity | 1.1 (1.0) | *RES-transport / biofuels* | |
| Tide & wave | 1.4 (1.2) | Traditional biofuels | 1.05 |
| Wind onshore | 0.95 | Advanced biofuels | 1.05 |
| Wind offshore | 1.4 (1.15) | Biofuel imports | - |

Note: Numbers in brackets refer to the period post 2020.

- A *'country risk'* component: Nowadays investment risks are prominently discussed as a consequence of the global financial crisis and the subsequent state debt crisis that popped up in recent years in at least several European countries. In an indicative assessment done within the RE-Shaping study (see Rathmann et al. (2011) a closer look was taken on the possible impact of risk arising from a country's general financial performance on the risk of RES projects planned within that country. In accordance with that study and approach, the country performance in Credit Default Swaps (CDS) is used in this study to estimate a country-specific risk adder assuming that this equally affects all RES options within a country. The derived risk multipliers by country are shown in Figure 9 below. Please note however that in assessed RES cooperation scenarios the assumption is taken that with the introduction of a harmonised RES policy framework across all participating countries this risk component is no longer impacting financing conditions for RES – i.e. a "harmonisation" of financing conditions would then take effect under all RES technologies covered by the new (harmonised) RES support scheme (i.e. for example the harmonised quota scheme for renewable electricity with green certificate trading as proclaimed in the scenarios on RES cooperation).

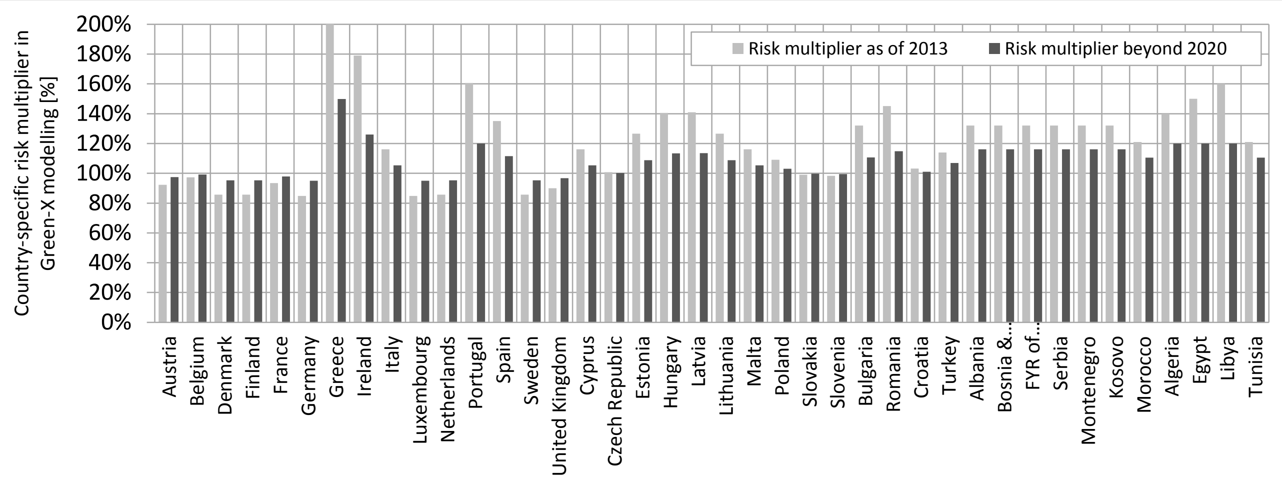



**Figure 9: Country-specific risk factor**

Please note that as default all risk elements are considered in the assessment, leading to a different – typically a higher – WACC than the default level of 7.5%.

## ***Assumptions for simulated support schemes***

A number of key input parameters were defined for each of the model runs referring to the specific design of the support instruments as described below.

Consumer expenditure related to RES support schemes is heavily dependent on the design of policy instruments. In the policy variants investigated, it is obvious that the design options of the various instruments were chosen in such a way that expenditure is low. Accordingly, it is assumed that investigated schemes are characterized by:

- A stable planning horizon;
- A continuous RES-E policy / long-term RES-E targets and;
- A clear and well defined tariff structure / yearly targets for RES(-E) deployment.

In addition, for all investigated scenarios, the following design options are assumed:

- Financial support is restricted to new capacity only;[10]
- The guaranteed duration of financial support is limited.[11]

With respect to model parameters reflecting dynamic aspects such as technology diffusion or technological change, the following settings are applied:

- *Removal of non-financial barriers and high public acceptance in the long term:* In all derived scenario runs it is assumed that the existing social, market and technical barriers (e.g. grid integration) can be overcome in time. More precisely, the assumption is taken that their impact is still relevant at least in the short-term as is reflected in the “business-as-usual” settings compared to, e.g. the more optimistic view assumed for reaching an accelerated RES deployment. Further details on the modelling approach to reflect the impact of non-economic barriers are provided in the subsequent section of this report;
- *A stimulation of ‘technological learning’ is considered – leading to reduced investment and O&M costs for RES over time:* Thereby, generally moderate technological learning is assumed for all assessed cases.

[10] This means that only plants constructed in the period 2021 to 2040 are eligible to receive support from the new schemes. Existing plants (constructed before 2021) remain in their old scheme.
[11] In the model runs, it is assumed that the time frame in which investors can receive (additional) financial support is restricted to 15 years for all instruments providing generation-based support.

## ***RES technology diffusion – the impact of non-economic RES barriers***

In several countries financial support appears sufficiently high to stimulate deployment of a RES technology, in practice actual deployment lacks however far behind expectations. This is a consequence of several deficits not directly linked to the financial support offered which in literature are frequently named "non-economic /non-cost barriers". These barriers refer to administrative deficiencies (e.g. a high level of bureaucracy), diminishing spatial planning, problems associated with grid access, possibly missing local acceptance, or even the non-existence of proper market structures.

In the Green-X model dynamic diffusion constraints are used to describe the impact of such non-economic barriers. Details on the applied modelling approach are explained subsequently.

Within Green-X dynamic diffusion constraints are used to describe the impact of such non-economic barriers. They represent the key element to derive the feasible dynamic potential for a certain year from the overall remaining additional realisable mid- / long-term potential for a specific RES technology at country level. The application of such a constraint in the model calculations results in a technology penetration following an "S-curve" pattern – obviously, only if financial incentives are set sufficiently high to allow a positive investment decision.

In accordance with general diffusion theory, penetration of a market by any new commodity typically follows an "S-curve" pattern. The evolution is characterised by a growth, which is nearly exponential at the start and linear at half penetration before it saturates at the maximum penetration level. With regards to the technical estimate of the logistic curve, a novel method has been employed by a simple transformation of the logistic curve from a temporal evolution of the market penetration of a technology to a linear relation between annual penetration and growth rates. This novel procedure for estimating the precise form of the logistic curve is more robust against uncertainties in the historic data. Furthermore, this method allows the determination of the independent parameters of the logistic function by means of simple linear regression instead of nonlinear fits involving the problem of local minima, etc.

Analytically the initial function, as resulting from an econometric assessment has a similar form to equation (1). However, for model implementation a polynomial function is used, see equation (2). This translation facilitates the derivation of the additional market potential for the year n if the market constraint is not binding, i.e. other applicable limitations provide stronger restrictions. As absolute growth rate is very low in the case of an immature market, a minimum level of the yearly realisable additional market potential has to be guaranteed – as indicated by equation (3).

$$X_n = \frac{a}{\left\{1 + b * e^{\left[-c*(\text{year}n - \text{start year} + 1)\right]}\right\}} \tag{1}$$

$$\Delta P_{Mne} = P_{stat\,long-term} * \left[A * X_n^{\,2} + B * X_n + C\right] * \left[\chi_{M\min} + \frac{\chi_{M\max} - \chi_{M\min}}{4} * b_M\right] \tag{2}$$

$$\Delta P_{Mn} = \text{Max}\ [\Delta P_{M\,min}; \Delta P_{M\,ne}] \tag{3}$$

where:

$\Delta P_{M\,n}$ ............ realisable potential (year n, country level)
$\Delta P_{M\,min}$.......... lower boundary (minimum) for realisable potential (year n, country level)
$\Delta P_{M\,ne}$ ........... realisable potential econometric analysis (year n, country level)
$P_{stat\,long-term}$ .....static long-term potential (country level)
a .................. econometric factor, technology specific
b.................. econometric factor, technology specific
c .................. econometric factor, technology specific
A quadratic factor yield from the econometric analysis
B linear factor yield from the econometric analysis
C constant factor yield from the econometric analysis (as default 0, considering market saturation in the long-term)

$X_n$ ................ calculated factor - expressing the dynamic achieved long-term potential as percentage figure: In more detail …

$$X_n = \frac{\text{dynamic achieved potential (year n, country level)}}{\text{total long - term potential (country level)}} \quad ; X_n\ [0, 1]$$

$\chi_{M\,max}$ absolute amount of market restriction assuming very low barriers; $\chi_{M\,max}$ [0, 1]; to minimise parameter setting $\chi_{M\,max} = 1$

$\chi_{M\,min}$ absolute amount of market restriction assuming very high barriers; $\chi_{M\,min}$ [0, $\chi_{M\,max}$]

$b_M$ barrier level market / administrative constraint assessment (level 0 - 5) [12]; i.e. the country-specific parameter to describe the impact of non-economic barriers

For parameter setting, the econometric assessment of past deployment of the individual RES technologies at country level represents the starting point, whereby factors A, B and C refer to the "best practice" situation as identified via a cross-country comparison.[13] [14]

Generally two different variants of settings with respect to the non-economic barriers of individual RES technologies are used:

- High non-economic barriers / low diffusion ("business-as-usual settings")
  This case aims to reflect the current situation (business-as-usual (BAU) conditions) where non-economic barriers are of relevance for most RES technologies. The applied technology-specific parameters have been derived by an econometric assessment of past deployment of the individual RES technologies within the assessed country.
- Removed non-economic barriers / high diffusion ("Best practice")
  This case represents the other extreme where the assumption is taken that non-economic barriers will be mitigated in time.[15] Applied technology-specific settings refer to the "best practice" situation as identified by a cross-country comparison. Accordingly, an enhanced RES deployment can be expected – if financial support is also provided in an adequate manner.

Figure 10 illustrates the applied approach: On the right-hand side the resulting yearly realisable potential in dependence of applied barrier level and on the left-hand side related deployment – in case that no other (financial) constraint would exist – are depicted, illustrating schematically applied variants with respect to non-economic barriers as used in the follow-up scenario assessment.

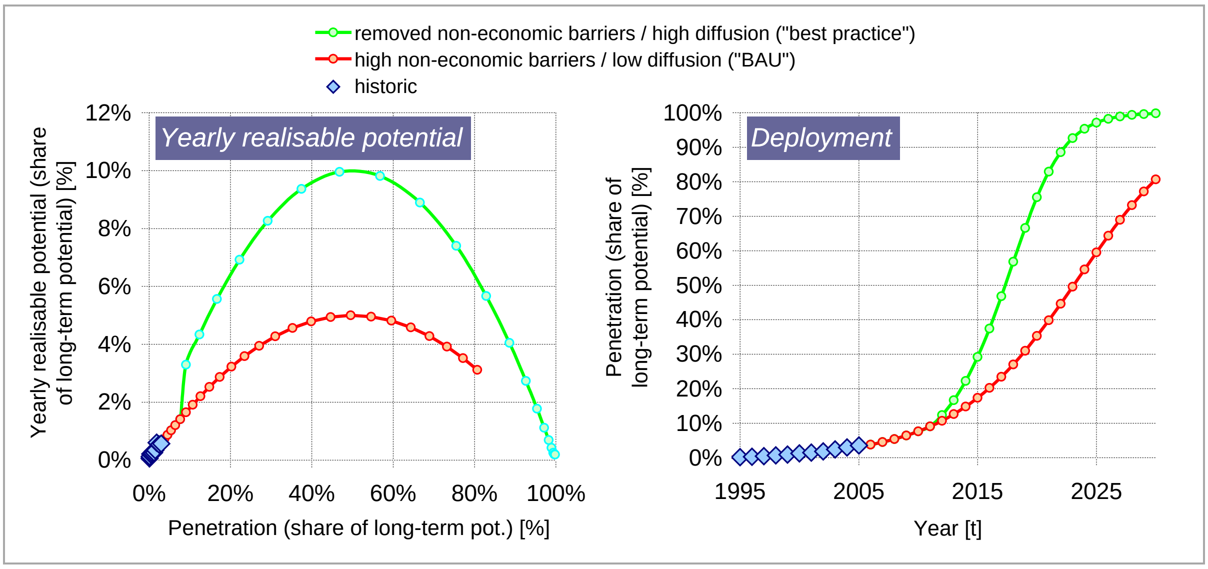
Finally, please note that in this assessment of prospects for RES cooperation between the EU and its neighbours a "business-as-usual" setting with respect to the impact of non-economic barriers on RES technology diffusion is used for the near future (up to 2015) whereas an optimistic view, i.e. the "best practice" setting, is taken for the period post 2020. A gradual removal/mitigation of non-economic barriers is consequently assumed to take place in the years in between, i.e. from 2016 to 2020.

[12] A value of 0 would mean the strongest limitation (i.e. no diffusion, except minimum level), while 4 would mean the strongest feasible diffusion (according to "best practice" observations).
Note, if the level number '5' is chosen, the default approach would be replaced by a simplified mechanism: In this case the yearly realisable potential is defined as share of the dynamic additional realisable mid-term potential on band level. Hence, it can be chosen separately how much of the remaining potential can be exploited each year.

[13] For the "best practice" country the applied market barrier $b_M$ equals 4 – see notes as given in the corresponding description. Consequently, the comparison to this "ideal" case delivers the barrier level $b_M$ for other countries.

[14] For novel technologies being in an early stage of development and consequently not applicable in historic record similarities to comparable technologies are made.

[15] More precisely, a stepwise removal of non-economic barriers is preconditioned which allows an accelerated RES technology diffusion. Thereby, the assumption is taken that this process will be launched in 2016.




Note: Key parameter have been set in this schematic depiction as follows: A = (-B) = -0.4; $b_M$ was varied from 2 (high barriers / low diffusion) to 4 (removed barriers / high diffusion)

**Figure 10 Schematic depiction of the impact of non-economic barriers on the feasible diffusion at technology and country level: Yearly realisable potential (left) and corresponding resulting feasible deployment (right) in dependence of the barrier level**

## ***Conventional supply portfolio* (Green-X assessment of benefits)**

The conventional supply portfolio, i.e. the share of the different conventional conversion technologies in each sector, is for the EU28 based on PRIMES forecasts on a country-specific basis. For the assessed neighbouring countries and regions an alternative dataset is derived, building on the detailed assessment of the status quo done by case region and assuming similar trends as expected at EU level by PRIMES modelling. These projections of the portfolio of conventional technologies particularly influence the calculations done within this study on the avoidance of fossil fuels and related $CO_2$ emissions. As it is beyond the scope of the Green-X model to assess in detail which conventional power plants would actually be replaced, for instance, by a wind farm installed in the year 2023 in a certain country (i.e. either a less efficient existing coal-fired plant or possibly a new highly-efficient combined cycle gas turbine), the following assumptions are made:

- Bearing in mind that fossil energy represents the marginal generation option that determines the prices on energy markets, it was decided to stick to the sector-specific conventional supply portfolio projections on a country level provided by PRIMES. Sector- and country-specific conversion efficiencies, derived on a yearly basis, are used to calculate the amount of avoided primary energy based on the renewable generation figures obtained. Assuming that the fuel mix is unaffected, avoidance can be expressed in units of coal or gas replaced.
- A similar approach is chosen with regard to the avoidance of $CO_2$ emissions, where the basis is the fossil-based conventional supply portfolio and its average country- and sector-specific $CO_2$ intensities that may change over time.

In the following, the derived data on aggregated conventional conversion efficiencies and the $CO_2$ intensities characterising the conventional reference system (excl. nuclear energy) are presented.

Figure 11 shows the dynamic development of the average conversion efficiencies as projected for EU member states by PRIMES for conventional electricity generation as well as for grid-connected heat production. Conversion efficiencies are shown for the PRIMES reference scenario (EC, 2013). Error bars indicate the range of country-specific average efficiencies among EU Member States. For the transport sector, where efficiencies are not explicitly expressed in PRIMES' results, the average efficiency of the refinery process used to derive fossil diesel and gasoline was assumed to be 95%. This graph also includes trend assumptions for neighbouring countries with respect to reference conversion efficiencies of fossil-based electricity generation.

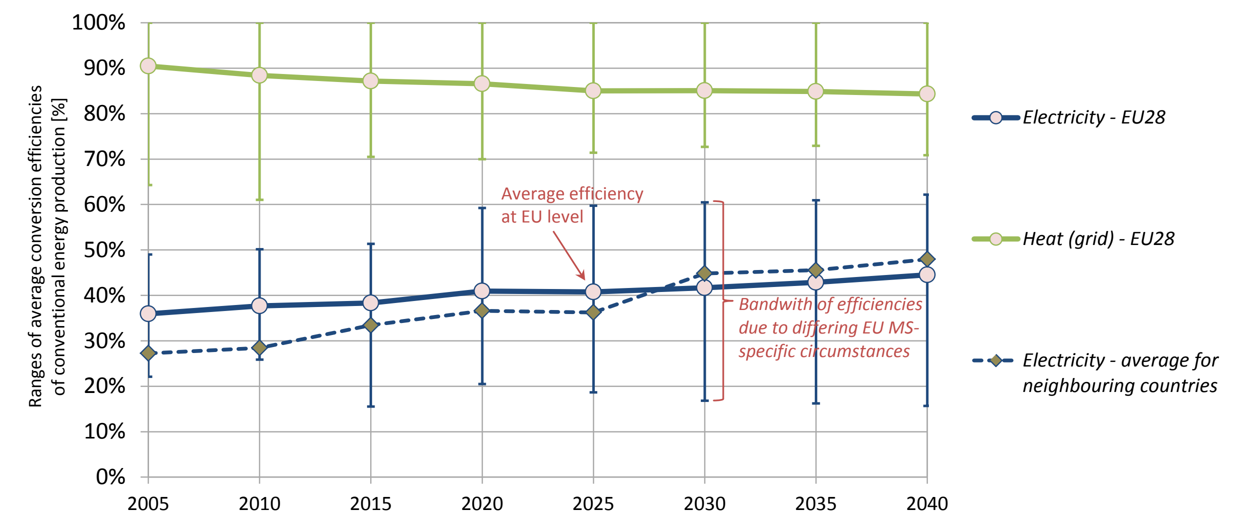



**Figure 11: Country-specific average conversion efficiencies of conventional (fossil-based) electricity and grid-connected heat production in the EU28**

Source: PRIMES scenarios (EC, 2013)

The corresponding data on country- and sector-specific $CO_2$ intensities of the conventional energy conversion system are shown in Figure 12. Similar to conversion efficiencies the data source for EU countries (where error bars again illustrate the variation across EU member states) is the PRIMES reference scenario whereas for neighbouring countries a trend assessment was conducted, building on the outcomes of the bottom-up case study works.

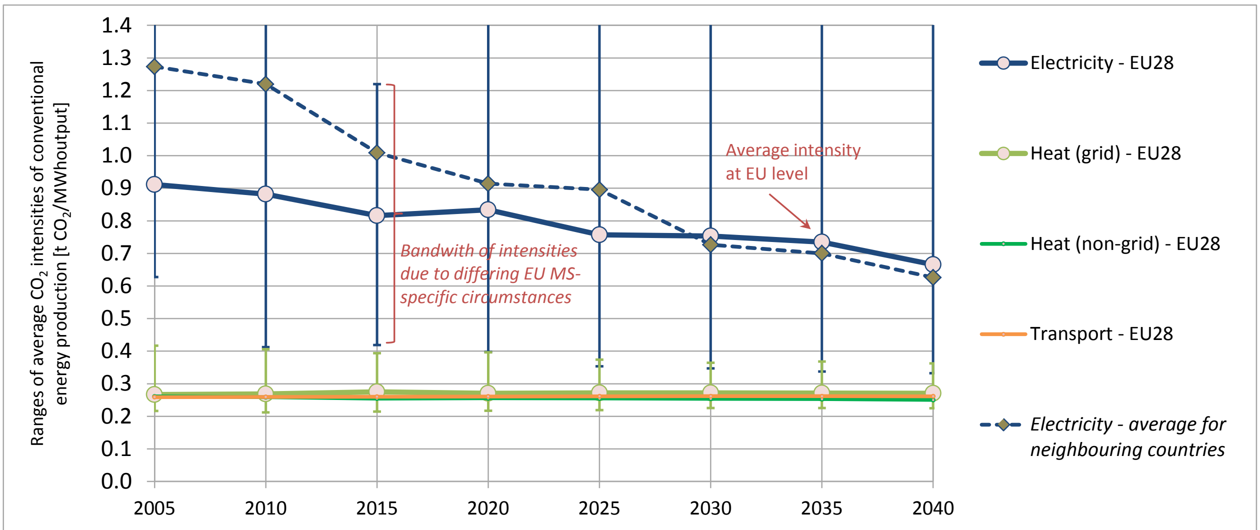



**Figure 12: Country-specific average sectorial $CO_2$ intensities of the conventional (fossil-based) energy system in the EU28**

Source: PRIMES scenarios (EC, 2013)

### 2.2.5 Key input parameters for the power-system-analysis (HiREPS)

Below we illustrate the key specific input parameters for the power-system analysis, done by use of TU Wien's HiREPS model. This concerns in particular the representation of the transmission grid (across the enlarged geographical area, i.e. EU28 plus assessed neighbouring countries) in the model-based assessment as discussed next.

***Transmission grid representation***

High resolution grid model (as starting point):

As starting point, the high voltage grid of all assessed 40 countries is constructed based on the power lines of the ENTSO-E grid map of 2012. The grid map is transformed in numerical data using the software QGIS 2.4.0-Chugiak. In this software the ENTSO-E grid map is projected onto a vector map and then georeferenced, from which the topographical data from the high voltage grid can be retrieved. This includes line lengths and locations of nodes (locations where power is injected in or retrieved from the grid). Additional information such as the voltage level is also added. From the power line length the reactance is calculated, as this is a length dependent property. And finally, other important characteristics can be coupled to the transmission lines based on their voltage level, like the number of circuits or the capacity of the line. As expressed in Table 5, a set of distinct voltage levels have been included in the grid model, and respective properties assigned to them.

The data for the properties of DC lines in the modelled grid are line specific. The only 110 kV lines that have been integrated are the intra-country power lines in Denmark and Sweden. Particularly in Denmark, the 110 kV lines form the densely constructed backbone of its transmission network. Therefore they should not be excluded from the grid model.

**Table 5: Properties of power lines.**

| Voltage (kV) | Resistance (Ohm/km) | Reactance (Ohm/km) | Capacity (MW) |
|---|---|---|---|
| **110** | 0.176 | 0.41 | 140 |
| **220** | 0.075 | 0.4 | 490 |
| **300-330** | 0.075 | 0.4 | 490 |
| **380-400** | 0.029 | 0.33 | 1700 |
| **500** | 0.029 | 0.33 | 1700 |
| **750** | 0.029 | 0.33 | 1700 |

Transformers have been included in the grid model as well. Transformers – just like transmission lines – carry a certain reactance and capacity, hence influencing power flows. A deeper analysis of the values of these characteristics shows that compared to transmission lines, the average transformer carries a reactance that is larger than the average line in the grid model. Consequently, it would be a major simplification not to involve transformers in the grid model. For further analysis those transformers could act as phase shifters or to maintain certain offset flows, and therefore the transformers have been modelled to act like additional power lines in the grid model. Any node to which a number of voltage levels are connected is split in just as many nodes. Although these nodes share the same coordinates, they are connected to each other by imaginary power lines in the grid model. The data used for the transformer properties stems from an internal database at TU Wien, Energy Economics Group, assigning default values to a certain transformer based on the country it is located. Moreover, as not all data for transformation between all voltage levels is available suitable assumptions have been made in the case of a lack of such information. The properties of a transformer are determined by the highest voltage level in a node. For instance, the properties of a 380 kV transformer are assigned to a transformer between a 220 kV and a 380 kV level.

As shown in Figure 13, the grid system for all 40 modelled countries contains 5141 nodes and 6737 power lines (including transformers). The size of the model is too large for long term simulations due to limitations in terms of computation time and power. Consequently, the extended grid model is reduced to smaller equivalent versions of the grid, with fewer nodes and lines. The method that is used for the grid reduction is described in the following sections.

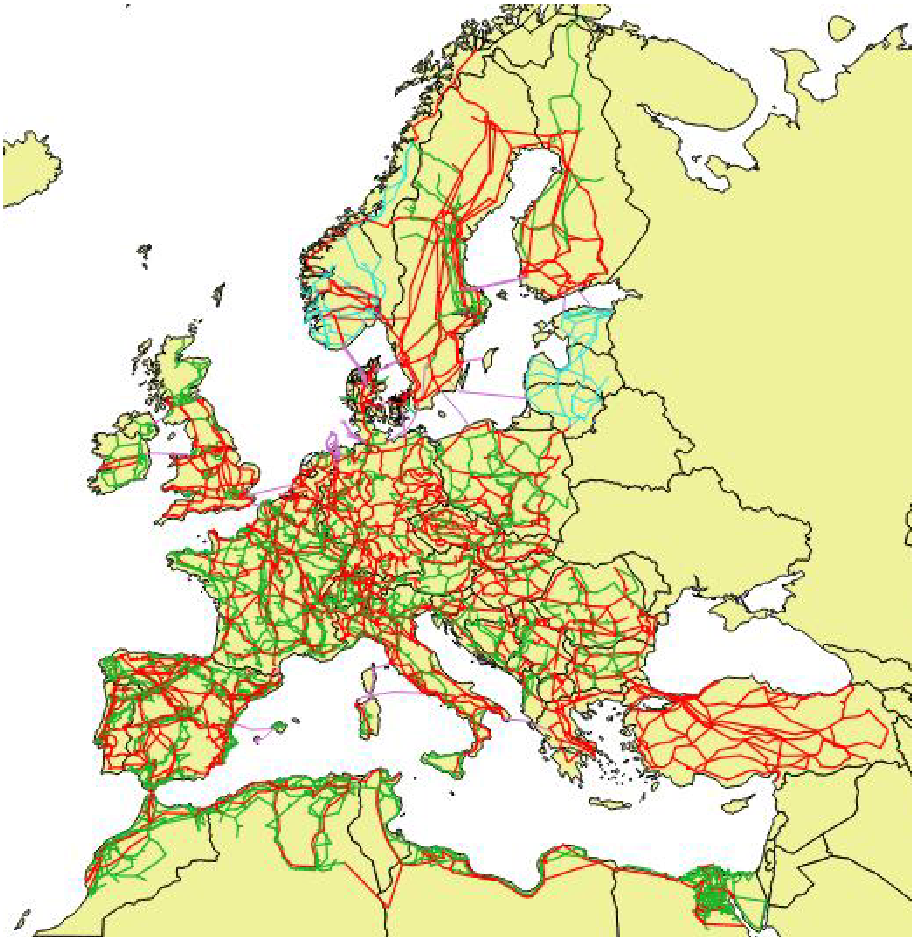


**Figure 13: Full representation of the high voltage grid.**

Low resolution grid model

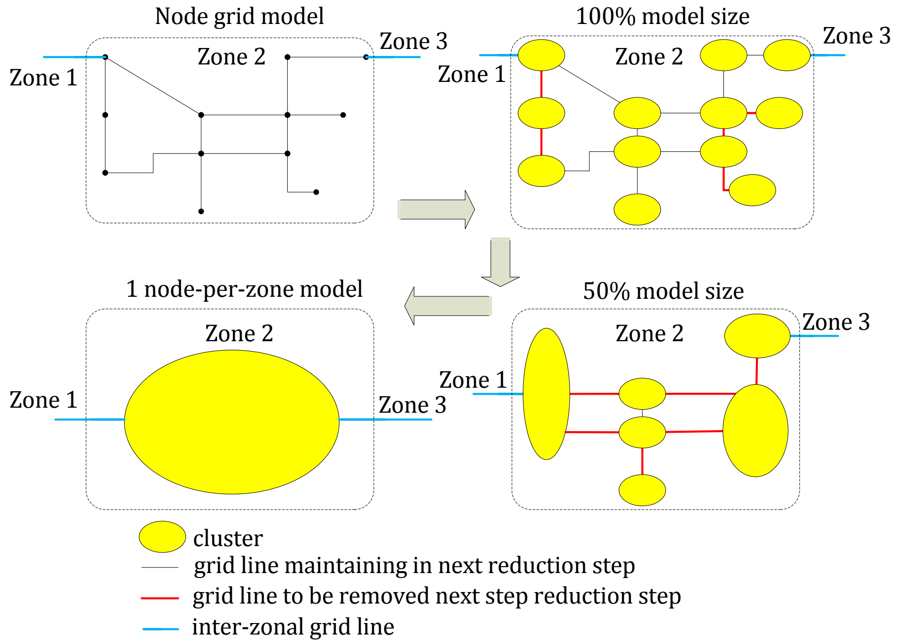
The simplification process reduces the power grid by clustering certain nodes together and removing the existing power line between them in the process (see Figure 14)As DC-lines behave differently, they are exempted from the clustering process, and will therefore remain in the model. The clustering process is performed separately for each zone, so only intra-zonal AC-lines are removed, and inter-zonal lines remain in the model. A zone is defined as a country or a designated set of countries. The 40 countries from the grid map have been categorised in 27 zones.

The extent to how far zones are reduced is dependent on the particular desired zone grid size, which can be defined by the targeted granularity denoted by ξ. The granularity is a percentage ranging from 0% to 100%, indicating the targeted model size. A ξ of 100% represents the full grid in a zone without any reduction whereas a percentage of 0% represents a one-cluster per zone situation by definition. From the targeted granularity ξ and the number of nodes $n_{nodes,k}$ in zone $k$, the targeted number of clusters $n_{clusters,k}$ can be obtained with equation (4).

$$\begin{cases} n_{clusters,k} = \xi \cdot n_{nodes,k} \\ if \;\; \xi \;\; \cdot n_{nodes,k} < 1 \;\; , \;\; n_{clusters,k} = 1 \end{cases} \tag{4}$$

Figure 14 illustrates an imaginative zone clustered to several sizes. In this figure the original grid is represented by the top left picture, whereas the following pictures show the 100%, 50%, and 0% zone sizes, in which lines are removed from the grid and nodes aggregated to clusters. This results in grids with 12, 6, and 1 clusters respectively. The red lines in the grids represent the power lines that are clustered in the next reduction step, whereas the blue lines represent the inter-zonal power lines that cannot be clustered.

As certain lines are combined in the clustering process, the properties of the reduced grid have to be newly calculated. The reactance of the equivalent lines can be calculated by using the method proposed by Shi (Shi, 2012).




Note: An imaginative zone is represented in a 100%, 50% and 0% (1 cluster-per-zone) model size.

**Figure 14: Schematic overview of the cluster process.**

Which specific lines in the zone are clustered, is dependent on the condition values of the power lines in the zone. The condition value $c_n$ indicates whether the particular power line is likely to form a bottleneck in the grid. $c_n$ is a binary indicator describing the likeliness of the line being a bottleneck. The first part of the binary indicator consists of the reactance $X_n$. The reactance is the decisive factor on the direction of power flows from a node. The reactance of lines is dependent on the line length and the voltage. A relatively low reactance indicates a high power flow over a particular line.

The second part of the binary indicator is a scaling factor, indicating whether power flows are critical or not. Power flows in a line are directly dependent on the phase angle difference between two nodes. A large difference in power injections will lead to a large power flow between two connected nodes.

Both demand and generation patterns per country have been derived via the construction of generic time series. Generation patterns as well as the demand time series in nodes and countries are estimated based on the respective production capacity at each node. First of all, we assign power plants from a locational power plant database to the closest node within the grid. Based on variable demand and production patterns throughout the year, and a merit order model for power production in every country, an approximation is made with respect to power injections for 960 different time steps. For every time step, the power injections are translated to resulting power flows using the Power Transfer Distribution Factor (PTDF) matrix of the grid system. Every power line $n$ has a value $\Delta P_{inj\ i,j}$ per time step, indicating the difference in power injections between the two nodes $i$ and $j$ it is connecting. The largest value for $\Delta P_{inj\ i,j}$ from all time steps is selected as the input for the condition value calculation of power line $n$, denoted as $max(\Delta P_{inj\ i,j})$. Whether a maximal power flow is critical for a line is dependent on the capacity of the line $TC_n$. Therefore the second part of the binary indicator is the ratio of $max(\Delta P_{inj\ i,j})$ and $TC_n$, resulting in a unit-less scaling factor of the reactance.

For every line $n$ the condition value $c_n$ is defined as:

$$c_n = X_n \cdot \frac{max(\Delta P_{inj\ i,j})}{TC_n} \qquad (5)$$

A high condition value indicates that the line is likely to become a bottleneck in the grid.

For every zone, the clustering process starts with a certain threshold value $\gamma$. Lines within the zone are only removed if the condition value $c_n$ is smaller than $\gamma$. As the initial starting value of $\gamma$ is very low, no lines will be aggregated during the first loop. In the next loop $\gamma$ is increased by 10%, and another clustering loop is performed. This process is continued until finally a value for $\gamma$ has been reached for which enough nodes have been aggregated, and the targeted number of clusters in the zone has been reached.

The schematic overview of this process is depicted in Figure 15 below. Thus, the individual steps can be summarised as follows:

(1) Select zone $Z_k$
(2) Initiate starting value $\gamma$
(3) Select all lines in $Z_k$
(4) Cluster all lines in $Z_k$ with $c_n \geq \gamma$
(5) Has ξ been reached for zone k? If no, increase $\gamma$ with 10% and return to step 4. If yes, k = k +1 and return to step 1.

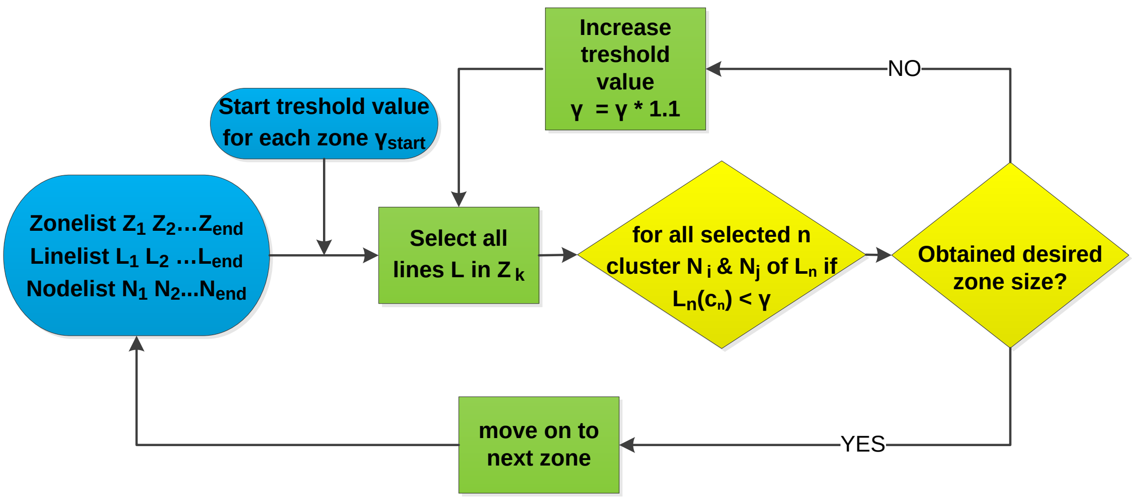



Figure 15: Schematic overview of the clustering process.

The result of this process is a set of reduced clusters, and the set of un-clustered equivalent lines. As every zone has been reduced to the same value of $\xi$, the final size of the full grid is also approximately $\xi$.

Significant gains can be achieved in transmission system modelling by reducing the size of the power grid. Transmission system modelling is typically conducted in optimization software tools. To find the optimum solution in AMPL® the Karmarkar's algorithm for the interior-point method is applied. The required computation time for this method is proportional to the number of variables to the power of 3.5. Simplifying the transmission grid and reducing the number of nodes to half of its original size, would therefore cut the required computation time by a factor of $2^{3.5}$ = 11.3.

Simplifying grid models will nevertheless lead to inaccuracy in the modelling of power flows. The allowable reduction degree in this analysis is defined as the reduction level for which an average inaccuracy smaller or equal to 20% of the available transfer capacity (ATC) of the power lines in a zone is maintained. The results show that every zone can be reduced to 37.5% of its original size without leading to inaccuracy greater than the set benchmark. Most other countries can be reduced to even smaller sizes before the analysed set of cross-border lines shows major inaccuracies.

Two reduced models have been developed to achieve shorter computation times. For one model every zone is reduced to the point where the number of clusters equals half the number of nodes from the full grid model (an $\xi$ of 50%, leading to 2615 clusters). Then, all lines that are just connected to the grid by one end are removed, as such power lines do not influence power flow in the rest of the grid. The node belonging to the dead end is added to the node on the other end of the removed power line, reducing grid size even further. The result of this process is displayed in Figure 16, leading to a reduced model containing 2392 clusters and 3412 equivalent power lines.

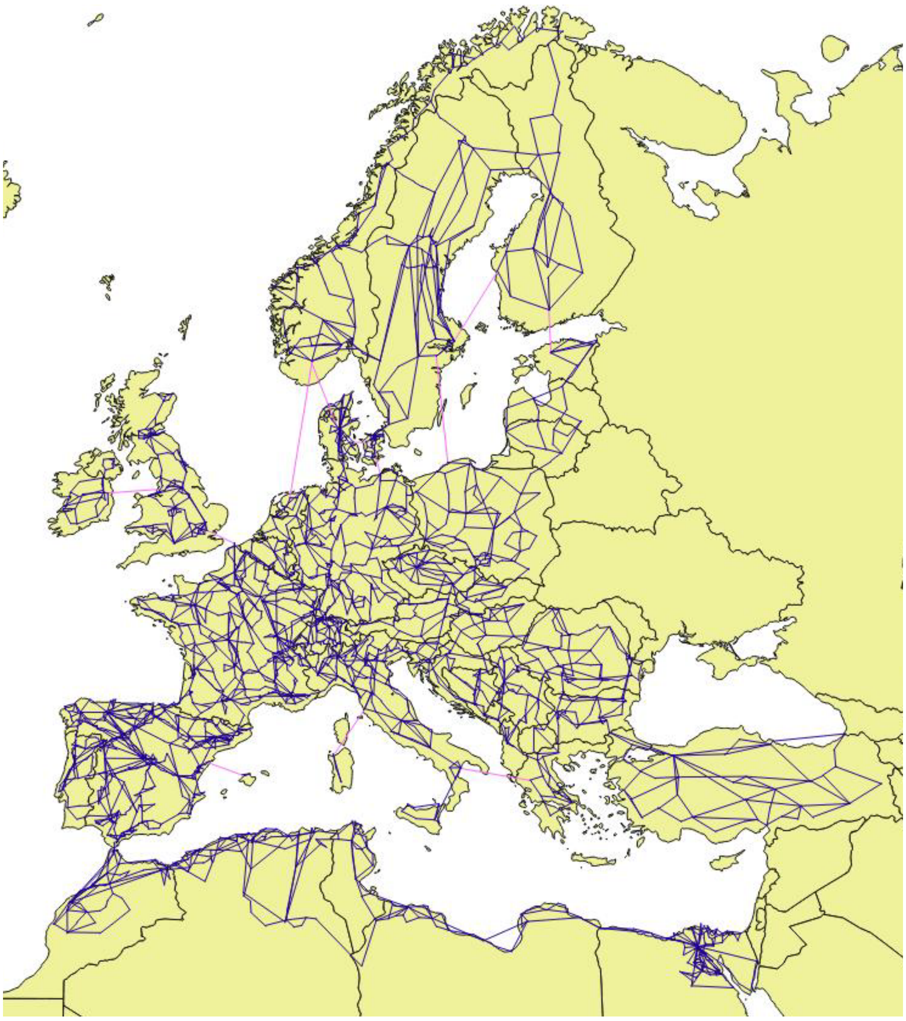


**Figure 16: The grid reduced to 50% of its original size.**

The second reduced model as shown in Figure 17 reduces every zone to a single cluster, leaving only inter-zonal power lines. This model consists of 30 clusters and 53 equivalent lines. It should be emphasized that this model exceeds the boundaries of accuracy, and can therefore only be used to obtain rough estimations of power grid flows.

In order to account for planned future grid extensions the ENTSO-E 2014 Ten Year Network Development plan[16] has been considered. All concrete projects have been added to the full grid model and the simplification process has been performed as described above. The resutling reduced model including the TYNDP projects are illustrated in Figure 18. Besides the TYNDP within Europe no further grid extensions have been assumed in the modelling. The infrastructure extensions necessary to physically import the amounts of surplus RES generation in North Africa have been modelled endogenously. The corresponding cost assumptions for grid extensions using High Voltage Direct Current (HVDC) lines are summarized in Table 6. The assumed additional payments to compensate land owners for land use, land aggregation and potential concession fees are shown in Table 7.

[16] see https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx.

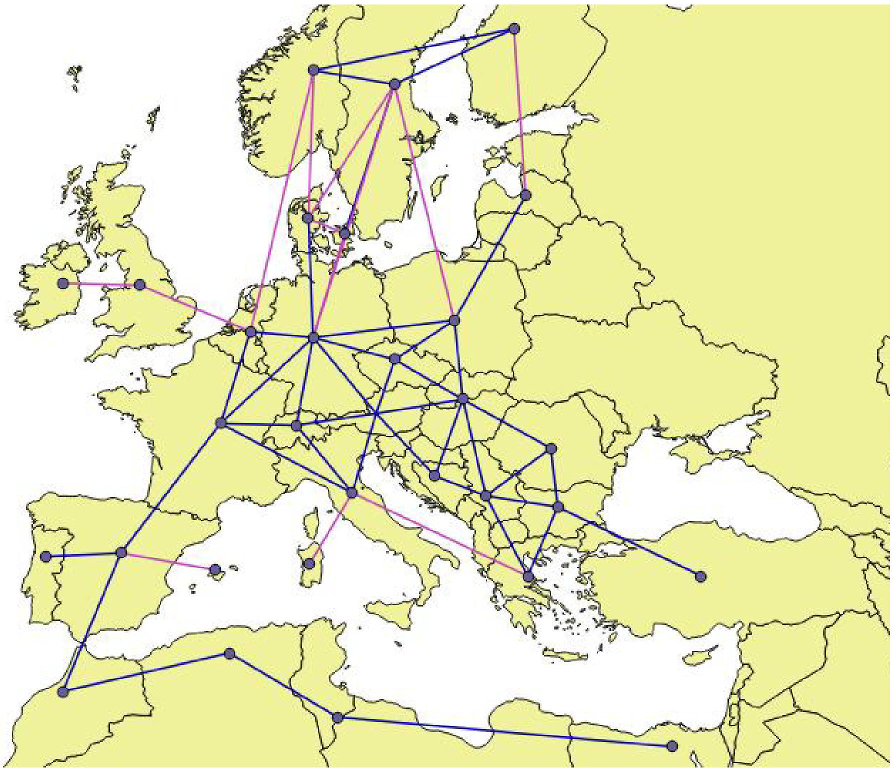
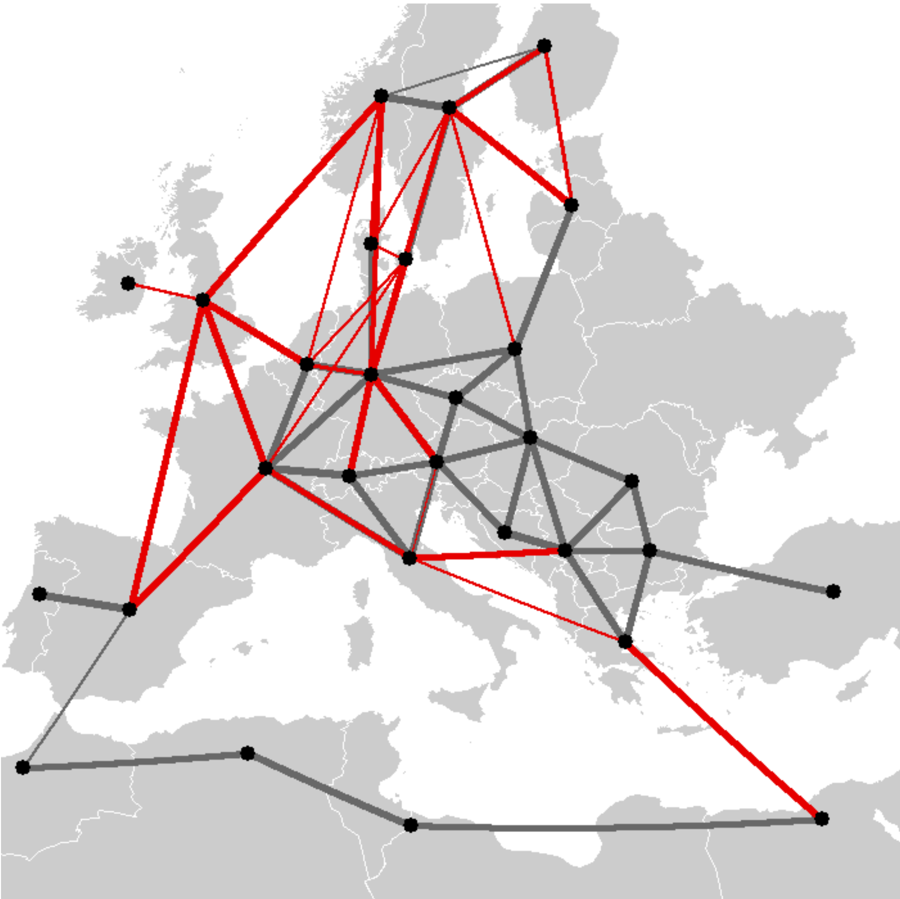


Figure 17: The grid reduced to its minimal form in which only one cluster remains per zone.



Note: The red lines indicate HVDC lines and the grey lines AC lines.

Figure 18: Grid representation including planned new lines of the TYNDP 2014.

**Table 6: Cost assumptions of HVDC lines.**

Source: Trieb (2014)

| **HVDC line** | | |
|---|---|---|
| **Investment costs** | **all costs in €$_{2010}$** | |
| Overhead line | | |
| material | 134 | €/MW/km |
| planning | 5 | % |
| construction | 136 | % |
| commissioning | 3 | % |
| Underground cable | | |
| material | 791 | €/MW/km |
| planning | 5 | % |
| construction | 32 | % |
| commissioning | 3 | % |
| Sea cable | | |
| material | 930 | €/MW/km |
| planning | 5 | % |
| construction | 32 | % |
| commissioning | 3 | % |
| Converter station | | |
| total | 130,000 | €/MW/per end node |
| Life time (general) | 40 | a |
| **Annual operation cost** | **all costs in €$_{2010}$** | |
| O&M HVDC link | 3,000 | €/km/a |
| O&M converter | 1,300 | €/MW/a |
| Insurance | 0.5 | % of total investment costs (annual-ly) |

**Table 7: Compensation costs assumptions.**

Source: Trieb (2014)

| **Compensation payment for both CSP and HVDC** | | | |
|---|---|---|---|
| Standard land values for agricultural crop or dessert areas | | | |
| | default | max | |
| Morocco | 0.1 | | €/m2 |
| Spain | 1.0 | | €/m2 |
| France | 0.5 | | €/m2 |
| Germany | 2.9 | 18.0 | €/m2 |
| Land use | | | |
| Overhead line | | 70,000 | m2/km |
| Underground cable | | 4,000 | m2/km |
| Pylon | | 90,000 | m2 |
| # Pylons | | 1.78 | pylons/km |
| CSP plant | | 150 | km2 |

***Complementary assumptions for the power-system analysis***

The additional complementary assumptions required for the power-system analysis using the HiREPS model are given below.

- Assumptions on technology-specific electricity generation in 2030 and 2040 by country: The renewable electricity generation mixes per country are taken from the Green-X modelling results. For Norway and Switzerland, which are not included in the Green-X dataset, it is assumed that hydropower is the dominant renewable electricity source and the installed capacities and the mean annual generation are taken from Eurelectric, ENTSO-E and Eurostat data. The installed coal and lignite capacities for both 2030 and 2040 are limited to the currently existing capacities. The installed nuclear capacities are taken from ENTSO-E Scenario A in 2025, but corrected for power plants decommissioned due to their age in 2030 or 2040. Within these limits the installed capacities for coal, lignite and gas power plants are optimised to provide the cost minimal generation mix under the given $CO_2$ price (set in accordance with the PRIMES reference case (cf. 2.2.2) and renewable electricity generation assumptions.
- Time series data for renewable electricity generation: The simulated photovoltaic and concentrating solar power generation is based on the hourly solar irradiation data from Meteosat satellites as provided by HelioCLIM[17]. For the simulation of wind power generation time series, a 3 $MW_e$ Enercon E101 wind turbine with a hub height of 100 meter is assumed to be operating. This wind turbine has a rather large rotor diameter in relation to the generator capacity, and therefore produces more electricity also at lower wind speeds. The simulated daily hydro discharge data for different rivers, needed to simulate the hydropower generation, is obtained by the E-HYPE 2.1 tool of the Swedish Meteorological and Hydrological Institute.
- Physical import: All renewable electricity generation in North Africa[18] that is built "under the umbrella of RES cooperation with Europe"[19] has to be physically imported into the European Union (EU) / Energy Community (EC) (i.e. EU28 plus Western Balkans and in most cases also Turkey) in order to be accounted for the EU/EC RES targets. In the simulation physical import is defined as the daily import power flow equalling the daily electricity generation from the related RES installation(s) in the host country.
- Grid assumptions: Within Europe it is assumed that only the Ten Year Network Development Plan 2014 of ENTSO-E will be realised up to 2040. One exemption in the modelling work is the interconnection between Italy and Germany that is allowed (if required/suggested model-wise) to be extended. In the "EU plus" scenarios HVDC lines are built in a cost minimal way to allow the required physical export volumes. The costs of the individual HVDC export lines were estimated using a line by line estimation based on Trieb (2014). By default in the "EU plus" scenarios only lines from North Africa and Turkey to neighbouring EU countries are considered. This approach is chosen to derive the minimum infrastructure requirements in order to transport electricity from neighbouring regions into the European Union. Furthermore, this approach does not consider a *supergrid perspective*, in which the import of electricity from Third countries requires severe modifications of the entire European electricity transmission grid. Another approach that is assessed in the course of the grid analysis is the concept of *dedicated CSP-to-grid HVDC links* as described in Box 5 below. The general idea behind this is to reserve a certain HVDC link explicitly for the transfer of electricity from a certain CSP plant in North Africa to load centres within

[17] http://www.soda-is.com/eng/helioclim/

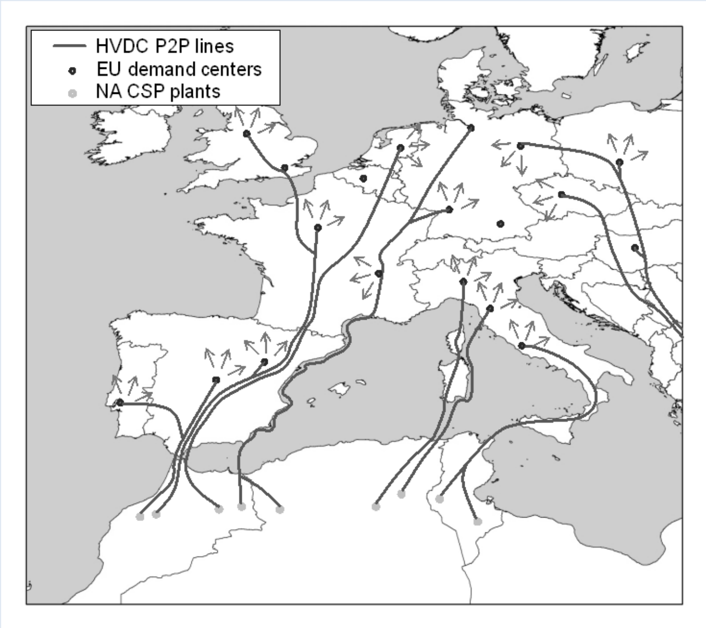
[18] In the sensitivity case for Turkey this import constraint is applied also to Turkey, assuming a non-affiliation with the Energy Community / European Union in forthcoming years.

[19] In the Green-X modelling exercise on prospects for RES cooperation the assumption is taken that a common RES-E trading regime would be implemented in the EU28 and in all assessed case regions. Thus, any newly built RES-E installation in North Africa, receiving support through the common RES trading regime, has to export not only the green value of the produced electricity (i.e. represented by the green certificate) but also the electricity itself.

Europe. Further details including an extensive description of the rationale behind this approach can be found in the BETTER deliverables of the North Africa case study (cf. Trieb, 2015).

**Box 5: CSP-HVDC Interconnections between North Africa and Europe**

CSP-HVDC links are point-to-point interconnectors between a large scale concentrating solar power station in North Africa specifically dedicated to export and a European Centre of demand. They are superposed on the conventional electricity grid, into which they feed flexible solar electricity just as required by the local load. The cost of such a line interconnecting a CSP plant in Morocco and a German city, providing 1.5 GW firm power capacity and about 9 TWh/a solar electricity has been estimated to about 16-20 billion €. Performance and cost of such infrastructure would be comparable to and competitive with present nuclear power projects in Europe.




Key characteristics of such interconnections are summarized in the following:

- Flexible solar power is delivered on demand from CSP plants with thermal energy storage in North Africa that are dedicated exclusively to export.
- Transport of flexible power takes place via point-to-point HVDC lines to European centres of demand in order to compensate local fluctuations from variable RES-E.
- Full traceability and physical accountability of imported electricity.
- High cost of initial projects but also high quality of flexible energy supply from CSP.
- No transfer bottlenecks due to dedicated HVDC links designed for nominal export capacity.
- Dedicated CSP-HVDC plants for export are independent from national grid and power supply and thus provide added value in both North Africa and EU.
- Surplus electricity is avoided by a balanced mix of variable and flexible sources.

## 2.3 Potentials and costs for RES in the European Union and assessed neighbouring countries / regions

Nowadays, a broad set of different renewable energy technologies exists. Obviously, for a comprehensive investigation of the future development of RES it is of crucial importance to provide a detailed investigation of the country-specific situation – e.g. with respect to the potential of the certain RES technologies in general as well as their regional distribution and the corresponding generation cost.

This section illustrates the consolidated outcomes on RES potentials and accompanying costs of an intensive assessment process conducted within several studies in this topical area. The derived data on realisable long-term (2050) potentials for RES in the European Union and assessed neighbouring countries fits to the requirements of the model Green-X and serves as sound basis for the subsequently depicted policy assessment of RES cooperation between the EU and its neighbours.

Please note that within this illustration the future potential for considered biomass feedstock is pre-allocated to feasible technologies and sectors based on simple rules of thumb. In contrast to this, within the Green-X model no pre-allocation to the sectors of electricity, heat or transport is undertaken as technology competition within and across sectors (as well as between countries) is appropriately reflected in the applied modelling approach.

### 2.3.1 The Green-X database on potentials and cost for RES – background information

The input database of the Green-X model offers a detailed depiction of the achieved and feasible future deployment of the individual RES technologies, initially constraint to the European Union (EU28) but within the course of this project extended to all assessed neighbouring countries / regions (i.e. Western Balkans, North Africa and Turkey). This comprises in particular information on costs and penetration in terms of installed capacities or actual & potential generation. Realisable future potentials (up to 2050) are included by technology and by country. In addition, data describing the technological progress such as learning rates are available. Both serve as crucial input for the model-based assessment of future RES deployment.

Note that an overview on the method of approach used for the assessment of this comprehensive data set is given in Box 6 (below).

**Box 6: About the Green-X potentials and cost for RES**

The Green X database on potentials and cost for RES technologies provides detailed information on current cost (i.e. investment -, operation & maintenance -, fuel and generation cost) and potentials for all RES technologies at country level. Geographically the scope of the database has been extended within this project from the EU28 to the assessed neighbouring countries / regions (i.e. Western Balkans, Turkey and North Africa).

The assessment of the economic parameter and accompanying technical specifications for the various RES technologies builds on a long track record of European and global studies in this topical area. From a historical perspective the starting point for the assessment of realisable mid-term potentials was geographically the European Union as of 2001 (EU-15), where corresponding data was derived for all Member States initially in 2001 based on a detailed literature survey and an expert consultation. In the following, within the framework of the study “Analysis of the Renewable Energy Sources’ evolution up to 2020 (FORRES 2020)” (see Ragwitz et al., 2005) comprehensive revisions and updates have been undertaken, taking into account recent market developments. Consolidated outcomes of this process were presented in the European Commission’s Communication “The share of renewable energy” (European Commission, 2004). Later on throughout the course of the futures-e project (see Resch et al., 2009) an intensive feedback process at the national and regional level was established. A series of six regional workshops was hosted by the futures-e consortium around the EU within 2008. The active involvement of key stakeholders and their direct feedback on data and scenario outcomes helped to reshape, validate and complement the previously assessed information.

Within the Re-Shaping project (see e.g. Ragwitz et al., 2012) and parallel activities such as the RES-Financing study done on behalf of the EC, DG ENER (see De Jager et al., 2011) again a comprehensive update of cost parameter was undertaken, incorporating recent developments – i.e. the past cost increase mainly caused by high oil and raw material prices, and, later on, the significant cost decline as observed for various energy technologies throughout 2008 and 2009. The process included besides a survey of related studies (e.g. Krewitt et al. (2009), Wiser (2009) and Ernst & Young (2009)) also data gathering with respect to recent RES projects in different countries.

Within this study and parallel activities the database has been extended geographically. The extended version comprises in addition to EU member states also all Contracting Parties of the Energy Community (i.e. Western Balkans), Turkey and selected North African countries. Within the case study work in the BETTER project a literature survey has been conducted, complemented by gathering of statistical information on land use, etc. Finally, a GIS-based assessment of wind and solar potentials was undertaken to derive an up-to-date data set following a harmonised approach for these important renewable energy technologies.

Within the Green-X model, supply potentials of all main technologies for RES-E, RES-H and RES-T are described in detail.

- RES-E technologies include biogas, biomass, biowaste, onshore wind, offshore wind, small-scale hydropower, large-scale hydropower, solar thermal electricity, photovoltaics, tidal & wave energy, and geothermal electricity
- RES-H technologies include heat from biomass – subdivided into log wood, wood chips, pellets, and district heating -, geothermal heat and solar heat
- RES-T options include first generation biofuels such as biodiesel and bioethanol, second generation biofuels as well as the impact of biofuel imports

The potential supply of energy from each technology is described for each country analysed by means of dynamic cost-resource curves. Dynamic cost curves are characterised by the fact that the costs as well as the potential for electricity generation / demand reduction can change each year. The magnitude of these changes is given endogenously in the model, i.e. the difference in the values compared to the previous year depends on the outcome of this year and the (policy) framework conditions set for the simulation year.

Moreover, the availability of biomass is crucial as the contribution to energy supply is significant today and its future potentials is faced with high expectations as well as concerns related to sustainability. At EU 28 level the total domestic availability of solid and gaseous biomass (incl. energy crops e.g. for transport purposes) was assessed at 349 Mtoe/a by 2030, increasing to 398 Mtoe/a by 2050 – mainly because of higher yields assumed for the production of energy crops. Biomass data has been cross-checked throughout various detailed topical assessments with DG ENER, EEA and the GEMIS database. As biomass may play a role in all sectors, also the allocation of biomass resources is a key issue. Within the Green-X model, the allocation of biomass feedstock to feasible technologies and sectors is fully internalised into the overall calculation procedure. For each feedstock category, technology options (and their corresponding demands) are ranked based on the feasible revenue streams as applicable for a possible investor under the conditioned scenario-specific energy policy framework, which obviously may change year by year. In other words, the supporting framework may have a significant

### 2.3.2 Future potentials for RES

This section is dedicated to illustrate the outcomes of the assessment of future potentials of renewable energy sources within the EU28 and analysed neighbouring countries / regions (i.e. Turkey, Western Balkans, North Africa). We start with a discussion of the general background and subsequently present the status quo of consolidated data on potentials and cost for RES in Europe and its neighbours as applicable in the Green-X database. These figures indicate what appears to be realisable within the 2050 timeframe.

***Classification of potential categories***

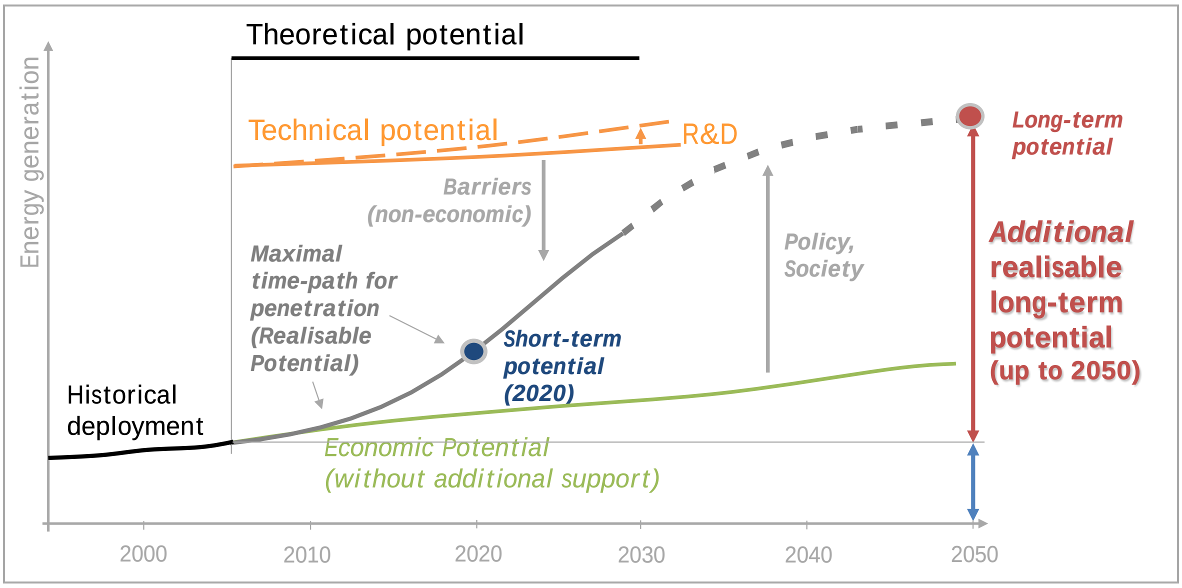



**Figure 19: Definition of potential terms**

The possible use of RES depends in particular on the available resources and the associated costs. In this context, the term "available resources" or RES potential has to be clarified. In literature, potentials of various energy resources or technologies are intensively discussed. However, often no common terminology is applied. Below, we present definitions of the various types of potentials as used throughout this report:

- *Theoretical potential:* To derive the theoretical potential, general physical parameters have to be taken into account (e.g. based on the determination of the energy flow resulting from a certain energy resource within the investigated region). It represents the upper limit of what could be produced from a certain energy resource from a theoretical point-of-view, based on current scientific knowledge;
- *Technical potential:* If technical boundary conditions (i.e. efficiencies of conversion technologies, overall technical limitations as e.g. the available land area to install wind turbines as well as the availability of raw materials) are considered, the technical potential can be derived. For most resources, the technical potential must be considered in a dynamic context. For example with increased R&D expenditures and learning-by-doing during deployment, conversion technologies might be improved and, hence, the technical potential would increase;
- *Realisable potential:* The realisable potential represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. Thereby, general parameters as e.g. market growth rates, planning constraints are taken into account. It is important to mention that this potential term must be seen in a dynamic context – i.e. the realisable potential has to refer to a certain year;

- *Realisable potential up to 2020:* provides an illustration of the previously assessed realisable (short-term) potential for the year 2020;
- *Realisable potential up to 2050:* provides an illustration of the derived realisable (long-term) potential for the year 2050.

Figure 19 (above) shows the general concept of the realisable potential up to 2020 as well as in the long-term (2050), the technical and the theoretical potential in a graphical way.

## ***Realisable long-term (2050) potentials for RES – extract from the Green-X database***

The subsequent graphs and tables aim to illustrate to what extent RES may contribute to meet the energy demand within the European Union (EU 28) and in assessed neighbouring countries up to the year 2050 by considering the specific resource conditions and current technical conversion possibilities[20] as well as realisation constraints in the investigated countries. Please note that North African countries are only represented in the discussion of RES potentials for electricity generation since our assessment of RES cooperation has been limited to that sector, and, consequently, data on potentials or demand for heating & cooling or transport has not been collected bottom-up wise for North Africa.

As explained before, *realisable long-term potentials* are derived, describing the feasible RES contribution up to 2050 from a domestic point of view. Thus, only the domestic resource base is taken into consideration, excluding for example feasible and also likely imports of solid biomass[21] or of biofuels to the European Union from abroad. Subsequently, an overview is given on the overall long-term potentials in terms of final energy by country, followed by a detailed depiction done for the electricity sector.

### RES potentials in terms of (gross) final energy[22]

Summing up all RES options applicable at country level, Figure 20 depicts the achieved (as of 2005) and additional long-term (2050) potential for RES in all EU Member States. Note that potentials are expressed in absolute terms. Consequently, large countries (or more precisely those countries possessing large RES potentials) are getting apparent. For example, France, Germany, Italy, Poland, Spain, Sweden and the UK offer comparatively large potentials. To illustrate the situation in a suitable manner for small countries (or countries with a lack of RES options available), Figure 21 shows a similar depiction in relative terms, expressing the realisable long-term (2050) potential as share on current (2005) gross final energy demand. The corresponding illustration for assessed neighbouring countries (i.e. Western Balkans and Turkey) is provided by Figure 22, expressing the achieved and the (additional) long-term (2050) potential for all assessed renewables in the various energy sectors both in absolute (left-hand side) and in relative (right-hand side) terms.

The overall long-term potential for RES in the European Union amounts to 890 Mtoe, corresponding to a share of 71.8% compared to the overall current (2005) gross final energy demand. In general, large differences between the individual countries with regard to the achieved and the feasible future potentials for RES are observable. For example, Sweden, Latvia, Finland and Austria represent countries with a high RES share already at present (2005), whilst Estonia, Lithuania and Ireland offer the highest additional potential compared to their current energy demand. However, in absolute terms both are relatively small compared to other large countries (or

[20] The illustrated potentials describe the feasible amount of e.g. electricity generation from combusting biomass feedstock considering current conversion technologies. Future improvements of the conversion efficiencies (as typically considered in model-based prospective analyses) would lead to an increase of the overall long-term potentials.

[21] In comparison to this overview on RES potentials, as default, and also in the subsequent model-based assessment, the Green-X database considers imports of forestry biomass to the EU. Approximately 31% of the overall forestry potential or 12% of the total solid and gaseous biomass resources that may be tapped in the considered time horizon up to 2050 refer to such imports from abroad, assuming increasing potentials for imports in the period beyond 2030.

[22] (Gross) Final energy is hereby expressed in line with the definition as given in the Renewable Energy Directive (Directive 2009/28/EC) as adopted by the European Parliament and Council on 23 April 2009.

more precisely to countries with significant realisable future potentials) like France, United Kingdom, Germany, Italy, Spain or Poland.

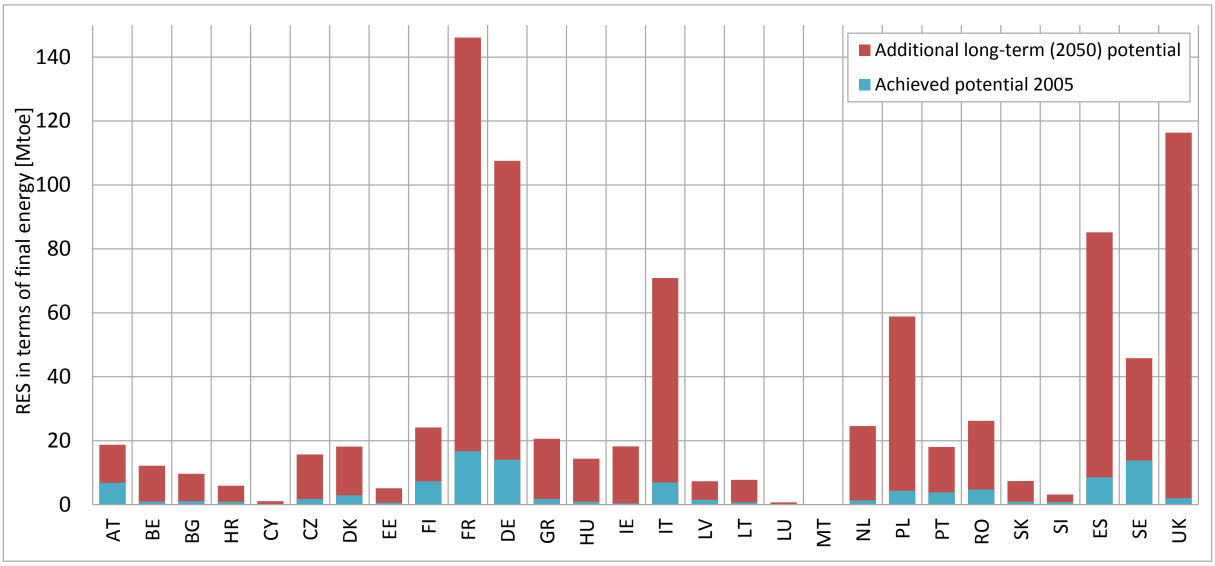



**Figure 20: Achieved (2005) and additional long-term (2050) potential for RES in terms of final energy for all EU Member States (EU 28) – expressed in absolute terms**

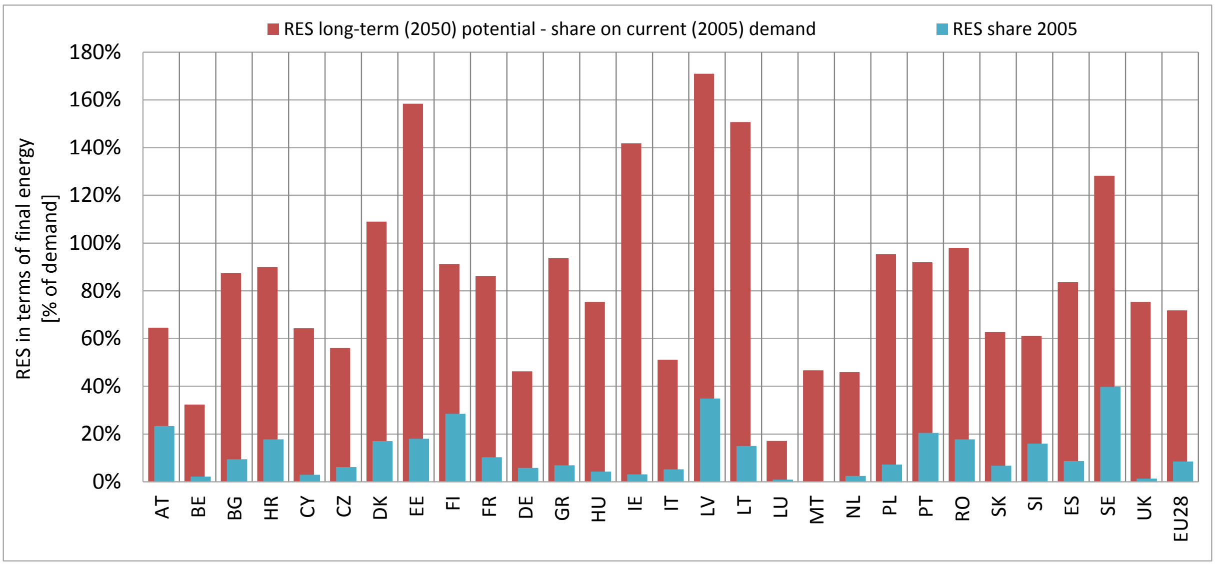



**Figure 21: Achieved (2005) and total long-term (2050) potential for RES in terms of final energy for all EU Member States (EU 28) – expressed in relative terms, as share on (gross) final energy demand**

Among the researched neighbouring countries Turkey takes an exceptional role: Not surprisingly, compared to all Western Balkan countries it offers significantly larger RES potentials if accounted in absolute terms (i.e. TWh or Mtoe). The overall long-term (2050) realisable RES potential of Turkey in size of 126 Mtoe is in the same order as RES potentials applicable in France, UK or Germany. Among the Western Balkan countries Serbia and Bosnia & Herzegovina offer the largest RES potentials in absolute terms whereas countries like Montenegro and Kosovo have to be ranked at the lower end. If country-specific long-term RES potentials are compared in relative terms, i.e. as share of current (2005) gross final energy demand, a different order occurs: Kosovo (222%) would rank first, followed by Albania (186%), Montenegro (165%) and Turkey (141%). Remarkably, with the exception of Serbia (98%), all assessed neighbouring countries possess a RES potential larger than their current (2005) level of energy consumption.

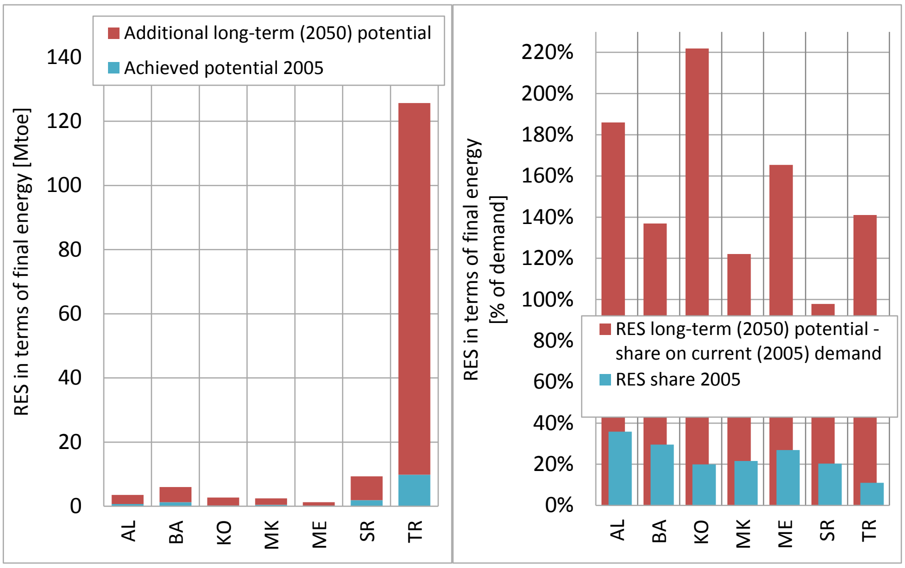



**Figure 22: Achieved (2005) and additional / total long-term (2050) potential for RES in terms of final energy for Western Balkan countries and Turkey – expressed in absolute (left) and relative terms (right), as share on (gross) final energy demand**

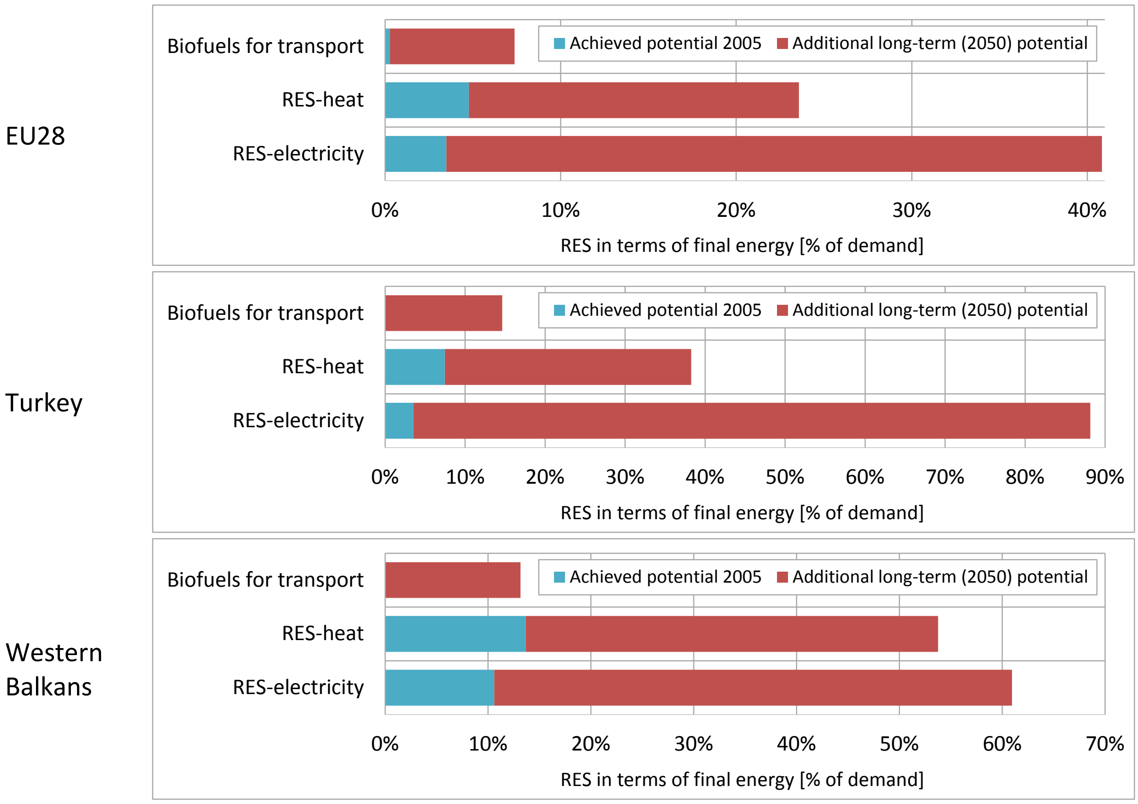



**Figure 23: Sector-specific breakdown of the achieved (2005) and additional long-term (2050) potential for RES in terms of final energy at EU 28 level (up), for Turkey (middle) and at Western Balkans level (bottom) – expressed in relative terms, as share on current (2005) (gross) final energy demand**

Finally, a sector-specific breakdown of the realisable RES potentials is given in Figure 23 for the EU28 (upper graph), Turkey (middle) and the Western Balkans (bottom). The largest contributor to meet future RES targets represents the electricity sector among all analysed countries. The overall long-term potential for RES-electricity in comparison to overall current (2005) gross final energy demand ranges however from 40.8% (EU28) to 88% (Turkey). Next to renewable electricity follows RES in heating and cooling in all assessed regions. Renewables in heating & cooling may achieve (in case of a full exploitation) a share of 23.6% in total final energy demand at EU28 level whereas in the Western Balkans their contribution may get twice as high (51% compared to total gross final energy demand). The smallest contribution can be expected from biofuels in the transport sector, which offer (considering solely domestic resources) potentials, again expressed as share in total gross final energy demand, in the range of 7.4% (EU28) to 15% (Turkey).

Long-term (2050) realisable potentials for RES in the electricity sector

Next, we take a closer look on the long-term prospects for RES at sector level, illustrating identified RES potentials in the 2050 time frame in further detail for the electricity sector. In the power sector, RES-E options such as hydropower, solar or wind energy represent energy sources characterised by a natural volatility. Therefore, in order to provide an accurate depiction of the future development of RES-E, historical data on electricity generation is translated into electricity generation potentials[23] – the *achieved potential* at the end of 2005 – taking into account the recent development of this rapidly growing market. The historical record was derived in a comprehensive data-collection – based on (Eurostat, 2007; IEA, 2007) and statistical information gained on national level. In addition, *future* potentials – i.e. the *additional realisable long-term potentials* up to 2050 – were assessed[24] taking into account the country-specific situation as well as overall realisation constraints.

Below we provide a cross-country and technology comparison at EU28 level, before discussing the potentials for renewable electricity in assessed neighbouring countries / regions (i.e. Turkey, Western Balkans, North Africa).

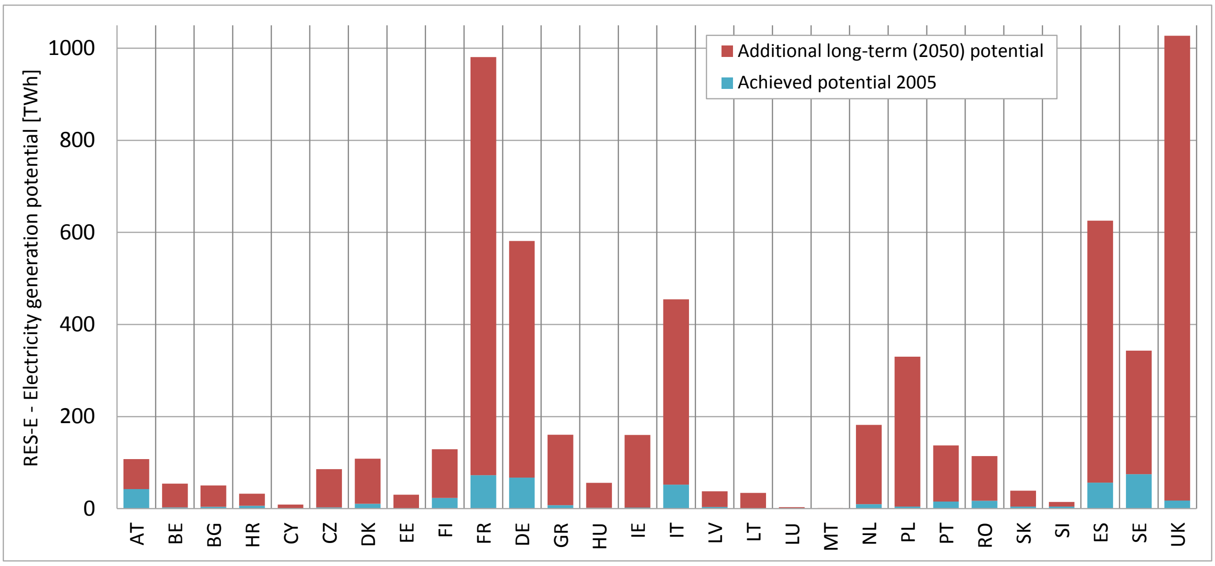



**Figure 24: Achieved (2005) and additional long-term potential 2050 for electricity from RES in the EU 28 at country level.**

Figure 24 depicts the achieved and additional mid-term potential for RES-E in the EU 28 at country level. For the 28 Member States, the already achieved potential for RES-E equals 504 TWh, whereas the additional realisable potential up to 2050 amounts to 5,385 TWh (about 163% of 2005's gross electricity consumption). Obviously, large countries such as France, Germany, Spain or UK possess the largest RES-E potentials in absolute terms, where still a huge part is waiting to be exploited. Among the new Member States Poland and Romania offer the largest RES-E potentials in absolute terms.

[23] The electricity generation potential with respect to existing plant represents the output potential of all plants installed up to the end of 2005. Of course, figures for actual generation and generation potentials differ in most cases – due to the fact that in contrast to the actual data, potential figures represent, e.g. in case of hydropower, the normal hydrological conditions, and furthermore, not all plants are installed at the beginning of each year.

[24] A comprehensive description of the potential assessment is given e.g. in (Resch et al., 2006) from a methodological point of view.

Consequently, Figure 25 relates derived potentials to gross electricity demand. More precisely, it depicts the total realisable long-term potentials (up to 2050), as well as the achieved potential (2005) for RES-E as share of gross electricity demand in 2005 for all Member States and the EU 28 in total. As applicable from this depiction, significant additional RES potentials are becoming apparent for several countries. In this context especially notable are Portugal, Denmark and Ireland, as well as most of the new Member States. If the indicated realisable long-term potential for RES-E, covering all RES-E options, would be fully exploited up to 2050, almost twice of all our electricity needs as of today (178% compared to 2005's gross electricity demand) could be *in principle*[25] covered. For comparison, by 2005 already installed RES-E plants possess the generation potential to meet about 15% of demand.

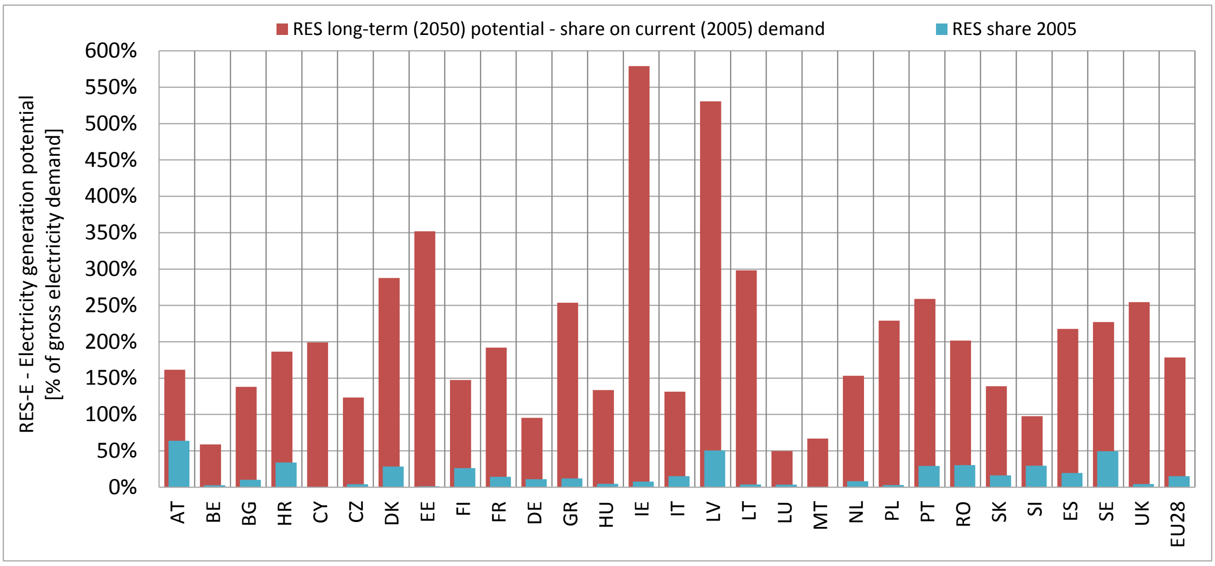



**Figure 25: Achieved (2005) and total long-term (2050) potential for electricity from RES in the EU 28 at country level, expressed in relative terms as share of gross electricity demand (2005)**

A closer look at the technology-level is provided by Figure 26. This graph offers a technology breakdown of the achieved (2005) and the additional realisable long-term (2050) potential for the EU28 as an aggregate. The figure depicts a high penetration and a small additional realisable potential for hydropower, both small- and large-scale. In general terms, wind onshore and solid biomass technologies are both already well developed, but still an enormous additional potential is apparent. Moreover, technologies like wind offshore, tidal stream and wave power as well as photovoltaics provide a large additional potential, waiting to be exploited in forthcoming years. A comparison of the additional long-term potential across technologies in terms of size leads to the following ranking: Wind onshore with an additional realisable potential of 2,054 TWh ranks first, followed by offshore wind (1,284 TWh) and photovoltaics (976 TWh). All other RES-E options (e.g. solar thermal electricity, biomass or biogas) offer a valuable but in magnitude significantly lower additional potential at EU28 level.

[25] In practice, there are important limitations that have to be considered: not all of the electricity produced may actually be consumed since supply and demand patterns may not match well throughout a day or year. In particular this statement is getting more and more relevant for variable RES like solar or wind where curtailment of produced electricity increases significantly with increasing deployment. This indicates the need for complementary action in addition to the built up of RES capacities, including grid extension or the built up of storage facilities.

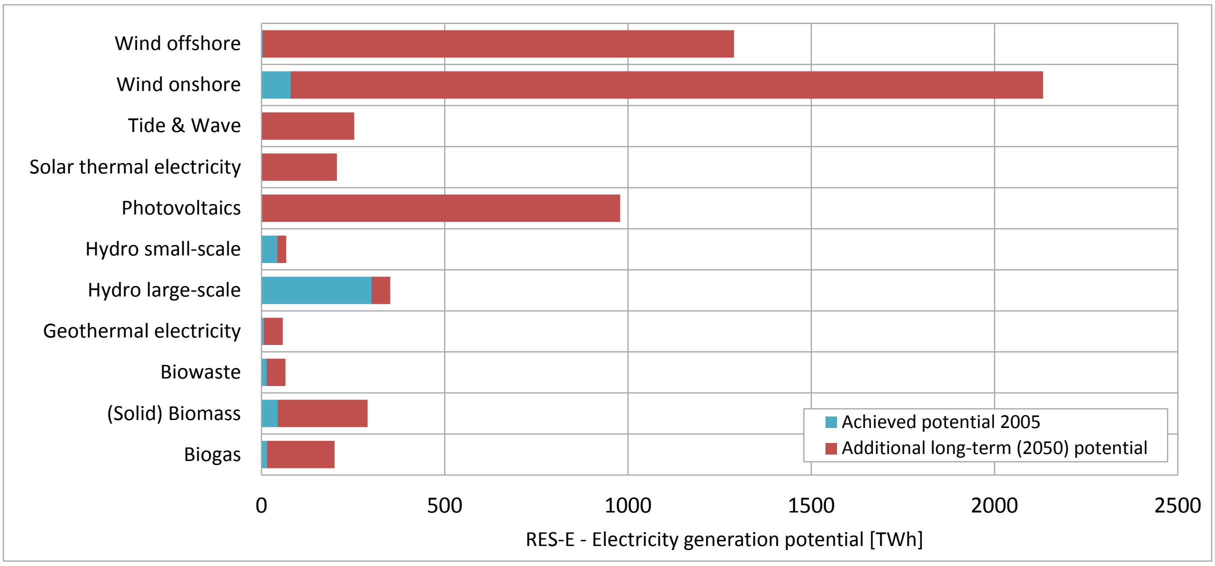



**Figure 26: Achieved (2005) and additional long-term (2050) potential for electricity from RES in the EU28 at technology level**

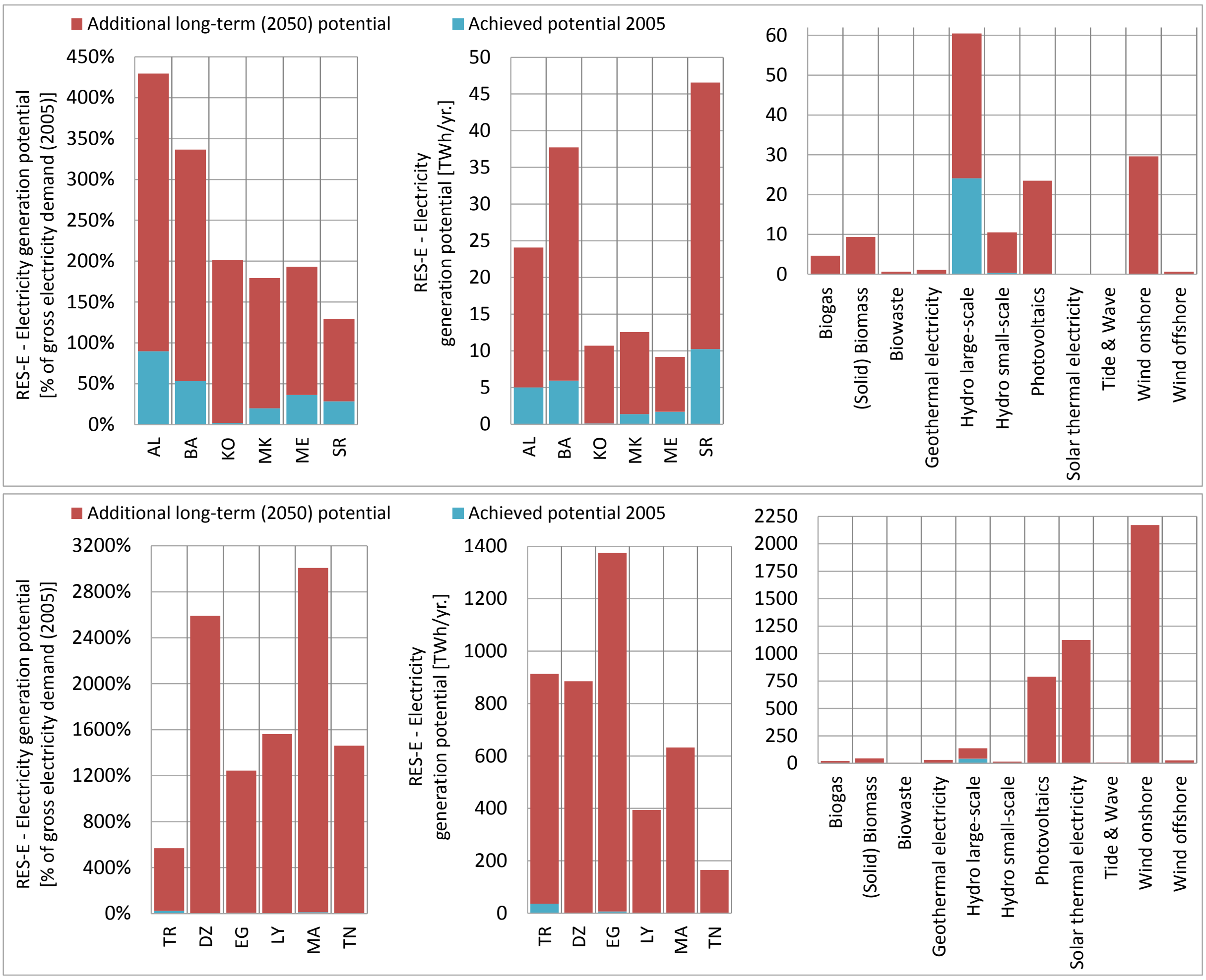
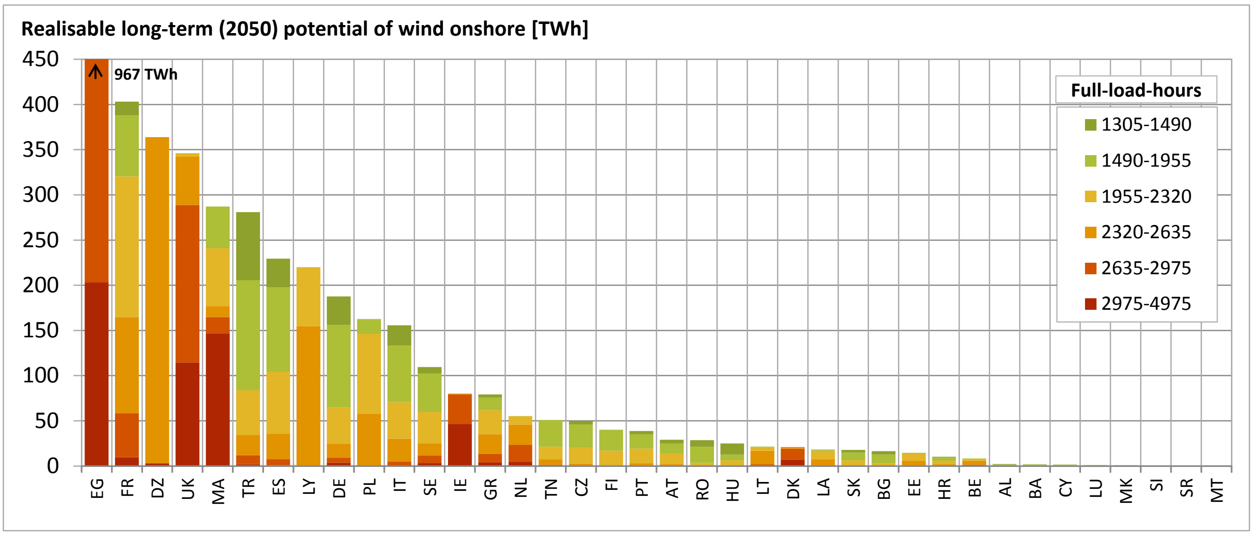



**Figure 27: Achieved (2005) and additional long-term (2050) potential for electricity from RES in the Western Balkans (up) and in Turkey & North Africa (bottom) at country (left, middle) and at technology (right) level**

In accordance with above Figure 27 offers the corresponding depictions for all assessed neighbouring countries. More precisely, Figure 27 includes both a country and technology breakdown of the achieved (2005) as well as of the additional long-term (2050) potential for electricity from RES for the Western Balkans (i.e. upper graphs) and for Turkey and North Africa (i.e. graphs at the bottom)[26]. Country-wise largest future potentials are applicable in North African countries and Turkey. Contrarily, future potentials in Western Balkan countries are roughly by a factor of 20 smaller compared to the average across North African countries. At technology level also significant differences between the Western Balkans and North Africa (combined with Turkey) are observable. In North Africa and Turkey, wind onshore and solar technologies (PV and solar thermal electricity) are of dominance, offering vast future potentials, whereas in Western Balkan countries hydropower ranks first, followed by wind onshore and photovoltaics.

A cross-country comparison of future potentials for selected key RES-E technologies

The following graphs take a closer look at key technologies with respect to future RES cooperation, showing realisable long-term (2050) potentials of wind power, solar photovoltaics, concentrated solar (thermal) power (CSP)[27] and hydro power for the EU28, North Africa, Turkey and the Western Balkan region. The resource quality is represented through categories of full-load-hours[28]. From Figure 28 can be seen that France, UK and Spain command over the highest wind onshore potentials within Europe, whereas UK stands out due to its excellent wind locations. Turkey ranks in between UK and Spain, offering comparable resource qualities to the latter. Due to their small size the Contracting Parties of the Western Balkans disappear in direct comparison with larger countries. In contrast to the Western Balkans, North African countries generally offer vast future potentials of wind onshore. In this case one needs to sum up the total available potential of the EU28 in order to get an idea of the relative proportions of the available potentials in this region. The available potential with excellent wind conditions in Egypt are in the size of all available locations of same quality within the EU28. Morocco follows next in the list of top-wind countries, possessing excellent sites (comparable in magnitude to those in UK) but also Algeria and Libya command over a considerable amount of good wind locations. Due to its size Tunisia seems less important, but is with 51 TWh in the same category with the Netherlands or the Czech Republic.




[26] For practical reasons – because of the large-size of the country and the respective potentials - Turkey is added here to the North African countries, and the technology-breakdown refers accordingly to the aggregate of both regions (i.e. Turkey plus North Africa).
[27] CSP known for its distinct dispatchability is sometimes also referred to as solar thermal electricity (STE).
[28] The term “full-load-hours” is a convenient notion for measuring the resource quality of variable renewable energy technologies. It expresses the number of hours a power plant is virtually operating at rated power throughout a year, assuming for technologies like wind, hydro or solar PV or CSP normalised meteorological conditions. Multiplied with the installed capacity, full-load-hours give the (normalised) electricity production during one year.

**Figure 28: Comparison of the realisable long-term (2050) potential of wind onshore in EU28 countries with those of North Africa, Turkey and Western Balkans**

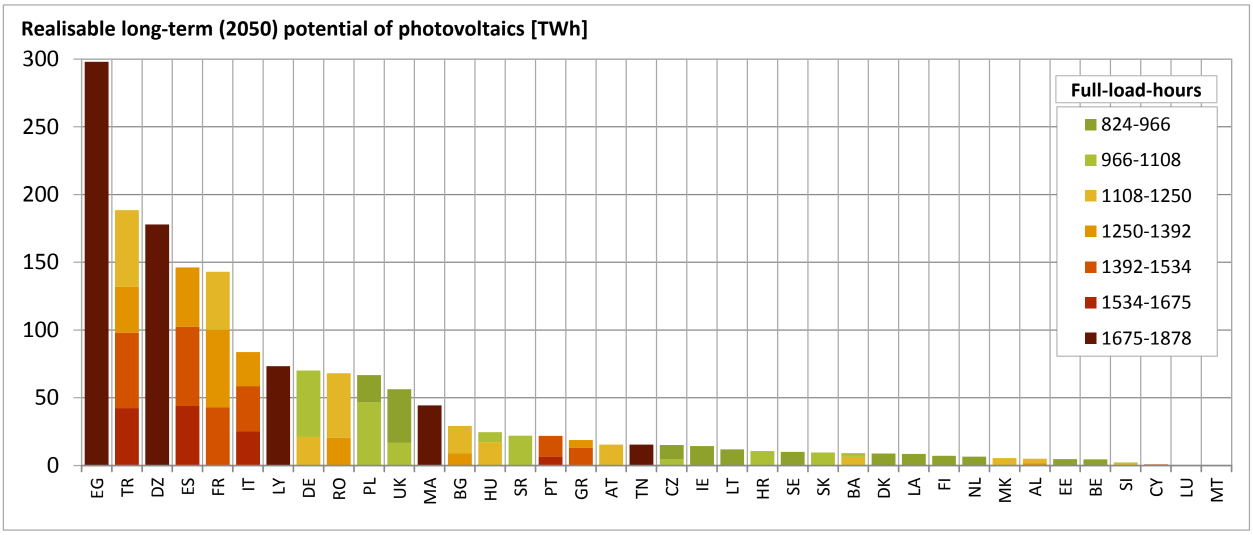



**Figure 29: Comparison of the realisable long-term (2050) potential of photovoltaics in EU28 countries with those of North Africa, Turkey and Western Balkans**

With regard to solar PV potentials, Egypt ranks first in a cross-country comparison (cf. Figure 29), followed by Turkey and Algeria. The available resources in all three top-ranking countries clearly exceed the ones in Spain, France or Italy. Generally, Figure 29 shows that all North African countries play in their own league with regard to available full-load-hours, which are all above 1675 h/a, a resource quality not available at all within the EU. The available potentials for solar PV within Libya are in the size of the potentials at best locations within Spain, Italy and Portugal together. Turkey, possessing the second largest PV potential among all assessed countries, offers compared to North Africa less perfect site conditions – but, if contrasted with the EU28, solar radiation can still be classified as superb, with comparable site conditions to the top-ranking EU country Spain. A closer look at the Western Balkan countries indicates that also most of them stick out due to their comparatively good solar conditions.

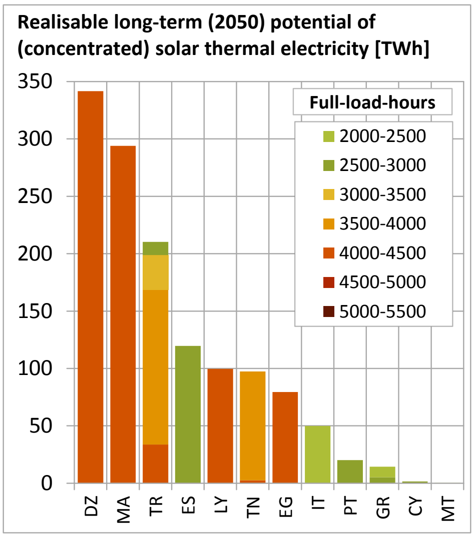



**Figure 30: Comparison of the realisable long-term (2050) potential of concentrated solar thermal power (CSP) in selected EU28 countries with those of North**

The realisable long-term (2050) potentials for concentrated solar thermal power can be seen in Figure 30. The countries with the largest potentials are Algeria, Morocco and Turkey. Similar to PV, resource conditions, expressed by the available full-load-hours, in all North African countries as well as in Turkey are in a considerable higher range compared to EU countries. Moreover, countries like Libya, Tunisia or Egypt, being last in the size ranking among North African countries, offer realisable long-term potentials of almost similar magnitude than the top-ranking EU country Spain.

Figure 31 shows the available long-term (2050) potentials of hydro power within the EU and assessed neighbouring countries. In this category both potentials from run-of-river plants and hydro storages are summed up. Not surprisingly offer countries in the mountainous parts of Europe (e.g. France, Austria or Italy with access to the Alps) or in Scandinavia (i.e. Sweden and Finland) the most promising locations for hydro power development within the EU. Top-ranking country is however Turkey, with a realisable long-

**Africa and Turkey**

term potential in size of 127 TWh by far exceeding the ones in France or Sweden. Also the Western Balkan countries offer a significant amount of suitable hydro power locations.

Hydropower in North Africa is only available to a small extent and mainly limited to countries like Egypt and Morocco[29]. Since hydro resources in North Africa appear limited and reserved for domestic use, they have been neglected in our assessment of RES cooperation with Europe.

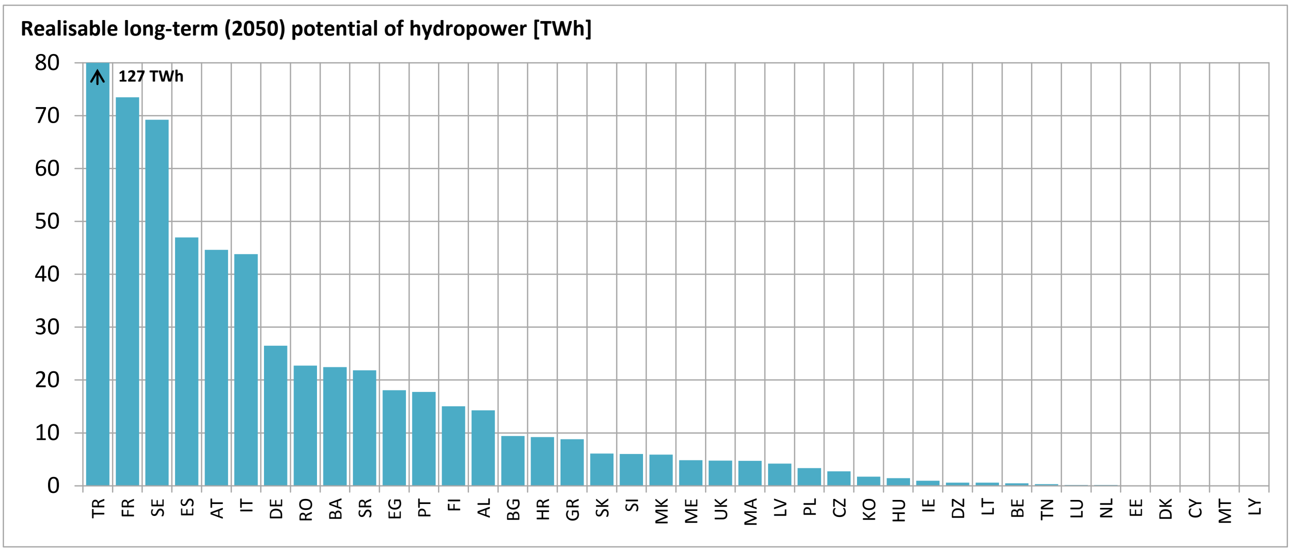



**Figure 31: Comparison of the realisable long-term (2050) potential of hydro power in EU28 countries with those of North Africa and Turkey**

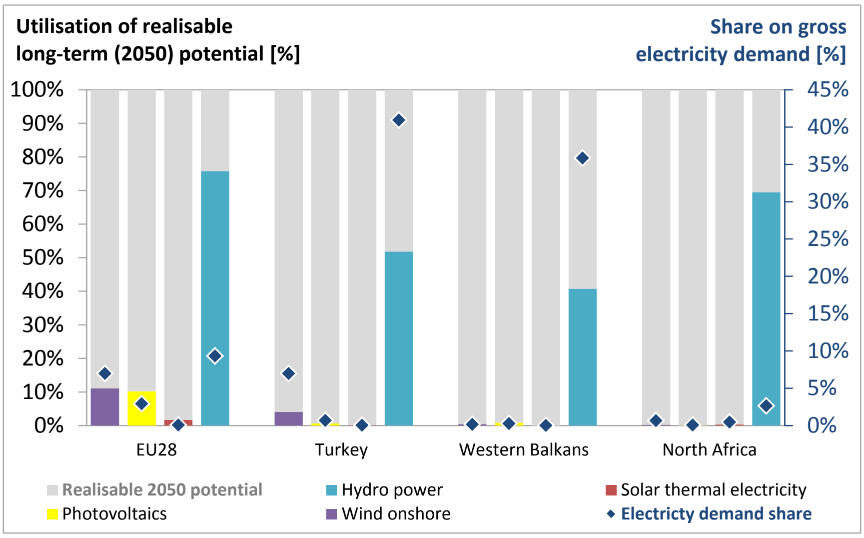



**Figure 32: Comparison of the current (2015) deployment status of selected RES-E technologies by region (EU28, Turkey, Western Balkans and North Africa), expressed as share of realisable long-term (2050) potential and as share of current (2015) gross electricity demand**

The question remains how much of these potentials have been utilized already. In Figure 4 the technology-specific deployment status (as expected by the end of 2015) at regional level (i.e. EU28, Western Balkans, Turkey

[29] The Moroccan integrated plan for hydro is 2 GW by 2020 with a correspondent share of 14% in the electricity installed capacity. However, the timeframe to achieve this objective is very short.

and North Africa) has been expressed as share of, on the one hand, the identified realisable long-term (2050) potential and, on the other hand, of gross electricity demand (as of 2015). It turns out that utilisation of the available potentials is largest for hydro power among all assessed renewable electricity options. With an utilisation rate larger than 70% the EU28 ranks here first, followed by North Africa. In Turkey about half of the total hydro potential is however still waiting to be exploited, and in Western Balkans the remaining available potential is even larger than the already exploited one. Whereas in Europe the utilised hydro potential accounts only for 10% of gross electricity demand the demand shares in the Western Balkans and Turkey are around 40%. However, as both regions, in particular Turkey, show considerable growth rates of electricity demand this share could decrease in the future again. With regard to wind and solar PV only the EU28 show utilisation shares of around 10%, whereas in the remaining regions nearly all of the available long-term potentials are still untapped. In the case of concentrated solar thermal power current utilisation is almost zero within all regions, meaning that significant amounts of high-quality solar power are waiting to be exploited in future years.

### 2.3.3 Costs of RES

***Assessment of current economic parameters and costs of RES***
***(extract from the Green-X database)***

The assessment of the economic parameters and accompanying technical specifications for the various RES technologies relies on a comprehensive literature survey and an expert consultation, cf. Box 6. All cost data represent a snapshot for the year 2010 and encompass RES within all energy sectors. The assessment provides important parameters for the BETTER modelling system (Green X and HiREPS) and is, hence, fully consistent to the Green-X model's framework and settings.

Economic conditions of the various RES technologies are based on both economic and technical specifications, varying across assessed countries.[30] In order to illustrate the economic figures for each technology Table 8 represents the economic parameters and accompanying technical specifications for RES technologies in the electricity sector, whilst Table 9 and Table 10 offer the corresponding depiction for RES technologies for heating and cooling and biofuel refineries as relevant for the transport sector. Note that all expressed data aim to reflect the current situation - more precisely, they refer to the year 2010 and are expressed in real terms (i.e. $€_{2010}$).

The Green X database and the corresponding model use a quite detailed level of specifying costs and potentials. The analysis is not based on average costs per technology. For each technology, a detailed cost-curve is specified for each year, based on so-called cost-bands. These cost-bands summarize a range of production sites that can be described by similar cost factors. For each technology a minimum of 6 to 10 cost bands are specified by country. For biomass, at least 50 cost bands are specified for each year in each country. Since the original development of the Green-X database in the year 2004, several updates and adjustments have become necessary due to cost dynamics of RES technologies. In many cases, there was a trend for an increase of investment costs in the years up to 2008, followed by a stagnation or decrease in subsequent years.

In the following the current investment cost for RES-E technologies are described alongside the data provided in Table 8, whereby a focus may be put on the description of some key technology options:

[30] Note that in the model Green X the calculation of generation costs for the various generation options is done by a rather complex mechanism, internalized within the overall set of modelling procedures. Thereby, band-specific data (e.g. investment costs, efficiencies, full load-hours, etc.) is linked to general model parameters as interest rate and depreciation time.

- The current costs of biogas plants range from 1445 €/kW$_{el}$ to 5085 €/kW$_{el}$ with landfill gas plants offering the most cost efficient option (1445 €/kW$_{el}$ – 2255 €/kW$_{el}$) and agricultural biogas plants (2890 €/kW$_{el}$ – 5085 €/kW$_{el}$) being the highest cost option within this category;
- The costs of medium- to large-scale biomass plants only changed slightly and currently lie in the range of 2540 €/kW$_{el}$ to 3550 €/kW$_{el}$. Biomass CHP plants typically show a broader range (2950 €/kW$_{el}$ – 4885 €/kW$_{el}$) as plant sizes are typically lower compared to pure power generation. Among all bioelectricity options waste incineration plants have the highest investment costs ranging from 5150 €/kW$_{el}$ to 7695 €/kW$_{el}$ whereby CHP options show about 5% higher investment cost but offer additional revenues from selling (large amounts of) heat;
- The current investment costs of geothermal power plants are in the range of 2335 €/kW$_{el}$ to 7350 €/kW$_{el}$., whereby the lower boundary refers to large-scale deep geothermal units as applicable e.g. in Italy, while the upper range comprises enhanced geothermal systems;
- Looking at the investment costs of hydropower as electricity generation option it has to be distinguished between large-scale and small-scale hydropower plants. Within these two categories, the costs depend besides the scale of the units also on site-specific conditions and additional requirements to meet e.g. national / local environmental standards etc. This leads to a comparatively broad cost range from 870 €/kW$_{el}$ to 6265 €/kW$_{el}$ for new large-scale hydropower plants. Corresponding figures for small-scale units vary from 980 €/kW$_{el}$ to 6590 €/kW$_{el}$;
- In 2010 typical PV system costs were in the range 2575 €/kW$_{el}$ to 3480 €/kW$_{el}$. These cost levels were reached after strong cost declines in the years 2008 and 2009. This reduction in investment cost marks an important departure from the trend of the years 2005 to 2007, during which costs remained flat, as rapidly expanding global PV markets and a shortage of silicon feedstock put upward pressure on both module prices and non-module costs (see e.g. Wiser et al 2009). Before this period of stagnation PV systems had experienced a continuous decline in cost since the start of commercial manufacture in the mid 1970’s following a typical learning curve. The new dynamic began to shift in 2008, as expansions on the supply-side coupled with the financial crisis led to a relaxation of the PV markets and the cost reductions achieved on the learning curve in the meantime factored in again. Furthermore, the cost decrease has been stimulated by the increasing globalization of the PV market, especially the stronger market appearance of Asian manufacturers.
- The investment costs of wind onshore power plants are currently (2010) in the range of 1350 €/kW$_{el}$ and 1685 €/kW$_{el}$ and thereby slightly lower than in the previous year. Two major trends have been characteristic for the wind turbine development for a long time: While the rated capacity of new machines has increased steadily, the corresponding investment costs per kW dropped. Increases of capacity were mainly achieved by up-scaling both tower height and rotor size. The largest wind turbines currently available have a capacity of 5 to 6 MW and come with a rotor diameter of up to 126 meters. The impact of economies of scale associated with the turbine up-scaling on turbine cost is evident: The power delivered is proportional to the diameter squared, but the costs of labour and material for building a turbine larger are constant or even fall with increasing turbine size, so that turbine capacity increases disproportionally faster than costs increase. From around 2005 on the investment costs have started to increase again. This increase of investment cost was largely driven by the tremendous rise of energy and raw material prices as observed in recent years, but also a move by manufacturers to improve their profitability, shortages in certain turbine components and improved sophistication of turbine design factored in.

**Table 8: Overview on economic-& technical-specifications for new RES-E plant (for the year 2010)**

| *RES-E sub-category* | *Plant specification* | *Investment costs* | *O&M costs* | *Efficiency (electricity)* | *Efficiency (heat)* | *Lifetime (average)* | *Typical plant size* |
|---|---|---|---|---|---|---|---|
| | | *[€/kW$_{el}$]* | *[€/ (kW$_{el}$*year)]* | *[1]* | *[1]* | *[years]* | *[MW$_{el}$]* |
| Biogas | Agricultural biogas plant | 2890 – 4860 | 137 - 175 | 0.28 - 0.34 | - | 25 | 0.1 - 0.5 |
| | Agricultural biogas plant - CHP | 3120 – 5085 | 143 – 182 | 0.27 - 0.33 | 0.55 - 0.59 | 25 | 0.1 - 0.5 |
| | Landfill gas plant | 1445 - 2080 | 51 – 82 | 0.32 - 0.36 | - | 25 | 0.75 - 8 |
| | Landfill gas plant - CHP | 1615 - 2255 | 56 - 87 | 0.31 - 0.35 | 0.5 - 0.54 | 25 | 0.75 - 8 |
| | Sewage gas plant | 2600 - 3875 | 118 – 168 | 0.28 - 0.32 | - | 25 | 0.1 - 0.6 |
| | Sewage gas plant - CHP | 2775 - 4045 | 127 – 179 | 0.26 - 0.3 | 0.54 - 0.58 | 25 | 0.1 - 0.6 |
| Biomass | Biomass plant | 2540 - 3550 | 97 – 175 | 0.26 - 0.3 | - | 30 | 1 – 25 |
| | Cofiring | 350 - 580 | 112 – 208 | 0.35 – 0.45 | - | 30 | - |
| | Biomass plant - CHP | 2600 - 4375 | 86 – 176 | 0.22 - 0.27 | 0.63 - 0.66 | 30 | 1 – 25 |
| | Cofiring – CHP | 370 - 600 | 115 – 242 | 0.20 – 0.35 | 0.5 - 0.65 | 30 | - |
| Biowaste | Waste incineration plant | 5150 – 6965 | 100 - 184 | 0.18 – 0.22 | - | 30 | 2 – 50 |
| | Waste incineration plant - CHP | 5770 - 7695 | 123 – 203 | 0.16 - 0.19 | 0.62 - 0.64 | 30 | 2 – 50 |
| Geothermal electricity | Geothermal power plant | 2335 - 7350 | 101 - 170 | 0.11 - 0.14 | - | 30 | 5 – 50 |
| Hydro large-scale | Large-scale unit | 1600 - 3460 | 33 – 36 | - | - | 50 | 250 |
| | Medium-scale unit | 2125 – 4900 | 34 – 37 | - | - | 50 | 75 |
| | Small-scale unit | 2995 – 6265 | 35 – 38 | - | - | 50 | 20 |
| | Upgrading | 870 – 3925 | 33 – 38 | - | - | 50 | - |
| Hydro small-scale | Large-scale unit | 1610 - 3540 | 36 – 39 | - | - | 50 | 9.5 |
| | Medium-scale unit | 1740 - 5475 | 37 – 40 | - | - | 50 | 2 |
| | Small-scale unit | 1890- 6590 | 38 – 41 | - | - | 50 | 0.25 |
| | Upgrading | 980 - 3700 | 36 – 41 | - | - | 50 | - |
| Photovoltaics | Small roof-top | 3000 - 3480 | 33 - 38 | | | 25 | 0.001 – 0.015 |
| | Large roof-top | 2750 - 3200 | 33 - 38 | | | 25 | 0.015 – 0.5 |
| | Building-integrated PV | 3000 - 4000 | 33 - 38 | | | 25 | 0.001 – 0.05 |
| | Large ground mounted PV plant | 2575 - 3000 | 33 - 38 | | | 25 | 0.5 – 200 |
| Solar thermal electricity | Concentrating solar power plant | 6135 -7440 | 136 - 200 | 0.33 - 0.38 | - | 30 | 2 – 50 |
| Tidal stream energy | Tidal (stream) power plant - shoreline | 6085 – 7100 | 95 – 145 | - | - | 25 | 0.5 |
| | Tidal (stream) power plant - nearshore | 6490 – 7505 | 108 – 150 | - | - | 25 | 1 |
| | Tidal (stream) power plant - offshore | 6915 - 8000 | 122 – 160 | - | - | 25 | 2 |
| Wave energy | Wave power plant - shoreline | 5340 – 5750 | 83 – 140 | - | - | 25 | 0.5 |
| | Wave power plant - nearshore | 5785 – 6050 | 90 – 145 | - | - | 25 | 1 |
| | Wave power plant - offshore | 7120 – 7450 | 138 – 155 | - | - | 25 | 2 |
| Wind onshore | Wind power plant | 1350 – 1685 | 30 – 36 | - | - | 25 | 2 |
| Wind offshore | Wind power plant - nearshore | 2850 - 2950 | 64 – 70 | - | - | 25 | 5 |
| | Wind power plant - offshore: 5…30km | 3150 – 3250 | 70 – 80 | - | - | 25 | 5 |
| | Wind power plant - offshore: 30…50km | 3490 - 3590 | 75 – 85 | - | - | 25 | 5 |
| | Wind power plant - offshore: 50km… | 3840 - 3940 | 80 – 90 | - | - | 25 | 5 |

**Table 9: Overview on economic-& technical-specifications for new RES-H plant (grid & non-grid) (for the year 2010)**

| *RES-H sub-category* | *Plant specification* | *Investment costs* | *O&M costs* | *Efficiency (heat)[1]* | *Lifetime (average)* | *Typical plant size* |
|---|---|---|---|---|---|---|
| | | *[€/kW$_{heat}$][2]* | *[€/(kW$_{heat}$*yr)][2]* | *[1]* | *[years]* | *[MW$_{heat}$][2]* |
| ***Grid-connected heating systems*** | | | | | | |
| Biomass - district heat | Large-scale unit | 380 - 390 | 19 – 20 | 0.89 | 30 | 10 |
| | Medium-scale unit | 420 - 460 | 21 – 23 | 0.87 | 30 | 5 |
| | Small-scale unit | 500 – 580 | 24 – 27 | 0.85 | 30 | 0.5 - 1 |
| Geothermal - district heat | Large-scale unit | 820 – 840 | 50 – 52 | 0.9 | 30 | 10 |
| | Medium-scale unit | 1490 – 1520 | 55 – 56 | 0.88 | 30 | 5 |
| | Small-scale unit | 2145 – 2160 | 56 – 59 | 0.87 | 30 | 0.5 - 1 |
| ***Non-grid heating systems*** | | | | | | |
| Biomass - non-grid heat | log wood | 390 – 430 | 12 – 15 | 0.75 - 0.85* | 20 | 0.015 - 0.04 |
| | wood chips | 525 – 675 | 14 – 17 | 0.78 - 0.85* | 20 | 0.02 - 0.3 |
| | Pellets | 510 – 685 | 11 – 15 | 0.85 - 0.9* | 20 | 0.01 - 0.25 |
| Heat pumps | ground coupled | 735 – 1215 | 5.5 - 7.5 | 3 - 4[1] | 20 | 0.015 - 0.03 |
| | earth water | 800 – 1195 | 10.5 - 18 | 3.5 - 4.5[1] | 20 | 0.015 - 0.03 |
| Solar thermal heating & hot water supply | Large-scale unit | 660 – 680[2] | 9 - 10[2] | - | 20 | 100 - 200 |
| | Medium-scale unit | 760 – 780[2] | 11 - 15[2] | - | 20 | 50 |
| | Small-scale unit | 860 – 880[2] | 15 - 17[2] | - | 20 | 5 - 10 |

<u>Remarks:</u>

[1] In case of heat pumps we specify under the terminology "efficiency (heat)" the *seasonal performance factor* - i.e. the output in terms of produced heat per unit of electricity input

[2] In case of solar thermal heating & hot water supply we specify under the investment and O&M cost per unit of $m^2$ collector surface (instead of kW). Accordingly, expressed figures with regard to plant sizes are also expressed in $m^2$ (instead of MW).

**Table 10: Overview on economic-& technical-specifications for new biofuel refineries (for the year 2010)**

| *RES-T sub-category* | *Fuel input* | *Investment costs* | *O&M costs* | *Efficiency (transport)* | *Efficiency (electricity)* | *Lifetime (average)* | *Typical plant size* |
|---|---|---|---|---|---|---|---|
| | | *[€/kW$_{trans}$]* | *[€/(kW$_{trans}$*year)]* | *[1]* | *[1]* | *[years]* | *[MW$_{trans}$]* |
| Biodiesel plant (FAME) | rape and sunflower seed | 205 – 835 | 10 – 41 | 0.66 | - | 20 | 5 - 25 |
| Bio ethanol plant (EtOH) | energy crops (i.e. sorghum and corn from maize, triticale, wheat) | 605 - 2150 | 30 - 142 | 0.57 - 0.65 | - | 20 | 5 - 25 |
| Advanced bio ethanol plant (EtOH+) | energy crops (i.e. sorghum and whole plants of maize, triticale, wheat) | 1245 - 1660[1] | 57 -74[1] | 0.58 - 0.65[1] | 0.05 - 0.12[1] | 20 | 5 - 25 |
| BtL (from gasifier) | energy crops (i.e. SRC, miscanthus, red canary grass, switchgrass, giant red), selected waste streams (e.g. straw) and forestry | 825 - 6190[1] | 38 - 281[1] | 0.36 -0.43[1] | 0.02 - 0.09[1] | 20 | 50 - 750 |

<u>Remarks:</u>

[1] In case of Advanced bio ethanol and BtL cost and performance data refer to 2015 - the year of possible market entrance with regard to both novel technology options.

## *<u>Technological change - future cost and performance expectations</u>*

Considering the assumptions of technology learning and cost reductions a brief overview is given here. For most RES-E technologies the future development of investment cost is based on technological learning. As learning is taking place on the international level the deployment of a technology on the global market must be considered. For the model runs global deployment consists of the following components:

- Deployment within the EU28 Member States and assessed neighbouring regions is endogenously determined, i.e. is derived within the model.

- Expected developments in the "rest of the world" are based on forecasts as presented in the IEA World Energy Outlook 2013 (IEA, 2013).

**Table 11: Assumed learning rates in case of moderate (default) learning expectations – exemplarily depicted for selected RES-E technologies**

| *Assumed learning rates for selected RES-E technologies* | *Geographical scope* | *Moderate learning* | | |
|---|---|---|---|---|
| | | *2006 - 2010* | *2011 - 2020* | *2021 - 2030* |
| Solid biomass - small-scale CHP (large-scale systems) | global learning system | cost increase* | 10.0% (5%) | 10.0% (5%) |
| Photovoltaics | global learning system | 20.0% | 20.0% | 17.5% |
| Wind energy | global learning system | cost increase* | 7.0% | 7.0% |

Note: *A cost increase (compared to 2006 levels) up to 2008 is assumed for solid biomass and wind energy (as well as for almost all other energy technologies) in line with historical observations. This increase is mainly caused by rising energy and raw material prices and in line with the assumptions on the development of energy prices (where high energy prices serve as default reference).

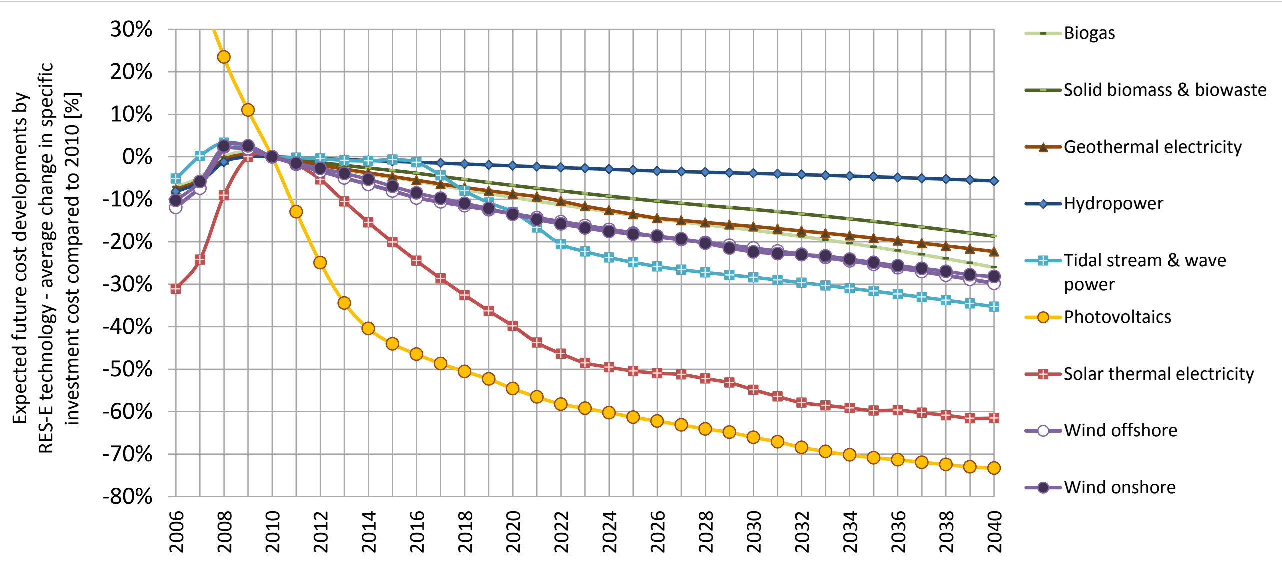



**Figure 33 Expected future cost developments by RES-E technology in the case of moderate future RES deployment (moderate RES target), expressed as change in specific investment costs compared to current (2010) levels[31]**

In the BETTER scenario runs different ambition levels are assumed concerning future RES deployment at European level and in assessed neighbouring regions, ranging from weak to strong post 2020 RES targets and related deployment (cf. section 2.2.2). These differences in technology-specific RES deployment also lead to a range in corresponding future cost reductions. The identical assumed learning rates for all assessed cases are depicted in Table 11. The consequences of the assumed RES technology diffusion and the underlying technology learning

[31] Deployment of RES-E technologies within the EU28 and assessed neighbouring regions is taken from the Green-X scenario where a moderate RES uptake is assumed in the period post 2020, leading at EU level to a RES share in gross final energy demand of about 30% by 2030. For the rest of the world the IEA's WEO 2013 projection, more precisely the New Policy Scenario, is used.

rates and efficiency improvements regarding the cost reduction of individual RES-E technologies are depicted in Figure 33 exemplarily for the median case of moderate RES targets. Remarkable is the negative development in the period 2007 to 2009 for most energy technologies, but probably mostly affecting the cost of wind turbines. This increase of investment cost was largely driven by the tremendous rise of energy and raw material prices as observed at the end of the past decade.[32] However, still substantial cost reductions are observable and expected for both selected mature (e.g. wind and photovoltaics) as well as novel technology options such as solar thermal electricity or ocean technologies.

Complementary to above, an overview on the resulting development of levelized cost of electricity (LCOE) is given for selected key technologies in Figure 34 (for solar PV and CSP) and Figure 35 (for wind on- and offshore). These graphs provide an interesting comparison between the EU28, where average cost are expressed, and assessed neighbouring countries, for which cost ranges are shown.

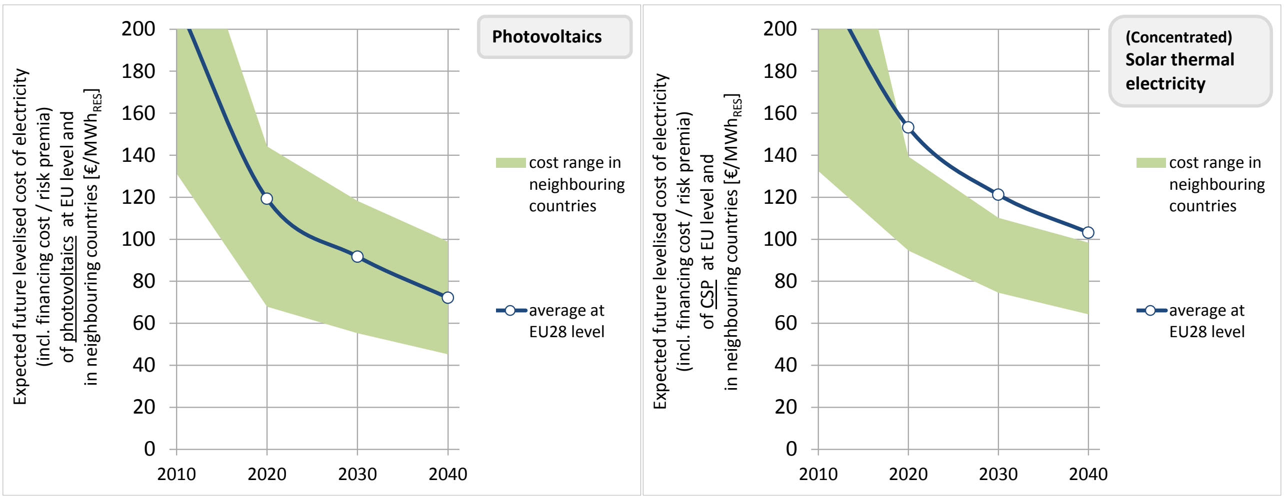



**Figure 34 Comparison of resulting levelised cost of electricity for solar technologies (PV, CSP) in the EU28 (on average) and in assessed neighbouring regions (cost range) according to a moderate future RES deployment (moderate RES target)**

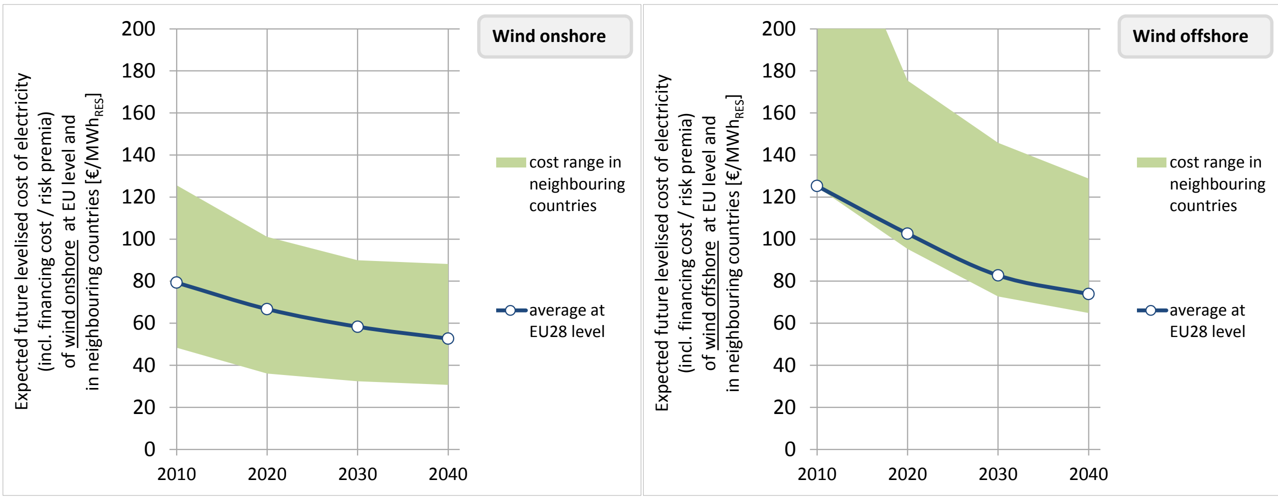



**Figure 35 Comparison of resulting levelized cost of electricity for wind technologies (onshore, offshore) in the EU28 (on average) and in assessed neighbouring regions (cost range) according to a moderate future RES deployment (moderate RES target)**

[32] For wind energy also an overheating of the global market was observable throughout that period, where supply could not meet demand. This led to a higher cost increase compared to other energy technologies.

The underlying data for Figure 34 and Figure 35 is taken from Green-X modelling of RES cooperation between the EU28 and its neighbours as discussed in the forthcoming section 3.[33] More precisely, in accordance with above, scenarios assuming a moderate ambition level concerning future RES deployment (moderate RES targets post 2020) serve as basis for these exemplary illustrations.

Besides the availability of considerable amounts of untapped RES potentials as discussed before (cf. subsection 2.3.2), the economics of the resources are decisive when it comes to the assessment of attractive cooperation opportunities. Due to the fact that most important renewable resources have low variable generation costs, the focus with regard to cost comparisons can be laid on investment costs of a RES power plant and the expected energy output, reflecting the available resource quality at a specific location. Thus, from the simplistic comparison provided by the figures above one can gain first insights on prospects for future RES cooperation in the enlarged geographical context:

- Average LCOE of a PV plant at EU28 level are within the cost corridor applicable for assessed neighbouring regions. There are however significant differences between EU neighbours: Whereas Western Balkan countries can be characterised by median to good resource conditions combined with higher country-specific risk premiums than at EU average, North African countries have a predominant cost advantage due to excellent site conditions concerning solar radiation. Turkey, offering also comparatively favourable solar conditions, lies here in between.
- For CSP, a viable option only for the Southern parts of Europe and for North Africa, a clear cost advantage to best sites at EU level is applicable for North Africa, and to a smaller extent also for Turkey: Costs at EU level lie well above the expressed cost range for Europe's Southern neighbours.
- In the case of wind onshore average cost at EU28 level are within the cost range applicable for assessed neighbouring countries. Similar to PV, preferable sites can here be found specifically in North Africa but also in Turkey whereas Western Balkan countries command over moderate wind locations.
- In contrast to above, offshore wind has a clear cost advantage at EU28 level where preferable locations can be found in particular in the Northern part of Europe.

[33] Please note that our calculations of LCOE also incorporate in the prescribed weighted average cost of capital (WACC) default assumptions concerning financing risks related to the individual technologies as well as country-specific circumstances. For details on approach and assumption we refer to subsection 2.2.4 of this report.

# 3 Results of the model-based assessment on prospects for RES cooperation between the EU and its neighbours

This chapter is dedicated to shed light on the results of the model-based assessment of future RES cooperation between the EU28 and its assessed neighbouring countries / regions (Turkey, Western Balkans and North Africa). The outcomes presented stem to a large extent from the techno-economic policy analysis conducted by use of the Green-X model whereas key results of complementary power-system analysis done by use of the HiREPS model are represented in an own subsection (section 3.4) at the end of this chapter. A broad set of scenarios have been assessed that allow for an identification of mid- (2030) to long-term (2050) prospects and impacts of enhanced future RES cooperation.

Below (section 3.1) we start with a quantitative outlook on future RES developments in the enlarged geographical context, indicating expected future RES deployment at the various levels in accordance with the scenarios assessed at the various levels. Next to that, prospects for RES cooperation are identified in section 3.2, indicating RES exchange between regions as well as the corresponding monetary transfer. Section 3.3 complements the energy-related survey through taking a closer look at the corresponding economic impacts: possible savings in terms of costs, in particular with respect to RES support, are provided, and information on costs, expenditures and benefits is presented for each assessed region.

Please note that, complementary to the modelling exercise, possible co-effects of a geographically enhanced RES cooperation are analysed within this project. The approach and outcomes of that complementary assessment are reported in chapter 4.

## 3.1 Results on future RES developments

This subsection is dedicated to shed light on expected RES developments at the various levels – i.e. at the aggregated level, looking at total RES use; in the electricity sector, specifically assessing the contribution of renewables to meet our (growing) electricity demand; at the sector level, summarising briefly complementary to the electricity sector, also RES developments in heating & cooling and in transport; and, finally, technology developments are discussed in particular for renewables in the electricity sector.

### 3.1.1 The aggregated picture – future development of total RES use (in terms of final energy)

We start with the aggregated picture, taking a closer look at the expected region-specific (i.e. EU28, Western Balkans, Turkey, North Africa) deployment of RES in total, comprising energy production that stems from renewable sources in the various energy sectors (including electricity, heating & cooling and transport). Thereby, with the exception of biofuels in transport where consumption matters, RES deployment is accounted for in the country / region of production. Thus, Figure 36 (left) depicts the scenario-specific RES share in gross final energy demand for the EU28, the Western Balkans and Turkey up to 2040, respectively. Hereby, the EU only (reference) scenarios under the different targets are depicted as well as the EU plus (default) scenarios of full RES cooperation between the EU and its neighbours (again under different targets for RES by 2030 and beyond). Furthermore, for all assessed neighbouring regions / countries the range of possible developments as modelled from the bottom-up perspective up to 2030 can be seen. Since only RES developments in the electricity sector are analysed for North Africa it is left out from this depiction.

For the EU28 Member States, the case is pretty clear that under all three ambition levels concerning future RES expansion, i.e. the assumed weak, moderate or strong targets for RES by 2030 and beyond, domestic RES deployment would be substituted to a certain extent by RES imports, when cooperation is made possible. These imports may be of virtual nature if Energy Community Contracting Parties are concerned (i.e. Western Balkans and, as assumed in the default cases, Turkey) or in the case of North African countries be physically transferred to the EU's internal market. Concretely, for a weak RES target, the EU would increase domestic RES generation to 26% by 2030 and 34.6% by 2040 in the (default) full cooperation scenario, whereas this share of RES in gross final energy demand would increase to about 27% by 2030 and 36.6% by 2040, respectively, if no cooperation with EU neighbours would take place. For moderate and strong targets, the case is similar and becomes even more visible over time, showing a difference of initially less than one percentage point between the EU plus (full cooperation) and the EU only (reference) scenario in 2025 up to a difference of three to four percentage points in 2040.

From the bottom-up perspective, for the Western Balkans, the maximum RES share in gross final energy demand could amount to 48% in 2030, if national support policies for RES are strengthened accordingly and prevailing non-cost barriers are mitigated over time. Assuming that national policies and barriers remain as currently implemented, on the other hand, would lead to a RES share of merely 27% of the gross final energy demand. The integrated assessment indicates possible RES developments within these boundaries for the time period up to 2030, depending on the cooperation scenario assumed. The reference (EU only) scenarios that assume no cooperation between the EU28 and the Western Balkans predict a linearly increasing RES deployment up to 2040 that ranges between roughly 54% and 61%, depending on the overall ambition level concerning RES, i.e. the RES target set for 2030 and beyond. In the EU plus (default) scenarios, where cooperation takes place between the EU and its neighbours, including the Western Balkans, this share is a bit lower for the weak target scenario in the final period, e.g. at 51.3% instead of 53.6% by 2040 while in earlier years the opposite trend is applicable – i.e. RES deployment is higher in the case of full cooperation than under reference (EU only) conditions. This implies that, following a conservative pathway for renewables, the Western Balkan countries offer attractive opportunities for RES investments in the short- to mid-term while other neighbours, in particular North African countries, offer a more viable long-term perspective. Nevertheless, comparing the moderate or strong target scenarios, even though full cooperation is assumed to take place, a higher RES deployment can be achieved continuously compared to the EU only (reference) cases of no cooperation. Under a strong future RES target this difference increases in early years and, later on, remains constant at a level of about 2.3 percentage points.

For Turkey, from the bottom-up perspective in 2030, for the RES share in gross final energy demand by 2030 a large bandwidth of merely 9.5% (in a business as usual scenario) and up to 26.4% (assuming strengthened national RES policies and mitigated non-cost barriers) is identified. The integrated assessment provides results that are in this range. Solely the strong target cooperation case exceeds the previous projections and exhibits an even higher share (concretely 27.7% in 2030).[34] Assuming a strong target in the EU only (reference) case without cooperation, leads to a consistently lower RES share in comparison to the cooperation case, that lies roughly two to three percentage points below the ones for the EU plus (default) scenario. A moderate target also leads to a higher share in the cooperation scenario whereas a weak target exhibits lower RES shares for Turkey in gross final energy demand in the cooperation case when compared to the EU only (reference) scenario (cooperation only among EU28 Member States).

[34] Under these circumstances in the long-term Turkey massively imports biofuels for transport purposes as well as solid biomass feedstock for power generation and for heat supply from the EU and the Western Balkans, respectively. These import possibilities were neglected in the previous assessment undertaken from a bottom-up (i.e. Turkish) perspective.

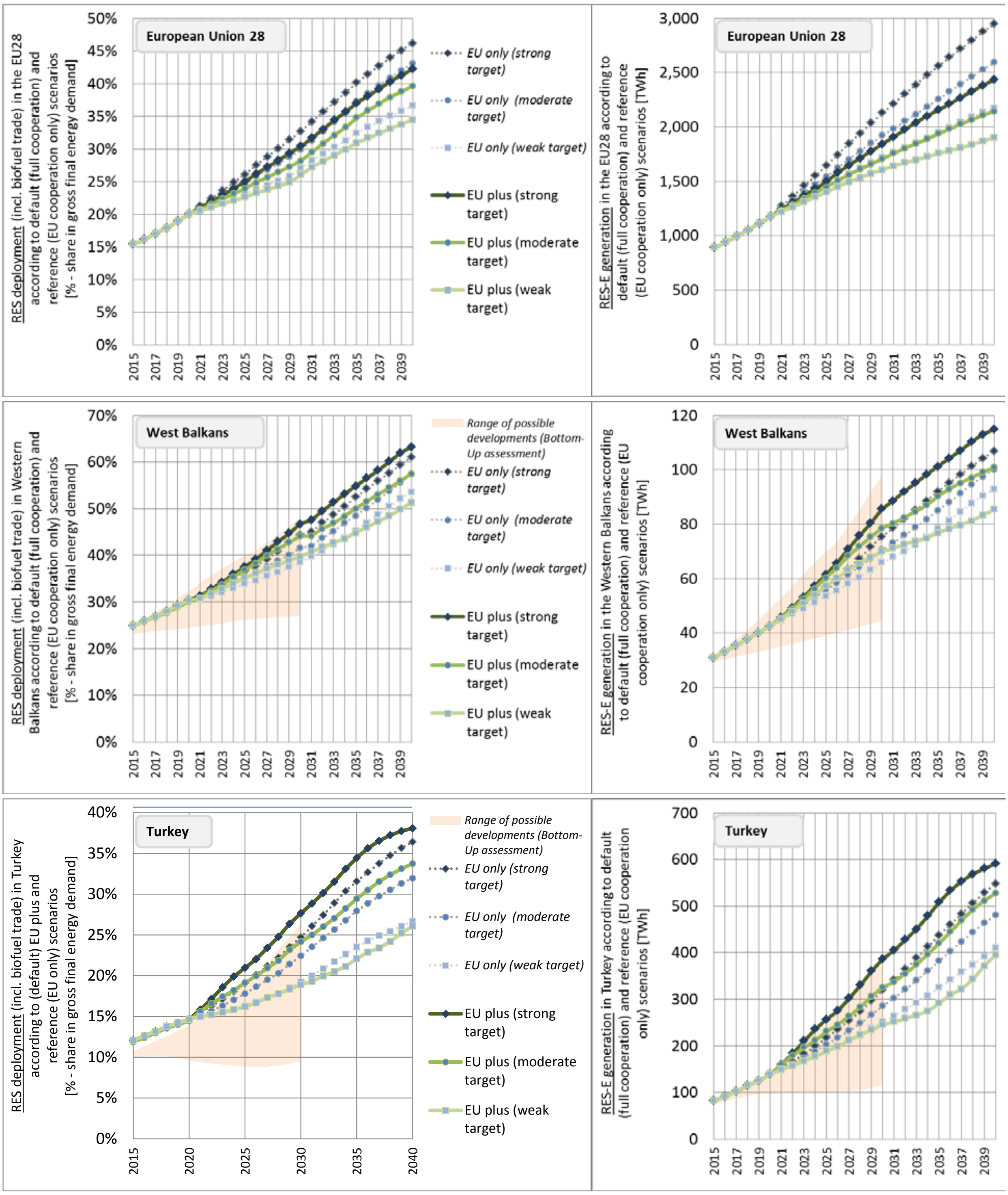



**Figure 36: RES share in gross final energy demand (left) and RES-E generation (right) by region (EU28 (top), Western Balkans (middle), Turkey (bottom)) according to EU plus (full cooperation) and EU only (reference) scenarios**

Note: For RES in the electricity sector and in heating and cooling deployment is accounted where electricity and heat generation takes place while for biofuels in transport consumption is relevant.

### 3.1.2 Focus on the electricity sector – electricity generation from renewables

Looking specifically into the electricity sector, Figure 36 (right) shows absolute values of TWh electricity generated from renewable sources for the same scenarios as depicted above.

In the European Union (EU28), unsurprisingly, generation of RES electricity is higher in the EU only (reference) case, i.e. when cross-border RES cooperation is limited to EU Member States. Assuming a strong target and no cooperation with Third countries, renewables in the EU28 would generate a maximum of almost 2,950 TWh in 2040. A weak RES target would induce generation of about 2,180 TWh in 2040, following a linear increase from roughly 1,450 TWh in 2025. Compared to the EU only case, full RES cooperation with the EU's neighbours would lead to a decline of renewable electricity generation within the EU28, ranging from 12.4% (weak target) to roughly 17.4% (moderate and strong target).

In the Western Balkans, the estimated future RES-E generation according to the assessed scenarios within the integrated assessment also lies in the corridor opened up via the bottom-up analysis, i.e. between 45 and 98 TWh in 2030. Looking at integrated assessment results, the maximum value to be reached through strong cooperation amounts to 86 TWh in 2030. In the following decade, comparing RES-E deployment in the EU plus (default) full cooperation and the non-cooperation (EU only) case is largely dependent on the respective targets assumed. For a weak RES-target, the reference case (without cooperation) lies above the EU plus case. As discussed above for overall RES deployment, this implies that under weak future RES targets the Western Balkan countries offer attractive opportunities for RES investments only in the short- to mid-term, whereas other neighbours, in particular North African countries, offer a more viable long-term perspective. In the moderate and strong RES-target case nevertheless, for the time between 2030 and 2040, RES-E generation is higher in the cooperation scenario. In the case of strong cooperation, RES-E generation nearly doubles between 2020 and 2040, amounting to almost 115 TWh.

Turkey exhibits a corridor between 118 and 389 TWh from the bottom-up perspective for 2030. The integrated assessment estimates values for the period up to 2030 that all lie within this range, the maximum with underlying strong cooperation being 387 TWh in 2030 for the EU plus (default) case and a strong RES target – very similar to the bottom up perspective. The paths for the following decade up to 2040 follow a pattern comparable to that of the Western Balkans: RES-E generation is continuously higher in the full cooperation case when strong and moderate targets are assumed, compared to the EU only (reference) case, where no cooperation takes place. In absolute terms, this shows for instance that assuming a strong target for RES deployment leads to an average of a 50 TWh difference between the two paths over the decade between 2030 and 2040. In 2040 for instance, the value amounts to 548 TWh in the EU only case in comparison to 591 TWh when full cooperation occurs. In the case of a weak target, more RES-E generation would take place for the EU only scenario, where only EU28 Member States cooperate amongst themselves as compared to the cooperation scenario. Expressed in numerical terms, e.g. in 2040 this means 411 TWh in the EU only (reference) scenario as compared to 395 TWh in the EU plus (default) case.

For North Africa, the values determined by the integrated assessment have been compared with the results of two studies on RES potential by Dii (Dii, 2013) and DLR (DLR, 2009) respectively, cf. Figure 37. These results were used to span the bottom-up bandwidth of potential RES-E generation. As explained above, the comparison is solely executed for the RES electricity sector. Whereas for 2020, the results of the integrated assessment exhibit substantially smaller amounts of RES-E generation compared to the studies by Dii and DLR (roughly 33 TWh in comparison to 86.7 and 89.5 TWh, respectively), the medium term perspective is quite similar. For 2030, the integrated assessment indicates feasible volumes of RES-E generation of up to 340 TWh in 2030 and up to 831 TWh in 2040 for the EU plus (default) case with cooperation considering a strong RES target. Assuming a moderate target for RES-E deployment leads to a scenario that is slightly lower but follows the same path as the deployment with the most ambitious target. The weak target scenario again lies below this path. A striking difference compared to the other countries that have been assessed (namely the Western Balkans and Turkey) can be seen in the EU only (reference) scenarios. If no cooperation occurs with EU28 member countries, all EU only scenarios turn out to induce roughly the same generation of RES-E, independent of the target assumed. In actual numbers, this means that in 2030, the weak and moderate target lead to a generation of 185 TWh and 186 TWh respectively if the target is strong and non-economic barriers are mitigated. For 2040, the values amount to 522 TWh with a strong and 521 TWh with a weak or moderate target. However, this is not surprising since all EU only scenarios reflect domestic demand driven by national RES-E support within the assessed region – and this policy does not change, meaning it is independent from the targets chosen at EU level.

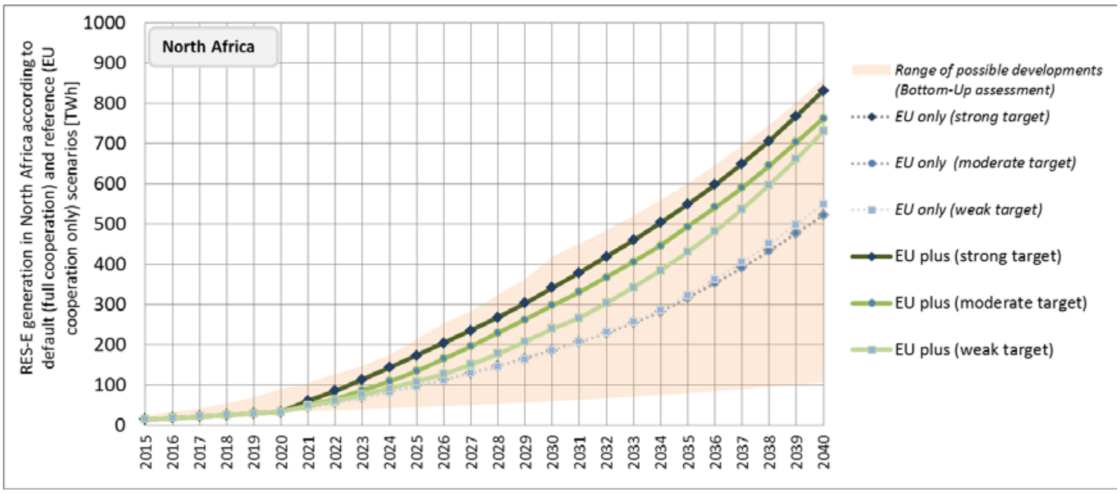



**Figure 37: RES-E generation in North Africa according to EU plus (full cooperation) and EU only (reference) scenarios**

Note: Deployment is accounted where electricity generation takes place.

To sum up the findings, one can say that the results from the different assessments show how cooperation with EU28 Member States can incentivise RES deployment and in that respect RES-E generation in the EU's neighbouring countries. How these different levels of RES deployment would be used, i.e. which share would be used domestically and how much would then be available for export is shown in the following, cf. section 3.2. Before discussing cooperation perspectives in detail, the following subsections present detailed sector- and technology-specific breakdowns of the different categories of RES deployment and respectively RES-E generation that the above levels are composed of.

### 3.1.3 Sector-specific RES developments

In the following, further insight into the RES developments in the different energy sectors, namely biofuels in transport, RES-heating and cooling and RES-electricity is given for the assessed regions (EU28, Western Balkans, Turkey and North Africa. Figure 38 gives an overview for all countries of interest in the years 2010, 2020, 2030 and 2040 for the EU only (reference) and the EU plus (default) case – assuming a strong RES target in the EU. The upper part of the figure shows how energy production from RES would develop, if the EU28 Member States were only to cooperate amongst themselves.

In 2010, the EU exhibited an overall energy production from RES of 1718 TWh. This amount could be broken down into 161 TWh of biofuels in transport, 878 TWh for RES-heating & cooling and 679 TWh in RES-electricity. In 2020 the overall amount increases to 2755 TWh – the shares of RES-electricity and biofuels in transport thereby increase more than the ones in the RES-heating and cooling sector.

Turkey, the Western Balkans and North Africa exhibit a quite small RES sector in 2010. The overall production from RES amounts to 127 TWh in Turkey, 59 TWh in the Western Balkans and merely 22 TWh in North Africa[35]. While biofuels in transport do not add to the mix in any of the countries / regions, in Turkey 52 TWh are made up by RES-electricity and the missing 75 TWh result from RES-heating & cooling. In the Western Balkans, the shares amount to 26 and 32 TWh respectively. North Africa solely has RES-electricity to add to its overall RES share. This does not change in the following decades assessed in the EU only (reference) or cooperation (EU

[35] For North Africa this includes only renwables in the electricity sector since other sectors have not been assessed within this project.

plus) case, as the region's specific characteristics favour RES-E expansion and do not provide much scope for the remaining RES sectors.

In the following decades, the RES-E sector grows the strongest in all three regions / countries. It catches up to RES-heating and cooling in the Western Balkans in 2020 – both sectors amounting to 42 TWh, and in Turkey, in 2020 it already overtakes the RES-heating and cooling sector with a generation of 140 TWh compared to 93 TWh. Biofuels in transport rise slightly in 2020 – to 7 TWh in Turkey and to 1 TWh in the Western Balkans.

In the medium and long term, the EU exhibits a strong increase in all three sectors. RES-electricity rises to 2130 TWh in 2030 and 2948 TWh in 2040, RES-heating and cooling exhibits respective levels of 1861 TWh and 2546 TWh. Biofuels in transport increase to 473 TWh in 2030 and then 914 TWh in 2040. In Northern Africa, RES-electricity increases steadily, up to 522 TWh in the long term (2040). In Turkey and the Western Balkans, both RES-electricity as well as RES-heating and cooling increase – to 548 TWh and respectively 278 TWh in Turkey in the long term and in the Western Balkans to 107 TWh and respectively 84 TWh. The share of biofuels in transport remains comparatively small with 27 TWh in Turkey and 7 TWh in the Western Balkans for 2040.

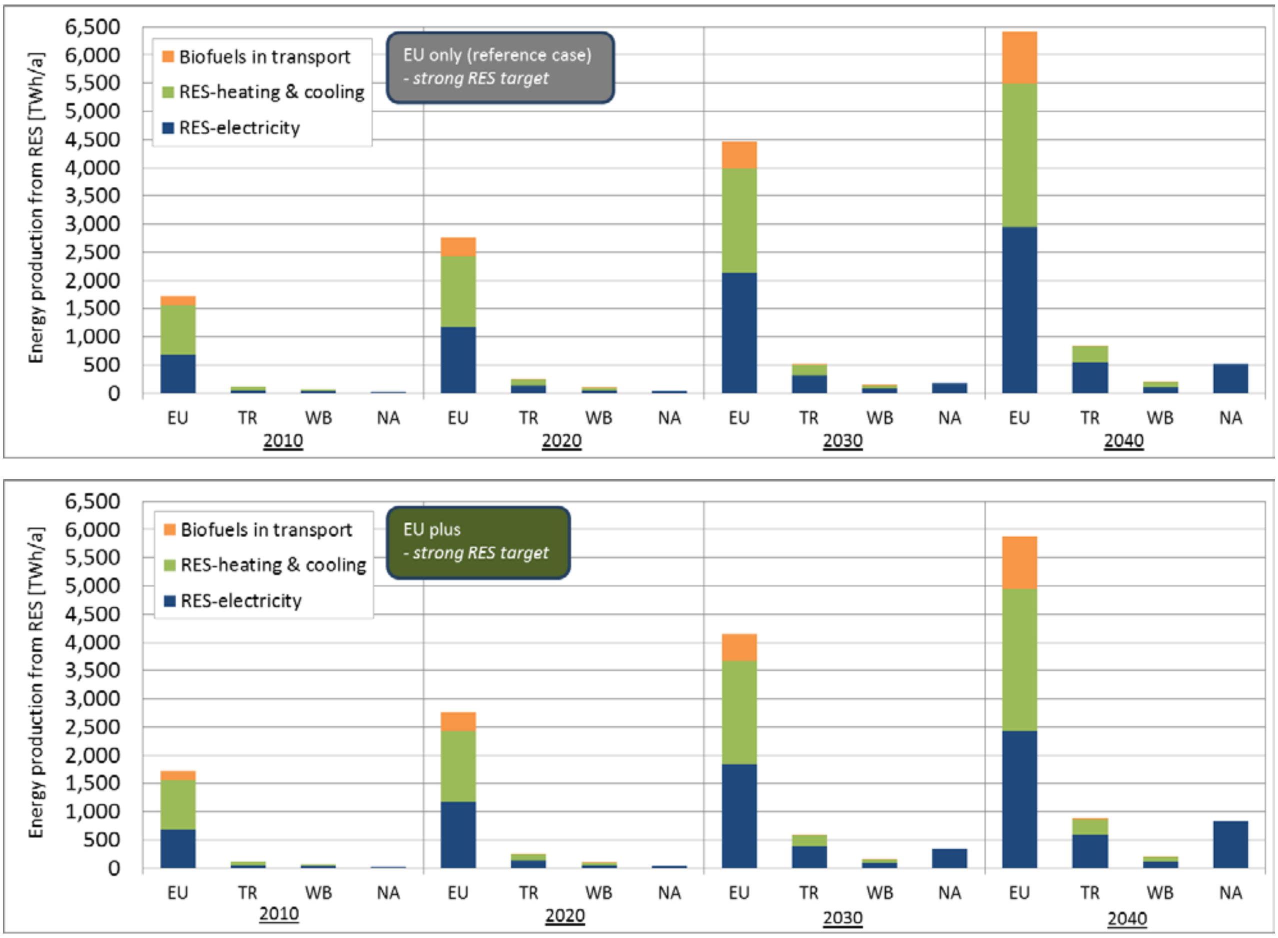



**Figure 38: Energy Production from RES for EU28, Turkey, Western Balkans and North Africa according to the EU only (reference) and EU plus (full cooperation) scenario under a strong RES target.**

Note: For RES in the electricity sector and in heating and cooling deployment is accounted where electricity and heat generation takes place while for biofuels in transport consumption is relevant.

The lower partition of Figure 38 shows the same overview but for the EU plus scenario where full RES cooperation across all assessed regions is presumed. It can be seen, that in the short term cooperation does not change the scenario – the values of RES generation remain unchanged for 2020. In 2030 the picture already looks differently. Energy production from RES in the EU is lower. This fall is almost exclusively due to the RES-electricity sector – a drop of roughly 300 TWh. One can observe that in turn RES-E generation in the remaining regions increases: in Turkey by 67 TWh, in the Western Balkans by 9 TWh and in North Africa by 155 TWh, almost double the EU only (reference case) value. In 2040 this pathway continues, i.e. the scenario depicts a substantially lower RES-E generation in the EU and a strong increase in the RES-electricity sector in North Africa (by 309 TWh) and also moderate increases in Turkey and the Western Balkans. A slight decrease in RES generation in the heating and cooling sector as well as in the biofuels for transport is also seen for the EU. This is nevertheless not balanced out by increases in Turkey, the Western Balkans or North Africa. This again shows that trade is more or less limited to RES electricity between the EU and its neighbours. Consequently, in the following subsection more information is provided on the respective technology options that could be used to generate renewable electricity.

### 3.1.4 Technology developments for RES in the electricity sector

Which sources of RES electricity make up the mix can be seen in Figure 39. As in the previous section, this figure consists of a depiction of the EU only (reference) case in the upper part for 2010 up to 2040 and the EU plus (full cooperation) scenario – in both cases with an underlying strong RES target.

In 2010, the starting point for both scenario developments, hydro power makes up the largest part of the total RES electricity generation: 355 TWh. It is followed by onshore wind, generating 152 TWh, biomass with 115 TWh and then photovoltaics generating a total of 40 TWh. Offshore wind, CSP and wave/tidal as well as geothermal generation from RES make up small shares below 10 TWh. In Turkey, only hydro power contributes to RES-E generation by a considerable amount (47 TWh). Aside of this, only 4 TWh from onshore wind and 1 TWh from geothermal sources is generated. In the Western Balkans and North Africa, 26 TWh and 6 TWh from hydro power are generated respectively, complemented by 2 TWh from onshore wind and 1 TWh from CSP in North Africa.

The EU only scenario for 2020 shows that wind onshore catches up with hydro power – amounting to 362 TWh and 374 TWh respectively. RES-E generation from biomass almost doubles and photovoltaics RES-E generation rises to 170 TWh, more than three times its 2010 amount. For the remaining regions / countries, no substantial increases in RES-E generation are to be expected in the short term, if the EU28 member states only cooperate among themselves. In Turkey, wind onshore generation increases to 43 TWh and hydro power generates 79 TWh in 2020. In the Western Balkans, an increase in RES-E generation from hydro power is also noticeable. The amount increases by 13 TWh to 39 TWh overall. In North Africa both CSP and wind onshore see a small expansion – respectively generating 12 TWh from RES-E. Slight increases can also be seen for some regions for RES-E generation from biomass and PV.

The medium-term perspective (2030) exhibits significant increases in RES-E generation for the EU28 Member States. A substantial expansion can be seen in the on- and offshore wind sectors as well as for photovoltaics. The three technologies generate 726, 245 and 337 TWh respectively. RES-E generation from biomass also almost doubles to 382 TWh. In Turkey, the hydro and onshore wind sectors are further expanded (to 109 and 122 TWh). Offshore wind also increases substantially to 41 TWh, as does wave/tidal/geothermal (22 TWh). In the Western Balkans, hydro power is further developed and a slight increase for biomass, onshore wind and photovoltaics, 7.7 and 5 TWh, respectively, can be observed. In North Africa onshore wind power is further developed, to 104 TWh respectively. Photovoltaics and especially CSP also exhibit an increase – to 13 and 58 TWh respectively.

Looking into the long-term perspective (2040) shows developments along the lines of the formerly described pathways. In the EU, RES-E generation increases further, to nearly 3,000 TWh overall. Thereby the main share is attributed to onshore wind – 1,153 TWh, or well over a third. While hydro power seems to have reached its full capacity at around 407 TWh, biomass, wind offshore and photovoltaics show further increases of 100 TWh or more each. The long-term perspective for Turkey shows increases especially in RES-E generation from photovoltaics (138 TWh/a) and wind onshore (207 TWh/a). In the Western Balkans, quite significant increases can be seen in onshore wind and photovoltaics (up to 17 TWh and 13 TWh, respectively). North Africa exhibits substantial increases in wind onshore (to 301 TWh) and in CSP (to 174 TWh).

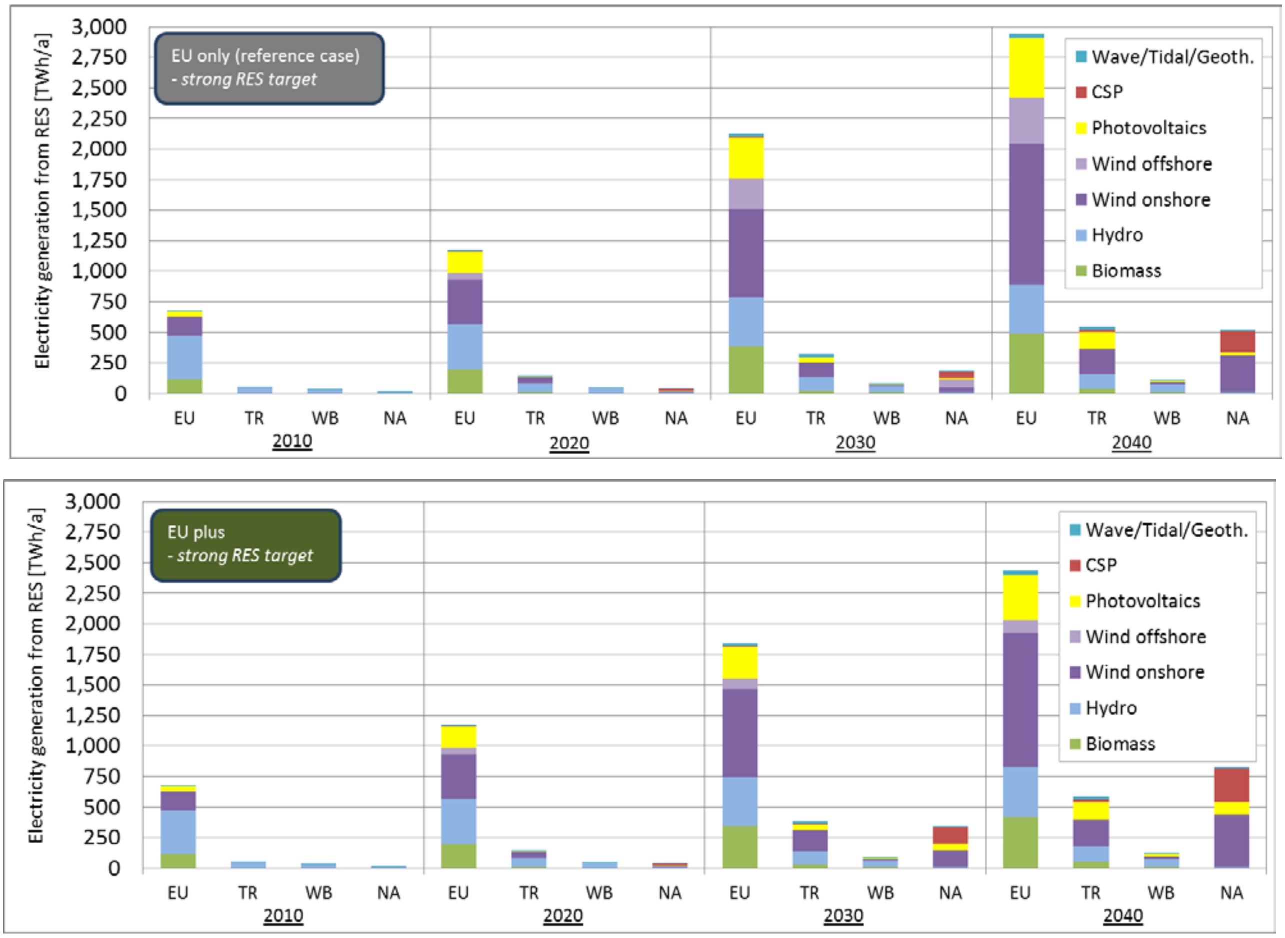



**Figure 39: RES-Electricity generation [TWh/a] for EU, Turkey, Western Balkans and North Africa in the strong RES target EU only (reference) and EU plus case (full cooperation)**

Note: RES in the electricity sector is accounted for where the electricity generation takes place.

Looking into the lower part of Figure 39 gives us insight into RES-E generation under the EU plus, i.e. full cooperation scenario. The short-term scenario does not differ from the EU only (reference) case, exhibiting the same levels of RES-E generation for all three case regions. In the medium term (2030) the picture changes: Whereas for the 28 EU Member States RES-E generation is lower than in the EU only scenario, the cooperating regions, i.e. North Africa, the Western Balkans and Turkey exhibit higher levels. In Turkey, more onshore wind and photovoltaics generation takes place, whereas in the Western Balkans, wind onshore generation increases from 7 to 13 TWh. The most obvious change takes place in North Africa: RES-E generation increases to 340 TWh, of which CSP makes up 134 TWh, while onshore wind and photovoltaics also increase to 137 and 58 TWh, respectively.

The long-term perspective (2040) also exhibits decreasing levels of RES-E generation for the EU as compared to the EU only scenario (cooperation among EU28 Member States only). To compensate for this decrease, the cooperation partner regions / countries exhibit increased RES-E generation. In North Africa, RES-E generation from CSP increases to 277 TWh in 2040, and wind onshore generation reaches 429 TWh. Photovoltaics also show a substantial increase to 104 TWh. In Turkey slight increases can be observed for biomass, wind onshore, photovoltaics and CSP. The change in the Western Balkan region is also not that substantial in comparison to the previous decade. In comparison to the EU only case, an increase can be observed in RES-E generation from photovoltaics, wind onshore, hydro and biomass. In the EU, a lower level of RES-E generation can be observed in all different technologies. The most substantial drop can be seen in offshore wind (i.e. from 376 to 109 TWh), but also onshore wind and photovoltaics exhibit levels that are up to 100 TWh lower as compared to the EU only case.

## 3.2 Prospects for RES cooperation

The following figures elaborate on how different levels of RES generation could be exchanged by 2030, dependent on whether the EU implements strong or moderate targets for RES generation. Note that all this builds on the assumption that a joint market is established for RES in the electricity sector, allowing full RES cooperation across the EU and its neighbouring countries (Turkey, Western Balkans and North Africa) in the period post 2020. Complementary to the comprehensive assessment of prospects for enhanced RES cooperation in the mid- (2030) to long-term (2040) also an analysis of short-term prospects has been conducted within the BETTER project. Thus, as reported in further detail in Resch et al. (2015), a model-based assessment has been conducted on that subject beforehand. Key outcomes of that as well as of a complementary qualitative assessment are highlighted in Box 7 (below).

**Box 7: Limited prospects for RES cooperation between the EU and assessed neighbouring countries in the 2020 context**

Despite these expected benefits, since 2009, not a single RES cooperation project between the EU and its neighbours in accordance with Article 9 of the RES directive 2009/28/EC project has been implemented – and prospects until 2020 are very limited. This statement builds on the outcomes of a qualitative assessment conducted at case study level throughout this project, underpinned by some quantitative analysis done related to the 2020 context. The outcomes of the qualitative work, i.e. our reasoning for the limited prospects for RES cooperation with third countries in the near future, are summarised below, and thereafter key results from the 2020 modelling work are presented.

Compared to the other cooperation mechanisms, additional barriers to the implementation of the cooperation mechanism between the EU and its neighbouring countries include a higher degree of grid infrastructure requirements, some degree of geopolitical unrest, more complex financing schemes, differences in public acceptance, potential socio-economic and environmental impacts, existing laws and regulations (Jacobsen et al., 2014). RES projects in neighbouring countries may also need a long lead-time before being fully interconnected to the territory of the EU (Karakosta et al., 2013). Thus, the physical import requirement as postulated by Article 9 currently represents an additional hurdle as very limited interconnections exist between Europe and neighbouring countries, while the existing interconnection capacity within many Member States is also a limiting factor.

Since 2009 there have been various unforeseen events which have not been conducive for the implementation of cooperation mechanisms:

- Among others, events such as the Eurozone crisis have led to a reduction in energy demand – as a direct result of the slow-down of economic growth, indirectly making it easier for some EU Member States to achieve their 2020 RES target domestically.
- Secondly, the cost decline of domestically available RES-E in the EU (particularly for solar PV) has reduced the cost advantage of RES-E imports from neighbouring countries to the EU.
- Third, following the Russia-Ukraine crisis, energy security concerns are now at the top of energy policy priorities. In this sense, following the Energy Union package in February 2015, the EU has taken steps to revitalise energy cooperation with neighbouring countries as a way to improve energy security (but mostly focusing on fossil fuels).
- In neighbouring countries, important events include episodes of civil unrest, such as the Arab Spring, which have led to higher country risks and financial costs, resulting in scepticism from foreign investors.

In accordance with above we have to conclude that at present, there is almost no demand for RES cooperation in general, and in particular for RES-E imports to the EU, as most Member States believe they can reach their 2020 RES target domestically while reaping the associated co-benefits (in terms of employment, job creation, etc.). On the other hand, neighbouring countries´ increasing internal electricity demand together with the need to reinforce their electricity system has limited their capacity to generate RES-E surplus that could potentially be exported to Europe in a short time frame (i.e. up to 2020).

The outcomes of the quantitative analysis done by use of the Green-X model confirm the pessimistic view on short-term (2020) prospects for RES cooperation with EU's neighbours. Due to the infrastructural constraints, RES cooperation with third countries is in the short term practically limited to the Western Balkan countries – all of them being Contracting Parties of the Energy Community.

As indicated in Table 12, under strong RES cooperation between EU and Western Balkans an ambiguous situation occurs where the future demand development in Western Balkan countries is the key determinant for the flow of exchange:

- In the case of low demand, the Western Balkan region becomes a net exporter, and export to the EU would amount to 2.4 TWh by 2020;
- In the case of a high demand growth the region would however be a net importer, and 4.2 TWh of renewable electricity would then flow from neighbouring EU countries to the Western Balkan region to assure 2020 RES target achievement.

Thus, the economically viable exchange by 2020 amounts to 2.8-4.4% (0.1-0.15%) of required RES volumes at West Balkans level (EU level).

**Table 12: RES exchange between the EU and Western Balkan countries by 2020 in the case of strong cooperation according to distinct energy demand developments (i.e. low and high demand case for Western Balkans)**

| | **EU plus** (strong cooperation incl. West Balkans) - **Low Demand** | **EU plus** (strong cooperation incl. West Balkans) - **High Demand** |
|---|---|---|
| **RES exchange between EU and Western Balkans by 2020** | **-2.4** TWh | **4.2** TWh |

**(- … import to EU, + … export from EU)**

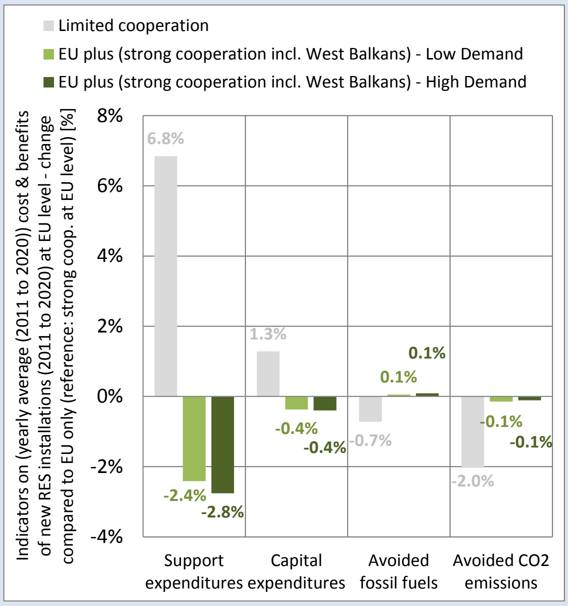



**Figure 40: Impacts of enhanced / limited RES cooperation on costs and benefits of renewable electricity for the EU28 in the short term (2011-2020), change compared to reference (EU only) scenario.**

As shown in Figure 40, a positive impact of enhanced RES cooperation with Western Balkans on costs and expenditures, in particular support expenditures for renewables, can be expected for the European Union in the 2020 context. According to the model-based assessment, in the low demand case this can reduce the required support expenditures on average throughout the period 2011 to 2020 by 2.4% in comparison to the reference case where RES cooperation is limited to EU countries only (EU only). As a consequence of additional income through RES cooperation EU Member States may however also benefit in the high demand case. Notably, the magnitude of savings is then even higher, 2.8% can be saved on support under these circumstances.

In practical terms, the possibilities for doing so appear however more limited – it would require immediate action and a rapid removal of non-economic barriers and, in turn, a new RES policy framework to be implemented in all analysed EU and neighbouring countries at short notice.

### 3.2.1 Electricity Transfers

As can be seen in Figure 41, depicted on the left side of the chart, the amount imported by the EU in 2030 depends strongly on whether a strong, moderate or weak target for RES deployment is set. In Turkey, a weak RES target would even imply importing RES as opposed to exporting it in a strong or moderate RES target framework.

Expressed in absolute terms, the EU would import 296 TWh in 2030 under a strong RES target according to EU plus (full RES cooperation) scenarios. A moderate target would then lead to imports of 224 TWh, whereas under a weak target merely 117 TWh would be needed as Third country imports for target fulfilment. Turkey would (virtually) export 67.9 TWh under a strong target, whereas it would (virtually) import 5.7 TWh in a weak target scenario. The Western Balkan states exhibit less distinct scenarios. A strong target leads to the virtual export of 10.7 TWh whereas the countries remain exporters, of a total amount of 7.7 TWh under a weak target. A strong target leads North Africa to in that case physically export quite a substantial amount of RES: 216 TWh as compared to merely 115 TWh when a weak RES target is assumed.

The right hand side of Figure 41 shows the share of these exports in the gross electricity demand of the respective countries and regions. Again, the three EU plus cases are shown, assuming a strong, moderate and weak target for RES deployment in the EU and the Energy Community. In relative terms, as can be seen on the right hand side of this graph, this would mean that the EU28 Member States import, partly virtually (from Turkey and Western Balkans) and partly physically, RES at a volume that equals 3.2% to 8.1% of the EU28's gross electricity demand in 2030. Turkey could be a net importer in a weak RES target scenario, where imports correspond to 1% of its 2030 gross electricity demand, whereas (virtual) exports could amount up to almost 11.4% (of gross electricity demand) by 2030 assuming a strong RES target. The Western Balkan region is predicted to be a net exporter in all scenarios. Concretely, these exports would range between 6.8 and 10.3% of the regions gross electricity demand. For North Africa, the potential RES-E share for physical export in 2030 lies between 17.5 and 32.8% depending on the respective target for RES deployment.

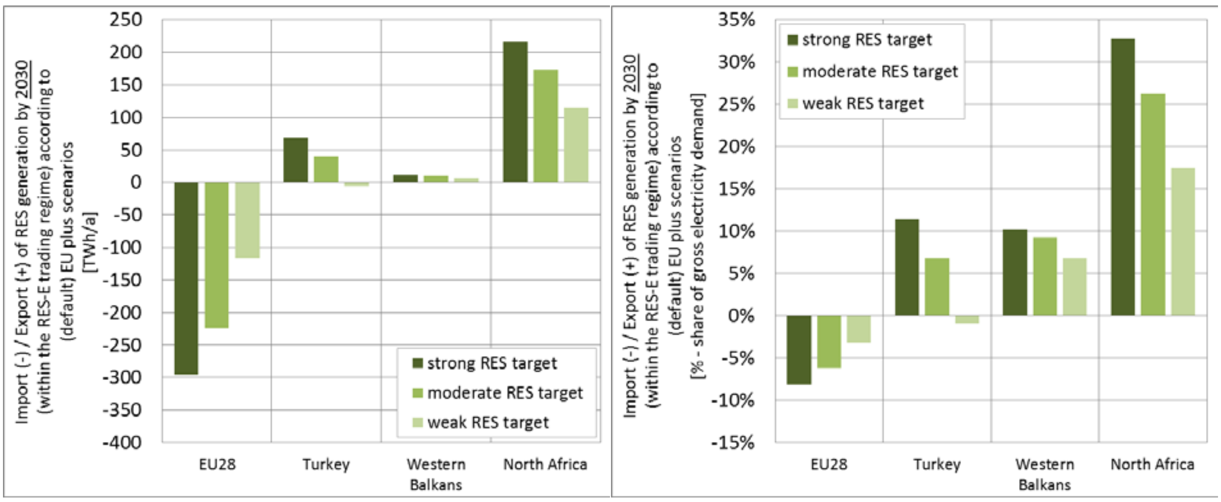



**Figure 41: Exchange of RES volumes between regions by 2030 in absolute terms (TWh) according to EU plus (full cooperation) scenarios following a strong, moderate or weak RES target (left) and in relative terms (right)**

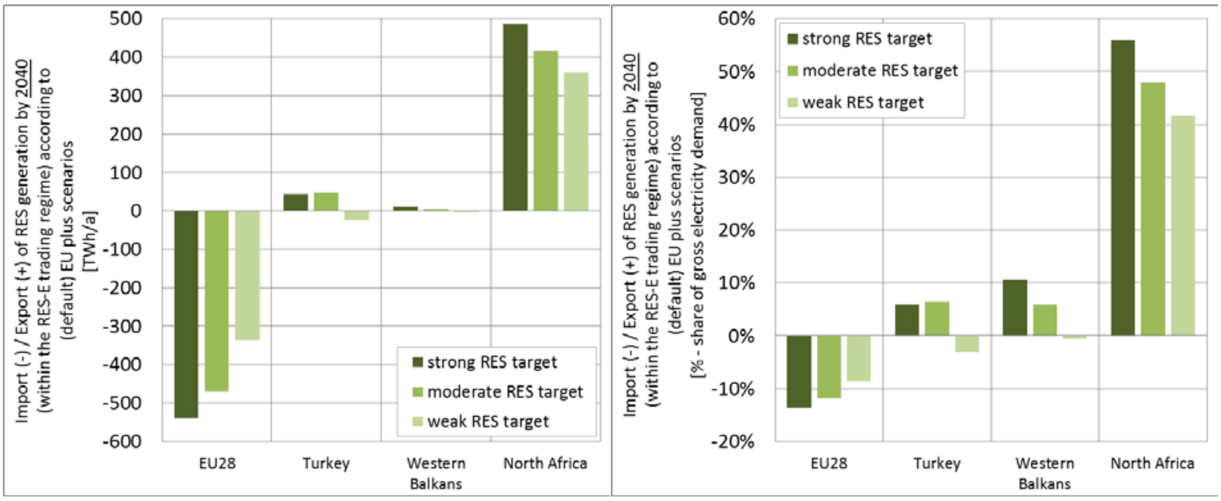



**Figure 42: Exchange of RES volumes between regions by 2040 in absolute terms (TWh) according to EU plus (full cooperation) scenarios following a strong, moderate or weak RES target (left) and in relative terms (right)**

Figure 42 displays the exchange of RES volumes by 2040 in absolute and relative terms for the EU plus (full cooperation) scenario. One can observe that in comparison to the 2030 mid-term perspective, imports to the EU 28 member states increase substantially. Specifically, assuming a strong target, the EU 28 member states would import 538 TWh by 2040, 469 TWh with a moderate target and 336 TWh if a weak target for RES deployment is assumed at EU level. In relative terms, as can be seen on the right hand side of Figure 42, this amounts to a range of 13.6% (strong target) to 8.5% (weak target) of EU's gross electricity demand in 2040.

In Turkey, a strong and moderate target would lead to roughly the same exports of RES that amount to 47 or 43 TWh respectively. A weak overall RES target would make Turkey a net importer even in the long term perspective up to 2040 (22 TWh of RES imports in 2040). In relative terms these scenarios make up a bandwidth of 5.9% (strong), 6.4% (moderate) or -3.1% (weak target).

For the Western Balkans, the long-term (2040) perspective is as follows: a weak overall target would lead to net imports of 0.5 TWh of RES by 2040, or 0.5% of gross electricity demand. A moderate target changes the flow of RES and makes the Western Balkans an exporting region. Under this specific target the Western Balkan region would export 5.9% of its gross electricity demand which amounts to a number of 5.9 TWh in 2040. Increasing the target for RES even further would increase exports by 5.2 percentage points up to a value of 10.7 TWh.

North Africa, in the long- as well as in the mid-term is a clear RES exporting region, independent of the respective target set at EU-level. Assuming a strong target for RES at EU level, North Africa would export 485 TWh in 2040, 56% of its gross domestic electricity demand. A moderate target leads to an export of 415 TWh or 48%, and a weak target to 360.7 TWh or 41.7% of gross domestic electricity demand, respectively.

## ***Sensitivity variants on regional specifics***

Next the different main sensitivity scenarios analysed, aiming to incorporate relevant regional specifics for Turkey and North Africa, are presented. More precisely, the following figures show sensitivity variants to the EU plus case (of full RES cooperation between the EU and its neighbours) and an underlying weak, moderate or strong RES target. The green bar depicts the amount of RES-E import or export as seen in the default cases beforehand. The red bar shows the sensitivity variant related to Turkey's national policy foreseeing a low ambition RES deployment target by 2030 and beyond. The underlying assumption, as described in section 2.2.2 in more detail, is that Turkey does not become a member of the European Union or the Energy Community and consequently does not align its mid- to long-term ambition concerning domestic RES deployment to that of the Community. RES-E produced would consequently only be needed to a minor extent for domestic RES target fulfilment, and the large remainder could then be physically exported. The last point is crucial, as the imports after accession to the EU or the Energy Community could also be of statistical nature and are not obliged to be physical by EU law. The third bar represents a sensitivity variant for North Africa in which electricity from CSP is transferred via High Voltage Direct Current (HVDC) lines directly to the centres of Europe. This may consequently lead to a delayed expansion of the EU plus transmission and distribution grid in North Africa including the interconnections with Europe. As a consequence the future development of wind and PV in North Africa (that appear less viable for direct HVDC transfer due to their variability) would be limited possibly to a larger extent.

Figure 43 shows the sensitivity variants explained beforehand under a weak target for RES at the European level. In comparison to the default case, the following scenarios develop. Concretely, in the case that North Africa has a moderate grid expansion due to a focus on CSP, they export around 20 TWh less than in the default weak target scenario. The EU also imports less RES in this scenario as Turkey and the Western Balkans do not completely compensate for that loss. In the case that Turkey does not affiliate to the EU and follows its own plan for RES expansion, Turkey would export a lot more RES in comparison to the default case (where it was a net importer). This in turn leads the EU 28 Member States to import roughly a percentage point more of their share in gross final electricity demand (around 20 TWh more) in 2030.

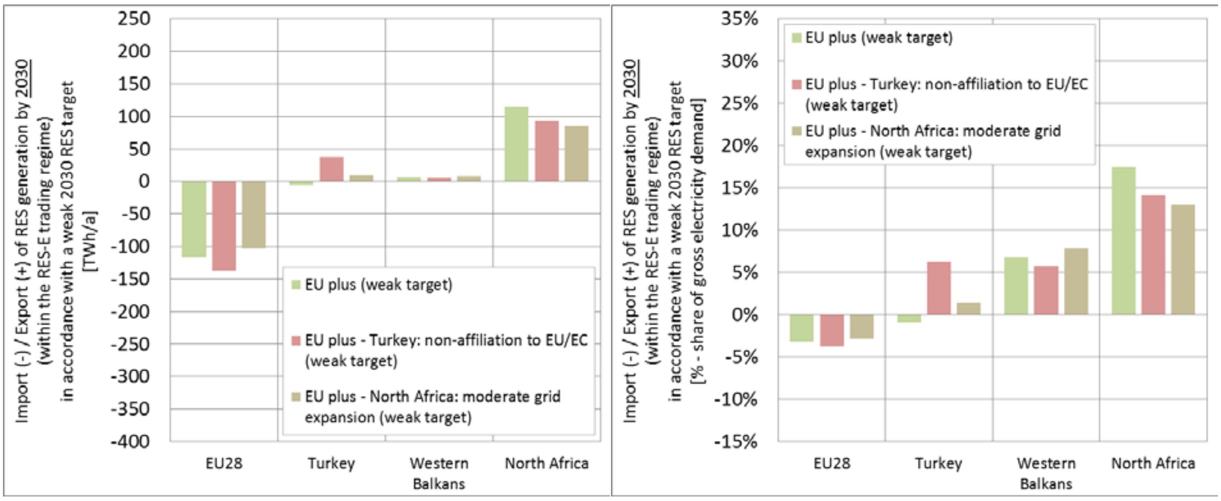



**Figure 43: Exchange of RES volumes between regions by 2030 in absolute and relative terms (% domestic demand share) according to EU plus (full cooperation) sensitivity cases for a weak RES target**

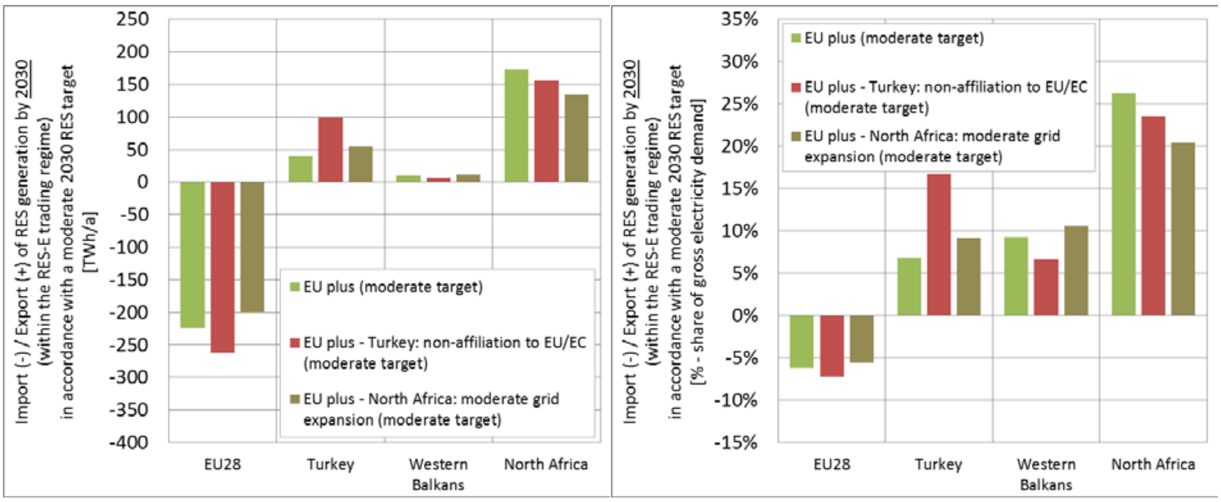



**Figure 44: Exchange of RES volumes between regions by 2030 in absolute and relative terms (% domestic demand share) according to EU plus (full cooperation) sensitivity cases for a moderate RES target**

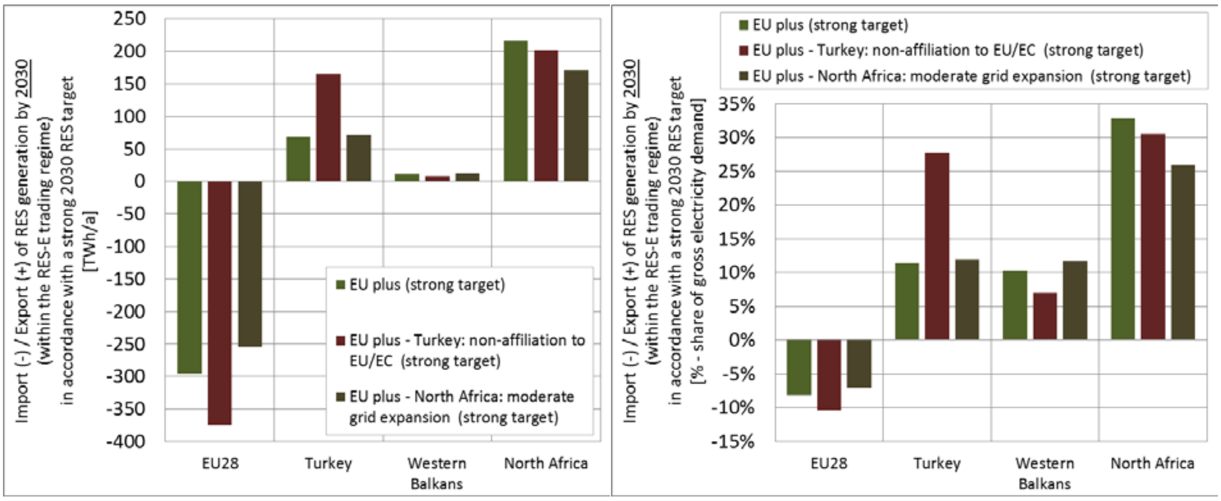



**Figure 45: Exchange of RES volumes between regions by 2030 in absolute and relative terms (% domestic demand share) according to EU plus (full cooperation) sensitivity cases for a strong RES target**

As to be expected (see Figure 44), exports from Turkey increase when their domestic target for RES deployment is less ambitious under a (at EU/EC level) moderate RES target: it increases from 40.3 TWh to 99.2 TWh. In the same scenario, the Western Balkan region and North Africa lower their exports, to compensate for this strong rise. The sensitivity variant for North Africa, in which a delay in the expansion of wind and PV occurs, as the transfer lines are constructed for a CSP dominated renewables deployment, leads to a slightly lower export potential. The total amount of RES-E exported is 136.6 TWh as compared to 173.3 TWh in the EU plus scenario.

The relative share in the sensitivity variants follows a similar pattern as the absolute values, as can be seen exemplarily in Figure 44 for the moderate target case. The EU28 Member States import on average 6.2% of their gross electricity demand in 2030 in the moderate target case. This share increases to 7.2% if low ambition in the Turkish national policies on RES deployment is assumed, i.e. if Turkey's RES-E exports increase. For Turkey itself, a less ambitious domestic target for RES deployment has an even larger impact on gross electricity demand in relative terms. The export share of RES increases from 6.8% to 16.7% in the case of a moderate target for RES deployment in the EU. This induces a relative decline in the exports of the Western Balkan and North African countries. For North Africa, the sensitivity variant that implies a substantial expansion of CSP and the associated transfer lines leads to lower exports of RES-E as a share of gross electricity demand in 2030. In comparison to the EU plus case with a moderate target, the share falls from 26.3% to 20.7%. The share imported by the EU28 Member States also falls by a small amount, namely to 5.6%. Turkey and the Western Balkans exhibit increased export shares in comparison to the EU plus case as to partly compensate for the lower exports from Northern Africa.

Figure 45 shows the sensitivity variants with an underlying strong target for RES deployment in the medium term (2030) perspective. The development is similar to the moderate and weak target cases: When Turkey does not become a member of the EU or Energy Community and is thus assumed to follow weak targets for domestic RES deployment, they have more RES potential to export. This amount is more than double the amount in the default strong target case. In turn, this increases imports to the EU 28 member states substantially. The second sensitivity variant, the delayed grid expansion in North Africa leads to lower exports from this region to the EU 28 Member States – overall imports to the EU thus decrease by roughly 50 TWh in 2030, or around 2 percentage points.

**Table 13: Exchange of RES volumes (within the RES-E trading regime) between regions by 2030 and 2040 according to default (EU plus) cases and sensitivity scenarios**

| **Import (-) / Export (+) of RES generation** (within the RES-E trading regime) by 2030 and 2040 according to **sensitivity scenarios** | | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion |
|---|---|---|---|---|---|---|---|---|---|---|
| | RES target (ambition level): | weak RES target | | | moderte RES target | | | strong RES target | | |
| **in absolute terms [TWh/a]** | | | | | | | | | | |
| EU28 | 2030 | -116.9 | -136.6 | -103.3 | -224.0 | -262.6 | -201.6 | -296.0 | -374.3 | -254.6 |
| | 2040 | -337.4 | -382.0 | -224.8 | -469.5 | -605.9 | -356.3 | -539.1 | -758.1 | -400.5 |
| Turkey | 2030 | -5.7 | 37.0 | 8.7 | 40.3 | 99.2 | 54.5 | 67.9 | 164.8 | 71.2 |
| | 2040 | -23.0 | 103.2 | 36.5 | 47.5 | 222.9 | 92.3 | 43.1 | 298.6 | 77.6 |
| West Balkans | 2030 | 7.1 | 6.0 | 8.2 | 9.7 | 6.9 | 11.0 | 10.7 | 7.3 | 12.2 |
| | 2040 | -0.5 | -1.9 | 5.7 | 5.9 | -0.8 | 12.5 | 10.7 | 0.1 | 16.6 |
| North Africa | 2030 | 115.3 | 93.5 | 85.9 | 173.3 | 155.8 | 134.8 | 216.5 | 201.4 | 170.9 |
| | 2040 | 360.9 | 280.7 | 182.6 | 416.0 | 383.8 | 251.7 | 485.2 | 459.3 | 306.2 |
| **in relative terms [% - share of gross electricity demand]** | | | | | | | | | | |
| EU28 | 2030 | -3.2% | -3.8% | -2.8% | -6.2% | -7.2% | -5.5% | -8.1% | -10.3% | -7.0% |
| | 2040 | -8.5% | -9.7% | -5.7% | -11.9% | -15.3% | -9.0% | -13.6% | -19.2% | -10.1% |
| Turkey | 2030 | -1.0% | 6.2% | 1.5% | 6.8% | 16.7% | 9.2% | 11.4% | 27.8% | 12.0% |
| | 2040 | -3.1% | 14.1% | 5.0% | 6.5% | 30.5% | 12.6% | 5.9% | 40.8% | 10.6% |
| West Balkans | 2030 | 6.8% | 5.7% | 7.9% | 9.3% | 6.6% | 10.6% | 10.3% | 7.0% | 11.7% |
| | 2040 | -0.5% | -1.9% | 5.7% | 5.9% | -0.8% | 12.5% | 10.7% | 0.1% | 16.6% |
| North Africa | 2030 | 17.5% | 14.2% | 13.0% | 26.3% | 23.6% | 20.4% | 32.8% | 30.5% | 25.9% |
| | 2040 | 41.7% | 32.5% | 21.1% | 48.1% | 44.4% | 29.1% | 56.1% | 53.1% | 35.4% |

Notes:
All scenarios assume full RES cooperation between the EU and ist neighbours
Virtual vs. physical trade of renewable electricity:
- For West Balkans virtual trade is assumed in all (default and) sensitivity scenarios
- For Turkey virtual trade is the default option, only in the sensitivitey case related to Turkey physical trade is presumed (since not part of the EU/EC)
- For North Africa physical trade is assumed in all (default and) sensitivity scenarios

Table 13 shows the data on exchange of RES-E generation across assessed regions / countries for the (default cases and) sensitivity scenarios, adding the long (2040) to the mid-term (2030) perspective as depicted and discussed beforehand. From left to right the columns show the weak, moderate and strong RES target scenarios. The rows from top to bottom depict the imports for the EU28 Member States, Turkey, West Balkans and North Africa first in absolute values (TWh) and then in relative terms (% - i.e. as share of gross electricity demand). One can see that overall the trends that have been described in detail for the period up to 2030 continue in the long term perspective. In all three target scenarios one can observe that the EU imports more RES when Turkey is non-affiliated and less if North Africa delays its grid expansion. In Turkey, exports further increase in the long term when they are not affiliated to the EU and their exports are also considerably higher when North Africa delays its grid expansion. This picture is consistent over the different target scenarios.

In the Western Balkans a change of direction is observed for the long term perspective. Concretely, in the "Turkey non-affiliation case" and for the weak and moderate RES target scenario, the region becomes a net importer of RES. Only for the strong target in this particular case, does the region export 0.1 TWh. In North Africa all medium-term trends can also be observed in the long-term perspective.

## 3.2.2 Country level insights

Figure 46 gives insights on the RES-E trading regime at the country level. While the upper part of the figure shows absolute values for the strong, moderate and weak RES targets, the lower part depicts the respective share of gross electricity demand – both for the medium term (2030).

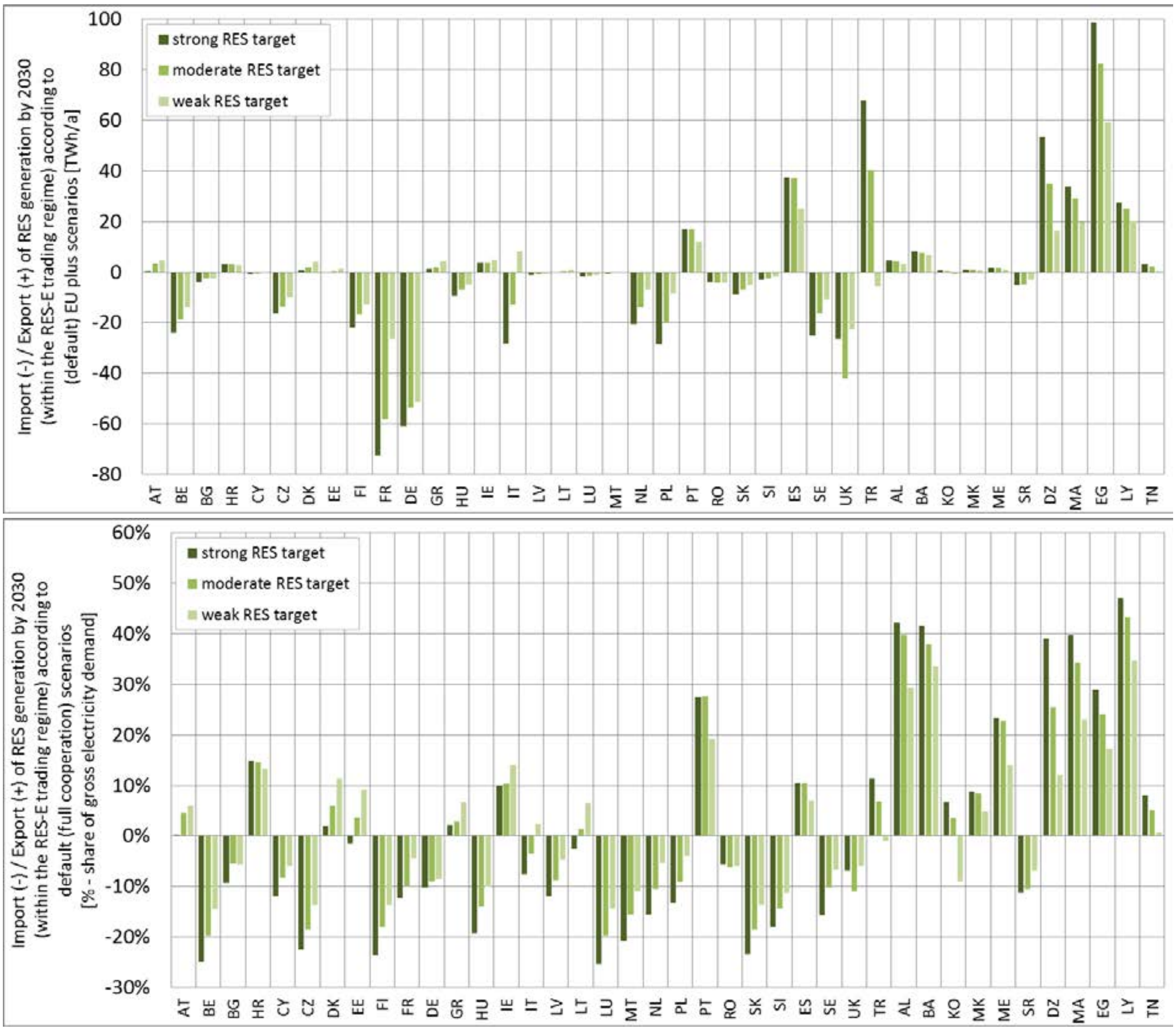



**Figure 46: Exchange of RES volumes between assessed countries by 2030 (within the RES-E trading regime) according to EU plus (full cooperation) scenarios. Upper graph: Absolute values shown in TWh for all EU countries as well as the assessed neighbouring countries. Graph at the bottom: Relative values shown in percentage share of gross electricity demand.**

In absolute values, France and Germany, obviously due to size are leading in terms of RES-E imports. Concerning the import share of RES electricity, nevertheless, other European Member States show substantially higher RES-E imports in their share of final gross electricity demand. In the strong RES target scenario in 2030, Belgium, the Czech Republic, Finland, Luxembourg and Slovakia would import more than 20% of their gross final electricity demand. At the same time, Bosnia, Albania and Libya would export over 40% and Egypt and Macedonia near to 40% of their gross final electricity demand. In absolute terms, Egypt stands out as the main exporting country with an amount of nearly 100 TWh of RES generation in the strong RES target scenario. It is then followed by Turkey, exporting 67.9 TWh and then Algeria with 53.4 TWh.

It is furthermore interesting to see, which EU Member States actually export parts of their RES-E under the trading regime. Whereas most exporting countries only trade small amounts of renewable electricity, as e.g. Croatia, Austria or Denmark (3.1, 0.2 and 0.6 TWh, respectively), others, such as Portugal or Spain export quite high amounts. Specifically, assuming a strong target would lead Portugal to export 17 TWh in 2030 and Spain would even export 37.4 TWh. A strong RES target also leads some countries, who would otherwise be exporting RES electricity to import a certain share of their gross final electricity demand to fulfil their national target. Specifically in Estonia and Lithuania 1.6% and respectively 2.6% of gross electricity demand would have to be imported under a strong RES target regime.

Looking at the moderate RES target scenario, the overall trade volume in RES-E falls, whereas the shares stay more or less the same. The most substantial changes when looking into absolute values are to be seen in Turkey, where exports of RES fall by more than 20 TWh as compared to the strong RES target scenario. Exports from Egypt and Algeria also fall by respectively over 15 TWh. At the same time, imports by Italy and France are around 10 TWh lower than in the strong RES target case - all other importing EU Member States exhibit slight decreases as well. Assuming a weak target for RES deployment leads to overall lower imports or exports, i.e. a linear decrease of the volumes. The same can be observed for the shares in gross electricity demand. Two countries nevertheless exhibit a change of direction of the RES electricity trade flow: under a low overall target, Italy starts exporting RES-E (8.3 TWh in 2030) whereas Turkey needs to import RES electricity of an amount of 5.7 TWh/a. In relative terms, a low target for RES also leads to a change of direction for Italy, Turkey and most visibly Kosovo*[36] (8.9% of the share has to be imported).

***<u>Sensitivity variants on regional specifics</u>***

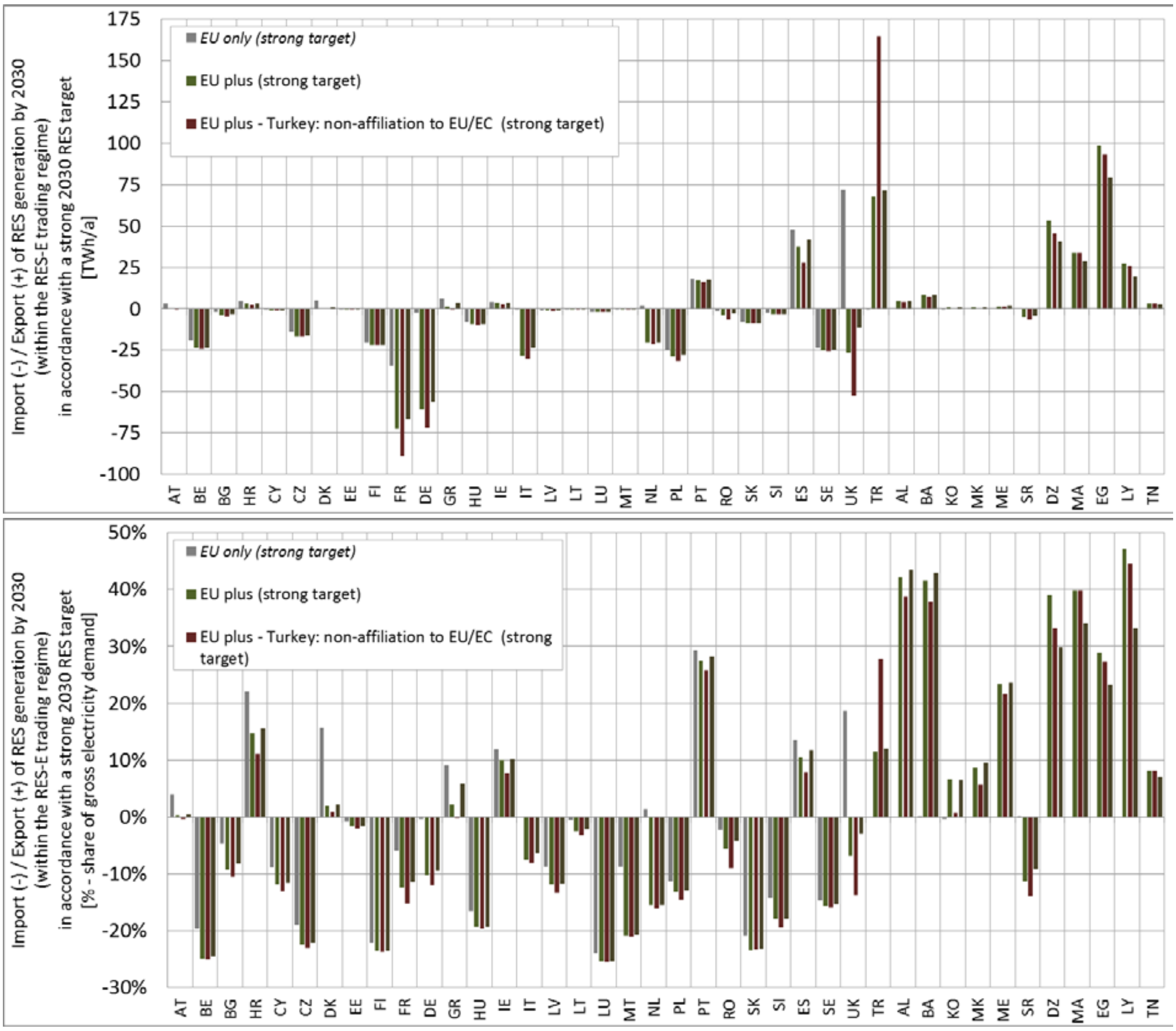



**Figure 47: Exchange of RES volumes between assessed countries by 2030 (within the RES-E trading regime) for the assessed sensitivity variants and assuming a strong target for RES deployment. Upper graph: Absolute values shown in TWh for all EU countries as well as the assessed neighbouring countries. Graph at the bottom: Relative values shown in %-share of gross electricity demand.**

[36] This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo Declaration of Independence.

For a strong RES target in 2030, Figure 47 displays the different sensitivity variants, i.e. the low national ambition variant for Turkey, as well as the delayed PV and wind expansion case for North Africa. Comparing trade between the EU only (reference) and the EU plus case shows the obvious difference that no trade takes place between the EU Member States and the Third countries (per definition). This obviously leads to trade volumes in the EU being higher for some countries: Spain, Greece and Portugal export more RES-E than in the EU plus case and the UK switches from importing around 25 TWh to exporting 71.8 TWh. The sensitivity variant that takes into account low ambition in Turkey for national RES deployment, unsurprisingly exhibits the most significant changes in Turkey's export volume. In the low ambition sensitivity variant, Turkey would export 164.8 TWh in 2030, assuming a strong RES target for the EU. This is more than double the amount exported under the EU plus scenario. In comparison, other countries, especially North African countries as e.g. Egypt export slightly less renewable electricity. Import volumes of EU28 Member States tend to increase under this scenario. The UK, France and Germany for instance import 52.7, 89.1 and 71.8 TWh, respectively.

These volumes all represent increases of 10 TWh or more than under the EU plus scenario. In relative terms, the picture looks quite similar. Nevertheless it is interesting to see for which countries the RES-E trade volume takes on substantial shares of the gross final electricity demand. In Turkey, exports increase from roughly 10% to 27.8% of its gross final electricity demand. Looking at imports, the share of gross final electricity demand of RES-E imports increases the most visibly in Romania, France and Serbia – respectively by more than 2%.

The delayed PV and wind deployment scenario for North Africa shows lower overall RES-E exports from the North African countries. Specifically, Algeria exhibits a decrease of 12.6 TWh to 40.8 TWh, Morocco a decrease of 4.8 TWh to 28.9 TWh and RES-E exports from Egypt even fall by 19.5 TWh to 79.3 TWh. Libya and Tunisia also show lower RES-E export volumes. The other countries under the RES-E trading regime are also affected by this delayed deployment: overall, importing countries import a little less whereas exporting countries export slightly higher volumes, e.g. Turkey minimally compensates in this RES-E trade regime, by exporting 71.2 TWh as compared to 67.9 TWh in the EU plus default case. In relative terms, namely expressed as share in gross final electricity demand, Libya and Algeria exhibit the strongest decreases. In Algeria, the share of exports in gross final electricity demand falls to 29.8% by almost 10%. In Libya, the share takes on 33.3% of the gross final electricity demand in 2030, a sharp fall by 13.8% compared to the default case. The remaining countries under the RES-E trade regime do not exhibit such significant changes in terms of their gross final electricity demand. The trend visible is the same as in the absolute volumes: countries that imported under the EU plus scenario import a little less, whereas exporting countries export marginally higher shares of RES electricity in terms of their gross final electricity demand.

### 3.2.3 Monetary Transfers

The flow of RES electricity (statistical or physical) has been described to a detailed extent in the previous section. Which monetary flows would be induced through this cooperation will be shown in the following. As starting point, it appears useful to provide further insights how these figures are derived: the monetary exchange (between regions or countries) represents the monetary value of the exchanged renewable electricity and is calculated by multiplying certificate prices with traded green certificates (between regions or countries). As alternative to above, one can start with certificate prices, translate them into support premiums per MWh renewable electricity,[37] and multiply them with corresponding amounts of (virtually or physically) traded electricity volumes.

In the medium term, as depicted in Figure 48, 6.3 billion € would flow annually from the EU28 Member States in the strong RES target scenario. This amount would be split among the partner regions. Namely, Turkey would receive an inflow of 1.6 billion € annually from this, the Western Balkans 0.2 billion € and North Africa

[37] Since a uniform RES-E trading regime is assumed where no technology banding is foreseen, one green certificate equals one MWh of RES generation.

4.5 billion € respectively. A moderate target would lower the monetary transfers to an overall 3.3 billion € being transferred from the EU28 Member States to the partner regions. A weak target would decrease this amount even further such that 1.1 billion € would move from the EU to Turkey (a marginal amount of 5.3 million €), the Western Balkans (0.1 billion €) and North Africa (1 billion €). In the long term up to 2040, monetary transfers increase. A strong target for RES leads the EU to annually transfer 8.2 billion € to Turkey, the Western Balkans and North Africa, which receive 1.6 billion €, 0.2 billion € and 6.3 billion € respectively. The moderate RES target at EU level leads to the monetary transfer from the EU to the partner countries to be reduced to roughly half the amount under the strong target. 4.3 billion € flow from the EU28 Member states to Turkey, the Western Balkans and North Africa. North Africa receives the highest share of this transfer, namely an amount of 3.4 billion € per year in the longer term. In the long term, a weak target has even lower monetary transfers as a consequence than in the medium term. 900 million € are transferred annually to Turkey, the Western Balkans and North Africa. In this scenario, again North Africa receives the main bulk of this transfer, specifically 862.5 million €.

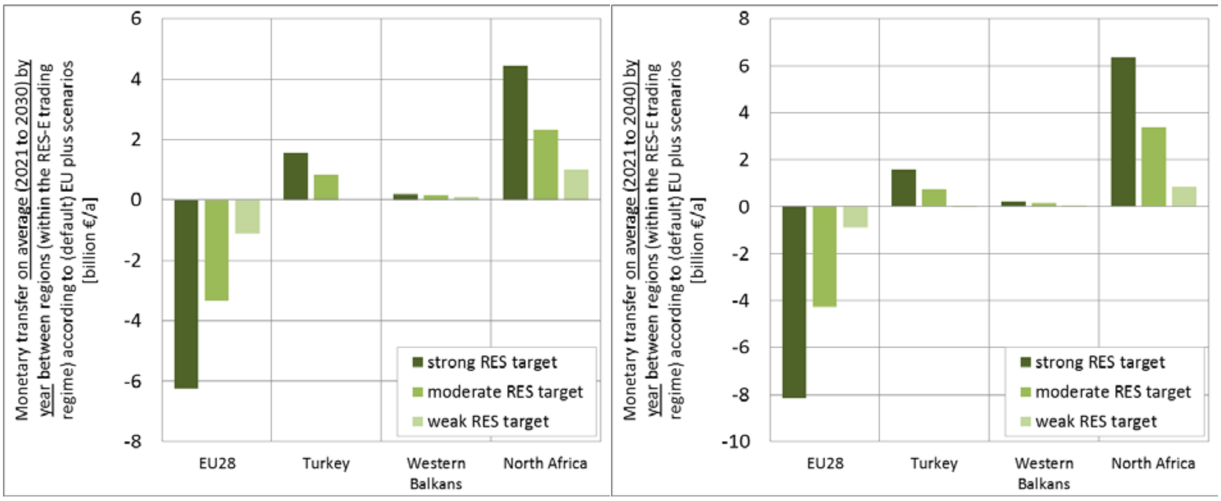



Figure 48: Yearly average (2021-2030 (left) and 2021-2040 (right)) monetary transfer between assessed regions in the full cooperation (EU plus) scenario and under strong, moderate and weak RES targets

## ***Sensitivity variants on regional specifics***

The sensitivity variants that have been assessed beforehand for the moderate RES target concerning the transfer of electricity have also been executed for the monetary transfer perspective.

It can be seen in Figure 49 than when a moderate overall RES target is assumed at EU level and if Turkey is not affiliated with the EU / Energy Community, the transfers from the EU28 Member States to the partner regions slightly increase. This increase is especially noticeable in Turkey, whereas the Western Balkans and North Africa exhibit slight decreases in the medium term under this sensitivity variant. In the long term this picture changes. If one looks into the time frame up to 2040, monetary transfers from the EU to Turkey, the Western Balkans and North Africa are slightly smaller than in the comparison case where full cooperation is assumed. Nevertheless a very substantial share of this transfer still goes to Turkey – the amount almost doubles compared to the full cooperation case.

The second sensitivity variant, in which Northern Africa concentrates largely on CSP technology and the therewith affiliated grid expansion, such that PV and wind exports are delayed, does not differ in terms of monetary flows from the EU to the Third countries in the mid-term perspective. It does nevertheless differ in how this monetary flow is distributed over the different countries. As the grid expansion is delayed in North Africa, the EU28 Member States engage in more cooperation with Turkey and Western Balkans. Not surprisingly, the monetary transfers received by these countries increase, whereas North Africa receives less annual monetary transfers as compared to the full cooperation baseline case.

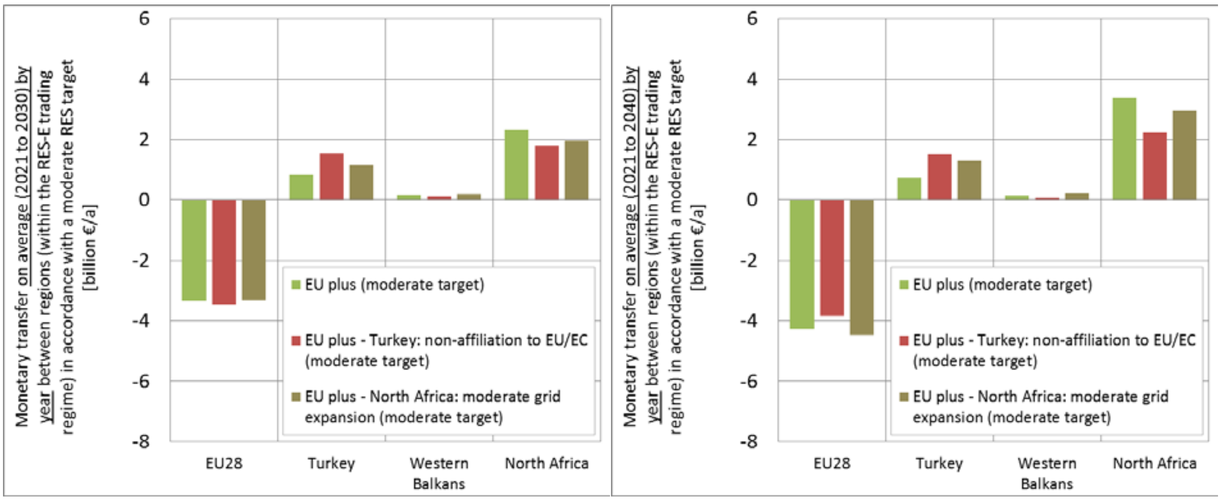



**Figure 49: Yearly average (2021-2030 (left) and 2021-2040 (right)) monetary transfer between assessed regions in the full cooperation (EU plus) scenario and for different sensitivity variants according to a moderate RES target.**

Table 14 shows the medium and long-term perspective for the sensitivity variants assessed in terms of monetary transfers. Whereas Figure 49 puts a detailed spotlight on the moderate RES target perspective in the medium to long term, the table contrasts this scenario with a weak and strong RES target intuition.

**Table 14: Monetary transfer on average per year (2021-2030 and 2021-2040) between regions (within the RES-E trading regime) according to default (EU plus) cases and sensitivity scenarios**

| **Monetary transfer on average per year between regions** (within the RES-E trading regime) according to **sensitivity scenarios** | | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion |
|---|---|---|---|---|---|---|---|---|---|---|
| | RES target (ambition level): | **weak RES target** | | | **moderte RES target** | | | **strong RES target** | | |
| **[billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | -1.11 | -1.22 | -1.03 | -3.35 | -3.46 | -3.32 | -6.25 | -6.80 | -5.70 |
| | 2021-2040 | -0.88 | -0.91 | -1.20 | -4.27 | -3.84 | -4.48 | -8.15 | -8.36 | -7.47 |
| Turkey | 2021-2030 | 0.01 | 0.36 | 0.16 | 0.83 | 1.55 | 1.16 | 1.58 | 3.16 | 1.70 |
| | 2021-2040 | -0.05 | 0.25 | 0.11 | 0.73 | 1.53 | 1.29 | 1.57 | 3.64 | 1.91 |
| West Balkans | 2021-2030 | 0.10 | 0.09 | 0.12 | 0.17 | 0.12 | 0.19 | 0.19 | 0.14 | 0.22 |
| | 2021-2040 | 0.06 | 0.05 | 0.09 | 0.15 | 0.08 | 0.21 | 0.22 | 0.11 | 0.30 |
| North Africa | 2021-2030 | 1.00 | 0.76 | 0.75 | 2.34 | 1.78 | 1.96 | 4.46 | 3.49 | 3.77 |
| | 2021-2040 | 0.86 | 0.61 | 1.00 | 3.39 | 2.22 | 2.97 | 6.34 | 4.60 | 5.25 |

Notes:
All scenarios assume full RES cooperation between the EU and ist neighbours
+ ... monetary transfer to host country/region, - ... monetary transfer from importing country/region.

For the weak target scenario one can observe that monetary transfers from the EU to the other regions decrease in the long term, whereas increases can be observed for the moderate and strong RES target scenarios. In the weak target scenario, Turkey e.g. exhibits small monetary outflows of 0.05 billion € per year on average throughout the period 2021 to 2040 in the default case. Contrarily, the sensitivity variants indicate that Turkey is becoming an exporter, receiving inflows of 0.25 and 0.11 billion € on average per year, respectively, which can be connected to the respective exports of RES described in more detail in section 3.2.1.

The Western Balkan region exhibits decreasing monetary inflows in a weak RES target scenario for the default as well as the sensitivity variants in the long term. For the moderate target, this trend is true for the default and the "Turkey non-affiliation" case, whereas inflows slightly increase if North Africa delays its grid expansion and the Western Balkan in turn increases its exports. In the strong RES target scenario, monetary transfers increase in the long term for the default case as well as the moderate grid expansion case for North Africa. In the case that Turkey is non-affiliated, monetary transfers decrease as Turkey can offer more RES exports to the EU as in the other scenarios –as they do not need the generation for their domestic target fulfilment.

In North Africa, the different scenarios also change in the 2040 timeframe. In the weak target case, monetary transfers to North Africa decrease in the default case and in the "Turkey non-affiliation" case. Only in the moderate grid expansion case a slight increase of 0.25 billion €/a can be seen. In the moderate target case increases can be observed in all sensitivities and the default case when one compares the medium to the long-term perspective. The same is true for the strong RES target scenario. Overall, one can conclude that with a few smaller exceptions cooperation and the associated monetary flows will be strengthened in the longer term and thus seems to be beneficial and sustainable. The following section looks deeper into the economic impacts of RES cooperation with third countries, and provides further backing on how the monetary exchange is derived as well as on related consequences.

## 3.3 Economic impacts

To enable conclusions on the economic feasibility of the different levels of RES deployment, they have to be quantified, i.e. expressed in economic terms. Guiding the interested reader through the modelling results related to economic is subject of this section. To start with, the (need for) financial support for RES, in particular for renewable electricity (for which cooperation opportunities and impacts are assessed), is discussed next. In subsection we then take a look at economic impacts in broader terms, looking at the impacts of RES cooperation on overall costs and benefits related renewable electricity at a regional level.

### 3.3.1 Financial support for RES (in the electricity sector)

Below the need for RES support in the post 2020 period is discussed in a more general manner (see Box 8) and, afterwards, the changes in support levels as a consequence of enhanced and geographically extended RES cooperation are shown and interpreted.

**Box 8: The need for RES support post 2020**[38]

As outlined in Held et al. (2015), to which extent dedicated support for renewables can be phased out in the upcoming decade will mainly depend on (i) the costs of renewable energy technologies and on (ii) future power and carbon prices. Further cost reductions for renewable energy technologies can be expected in the upcoming decade, also due to the increasingly global deployment of renewables. This will lower the costs of supporting the deployment of renewables. Future power and carbon prices are, however, subject to higher uncertainty. The EU carbon market is currently confronted with an oversupply of $CO_2$ emission allowances, while many EU power markets are struggling with overcapacity. Resolving these issues is also a matter of political intervention and therefore subject to high uncertainty. In the event that these markets regain their equilibrium, support costs for renewables can further decrease.

However, moderate support for renewable electricity generation will still be needed even beyond 2020, for two reasons:

- Some less mature technologies (e.g. offshore wind, wave and tidal stream or concentrated solar thermal power) will experience significant cost reductions thanks to technological learning also after 2020. Support for these technologies is motivated by the fact that they will most likely be needed for the long-term decarbonisation objectives of the EU by 2050.
- Due to the price-reducing effect of renewables with variable generation costs close to zero, the market value for variable renewables like solar and wind power is lower than the reference electricity price (see for example Sensfuß et al. 2008).

In accordance with Held et al. (2015), our model-based assessment of future renewables deployment at national and EU level assuming achievement of the 27% RES target by 2030[39] confirms the need for moderate RES support post 2020, and that the necessary remuneration for renewables is expected to decline over time. In Figure 50 we illustrate the development of remuneration levels and market values for dispatchable and variable renewables at EU level according to the reference case within our assessment of geographically enhanced RES cooperation. Therein, RES cooperation is consequently limited to the EU28. On the one hand, the analysis indicates a steady decline in remuneration levels for renewables over the whole assessment period as a result of expected technological progress across all key renewable technologies. This positive trend is driven by cost reductions for onshore and offshore wind as well as solar pho-

[38] Based on Held et al. (2015), accessible e.g. at www.towards2030.eu.

[39] Within our assessment of prospects for RES cooperation the scenario of aiming for 27% RES by 2030 at EU level is named as “weak RES target” since more ambitious alternative RES policy pathways are assessed additionally.

tovoltaics, which are expected to be the dominant renewable energy technologies in the power sector beyond 2020, at least at EU level. On the other hand, the decrease in market values of variable renewables partly diminishes these gains in later years. Market values of variable renewables are expected to more strongly decouple from average wholesale electricity prices. Overall, the need for net support, i.e. the difference between necessary remuneration and market value, is however shrinking for renewable electricity through to 2030 and beyond.

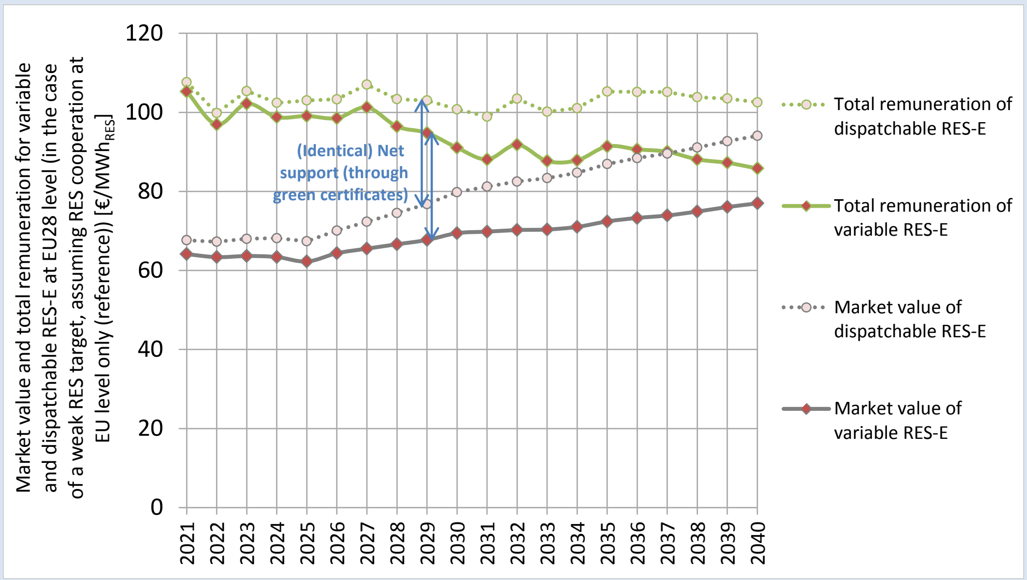



**Figure 50: Future development of remuneration levels and corresponding market values of dispatchable and variable RES-E technologies at EU28 level according to a Green-X scenario of meeting 27% renewables by 2030**

Note: In accordance with our scenario definition results refer to the EU only (reference) case under a weak RES target (of aiming for 27% RES by 2030)

Our assessment of prospects for RES cooperation in the extended geographical context builds on the assumption that a joint trading regime for renewable electricity – more precisely, for new RES-E plants installed post 2020 – is established across the EU and its neighbours, becoming operational from 2021 onwards. That implies that governments impose a mandatory demand via quota obligations (i.e. legally enforceable orders to producers for specified amounts of renewable electricity to be sold) to promote electricity generation from RES. Within such a system RES producers receive income through selling their produced electricity on the wholesale market and, in addition, through earnings gained through the green certificate market.[40] The green certificate price is consequently representing the net support for renewable electricity.

Figure 51 shows in which ways the green certificate price could evolve given different RES cooperation scenarios. One can see that with a strong RES target and in the case of unrestricted RES cooperation, considerable savings are possible. Comparing the EU only (reference) cases to the EU plus full cooperation scenarios (depicted in the above part of Figure 51), one can observe substantial differences. In the case of restricted cooperation (where only EU28 member states cooperate), certificate prices are substantially higher.

[40] A tradable green certificate (TGC) is used to represent the 'added value' or 'greenness' of one pre-defined unit of electricity produced from RES. Due to a quota obligation imposed by the government, an 'artificial' demand for TGC is created. The obligated bodies can be any of the 'actors' in the electricity chain, namely generators, transmission or distribution companies, brokers, suppliers or consumers. To fulfil the obligation, obligated actors are allowed to either produce renewable electricity themselves or to buy TGCs.

Expressed in numerical terms, this would mean that a strong target would yield a certificate price of 41 € per MWh[41] in 2030 and 27.9 €/MWh in 2040 when no cooperation takes place. This certificate price would fall to 33 €/MWh in 2030 in the EU plus cooperation scenario and would be even lower at a mere 15.2 €/MWh in 2040. In the case of a weak target for RES deployment, the scenario results in even more extreme values. Whereas in the EU only (reference) case the price for a certificate would be 21 € in 2030 and 8.5 € in 2040, the default case exhibits a value of only 11.7 €/MWh in 2030 and a certificate price of zero in 2040. This comparison again shows how the EU, North Africa, the Western Balkans and Turkey could benefit from cooperation within the RES-E trading regime.

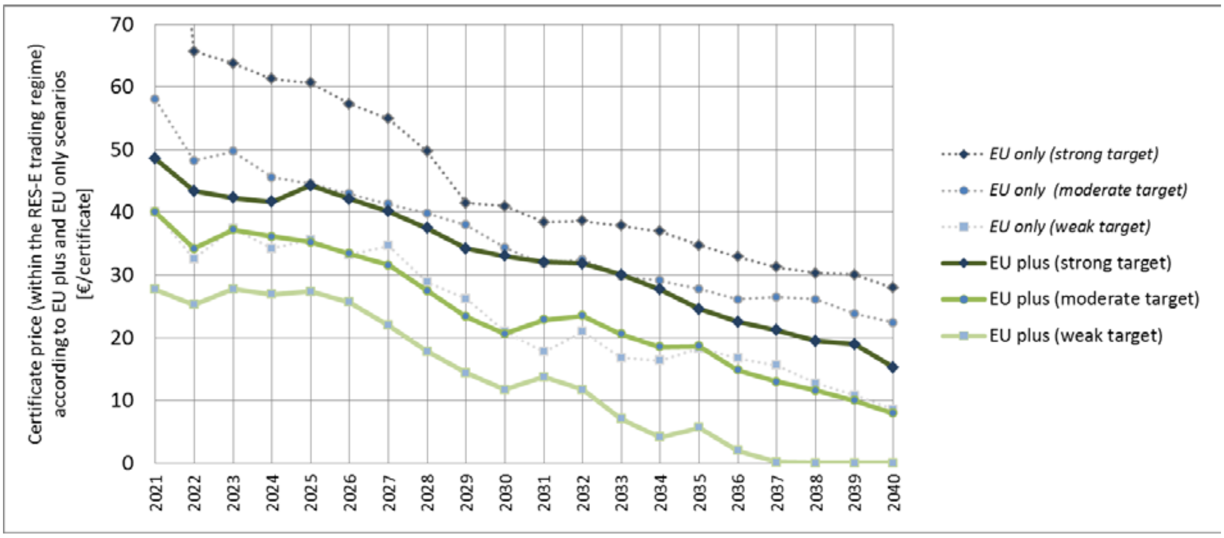



**Figure 51: Certificate prices (within the RES-E trading regime) according to EU plus (full cooperation) and EU only (reference) scenarios under a weak, moderate and strong RES target**

Figure 52 displays certificate price developments for the same period of time in the case of the assessed sensitivity variants. Several scenarios are contrasted. The range of certificate prices in non-EU countries according to the EU only case (where cooperation is constrained to EU Member States) is also shown (shaded area). The upper partition shows the development when a weak target for RES deployment is assumed. The highest price level of certificates can be seen for the EU only case (no cooperation). Overall, certificate prices fall more or less continuously from 40 €/MWh to roughly 8 €/MWh in 2040, with a few smaller spikes in e.g. 2027 or 2032 that show increases of around 4 €/MWh in comparison to the previous year.

Slightly lower certificate prices can be seen in the case that North Africa experiences delays in the deployment of PV and wind, the second sensitivity variant analysed. Following a similar slope, this sensitivity variant begins at a certificate price level of 28.7 €/MWh in 2021 and falls to 2.3 €/MWh in 2040. The EU plus (default) and the "low ambition for RES deployment in Turkey" sensitivity variant are the scenarios with the lowest certificate prices. They show a very similar development with the sensitivity variant being always slightly below the default case. Concretely, the prices fall up to 2030 with a spread of 26 to 10 €/MWh for the sensitivity and 27.7 to 11.7 €/MWh for the default respectively. Then the price reaches a plateau up to 2032 and finally falls steeply and reaches zero in 2037 for the sensitivity and in 2038 for the default case.

[41] Since a uniform RES-E trading regime is assumed where no technology banding is foreseen, one green certificate equals one MWh of RES generation.

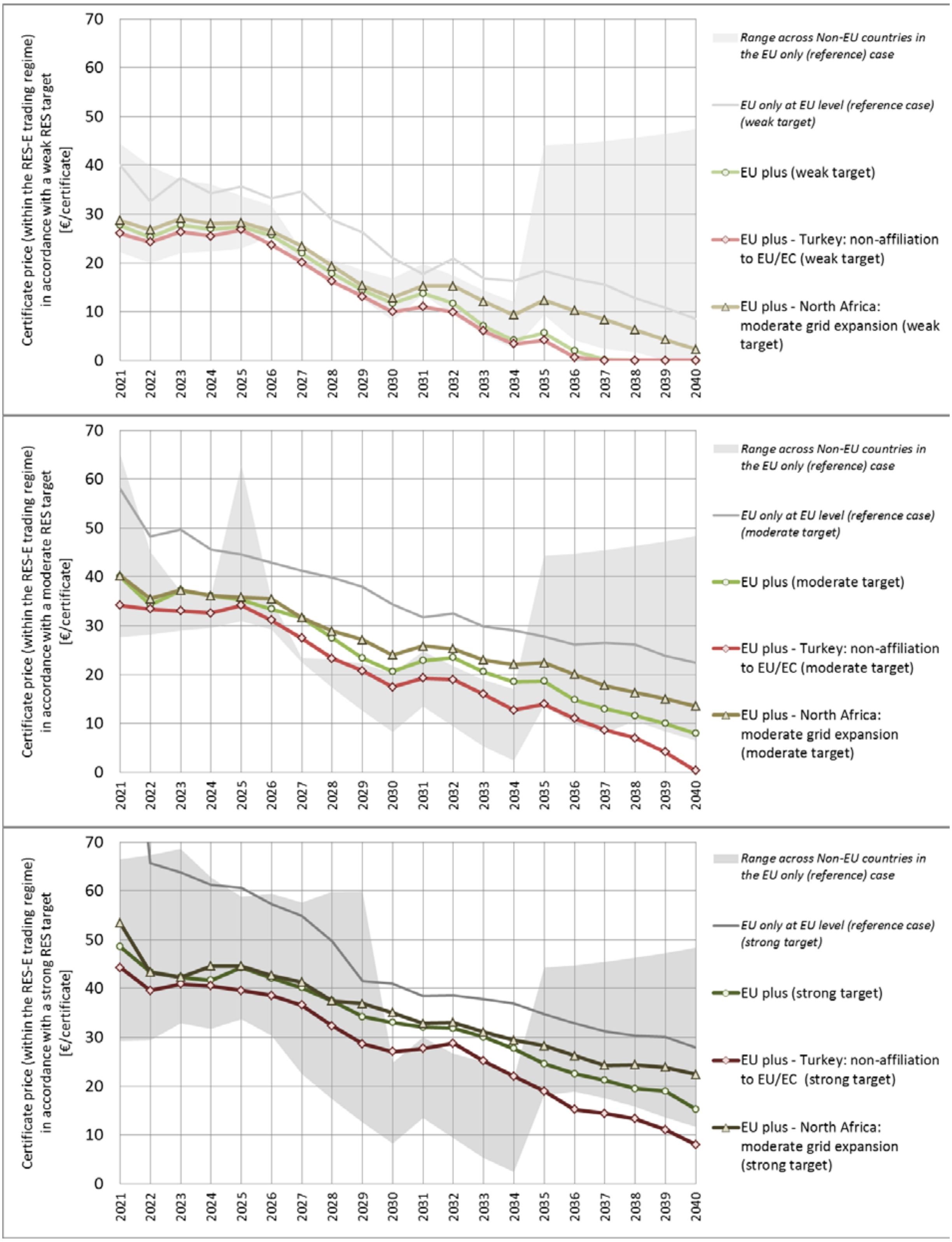



**Figure 52: Certificate prices (within the RES-E trading regime) according to EU plus (full cooperation) and EU only (reference) scenarios including sensitivity variants (assuming a weak (up), moderate (middle) and strong target (bottom) for RES deployment)**

A moderate target for RES deployment at EU level is shown in the middle partition of Figure 52. For the EU plus case, the certificate price starts at a level of 40 €/MWh in 2021 and then continuously falls to 20.6 €/MWh in 2030 and to 8 €/MWh in 2040. The low ambition policy variant for Turkey shows a similar pattern in its resulting certificate price but at an overall lower level. Concretely, the price starts at 34.2 €/MWh in 2021, falls to 17.4 €/MWh in 2030 and amounts to a mere 0.3 €/MWh in 2040. In the North Africa sensitivity variant, the certificate price remains at a constantly higher level after 2025 compared to the EU plus case. In 2030, for instance, the price amounts to 24.3 €/MWh (as compared to 20.6 €/MWh in the default case) and in 2040 it takes on a value of 13.5 €/MWh, 5.5 €/MWh higher than the EU plus price.

This price level nevertheless is still far below the reference (EU only) price level that would occur if the EU28 Member States only cooperated amongst themselves. This reference price is estimated to be at 58 €/MWh in 2021, in 2030 it would amount to 34.4 €/MWh and for 2040 it would still be at 22.4 €/MWh. This is a difference of more than 10 €/MWh annually throughout the complete two decades, in comparison to the EU plus case. Whereas in any scenario, prices continuously fall for the EU28 Member States, the range for the other countries of interest shows a more diverse pattern. For some countries, the certificate price is expected to spike in 2025. A strong increase is also visible up to 2035, such that a range between 8 and roughly 49 €/MWh is possible in 2040.

A strong target for RES deployment at EU level leads to the following developments in the certificate price (see lower part of Figure 52). In the EU only case, a very high price of initially 125 €/MWh can be observed in 2021 which falls steeply to roughly half its value in 2022 (65 €/MWh). After this strong break, the price falls continuously and slowly until 2026 and then exhibits a steep decrease until 2029 from 57.7 to 41.5 €/MWh. After that, the decrease continues but less steeply. In 2040 the certificate price amounts to 27.9 €/MWh.

The EU plus scenario as well as the sensitivity variants exhibit a similar development. They all start at a fairly high level with the North Africa sensitivity being the highest at 53.4 €/MWh followed by the EU plus default at 48.5 €/MWh and then the Turkey sensitivity with 44.3 €/MWh. In all three scenarios the price decreases substantially in the first year. Specifically it falls to 43.4 €/MWh in the default case and the North Africa sensitivity and to 39.6 €/MWh in the Turkey sensitivity. The price then falls in all three cases, whereas some smaller increases can be observed – for the North Africa sensitivity variant in 2024, in the default case in 2025 and in the Turkey sensitivity between 2030 and 2032. The overall path of all three cases is nevertheless downward. In 2040 the prices amount to 22.4 €/MWh in the North Africa sensitivity, to 15.2 €/MWh in the EU plus default case and to 8 €/MWh in the Turkey sensitivity variant.

### ***Savings related to RES support at EU level***

Multiplying national generation by the difference in certificate prices yields overall savings for the EU28 member states that can be achieved through RES cooperation. In the following, this cost perspective is discussed. As shown in Table 15, overall savings can be quantified for the medium-term period, namely the decade between 2021 and 2030, as well as for the long-term perspective (2040), indicating average yearly savings over the whole assessment period (2021 to 2040).

Beginning with a strong RES target, in the EU plus, i.e. full cooperation scenario, on average 8.6 billion € per year can be saved in the period up to 2030. This corresponds to 27% lower support expenditures that occur within the RES-E trading regime at EU level, compared to the reference (EU only) scenario where cooperation is limited to EU28 Member States only. Over the whole assessment period (2021 to 2040) even higher savings can be expected: 13.5 billion € or 29% (compared to reference). In the sensitivity variant that assumes low ambition for RES deployment in Turkey, the average savings are higher in absolute terms (20.6 billion € on average between 2021 and 2040) and relative terms (44% compared to reference). In the second sensitivity variant, that assumes delayed instalments of PV and wind in North Africa and consequently slightly reduced possibilities for RES cooperation, 21% savings are possible for the EU28 Member States on average (2021-2040), amounting to a total of 9.8 billion € annually.

Under a moderate RES target, annual savings for the EU plus case amount to 6 billion € on average in the period 2021 to 2030. In relative terms, this makes up a decrease in policy costs (i.e. support expenditures within the RES-E trading regime) of 29% compared to the corresponding EU only (reference) case. Again, higher figures occur once the whole assessment period (2021 to 2040) is considered: 12.2 billion € or 39% (compared to reference). Assuming a low ambition target for domestic RES deployment in Turkey, relative savings increase to 55%, and in absolute values to 16.9 billion € on average (2021-2040). For the second sensitivity variant where the transmission grid and consequently wind and PV expansion is delayed in Northern African countries, savings amount to 8.5 billion € per year or 27%, respectively.

For a weak RES deployment target, the savings between 2021 and 2030, even though substantially lower in absolute terms, make up an even higher share than under a moderate or strong target. Concretely, this means that in the EU plus case, savings amount to 33% (compared to the corresponding EU only (reference) case) or 3.8 billion €. Similar to above, savings increase further to 8.7 billion € or 60% (compared to reference). According to the first sensitivity variant, i.e. low ambition level in Turkey, they even increase to 65% (on average throughout the whole period) or 9.4 billion € annually. In the second sensitivity case, i.e. the delayed grid expansion in North Africa, 37% of policy costs can be saved compared to reference, amounting to 5.3 billion € per year on average.

**Table 15: Direct economic benefits at EU level (i.e. savings in support expenditures within the RES-E trading regime) from RES cooperation with assessed neighbouring countries**

| **Economic benefits at EU level** (savings in support expenditures for new RES-E installations (post 2020) within the RES-E trading regime, compared to reference (EU only)) | | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion | *default case* | Turkey: non-affiliation to EU/EC | North Africa: moderate grid expansion |
|---|---|---|---|---|---|---|---|---|---|---|
| RES target (ambition level): | | weak RES target | | | moderte RES target | | | strong RES target | | |
| **in absolute terms** [billion €, on average per year] | 2021-2030 | -3.8 | -4.4 | -3.4 | -6.0 | -7.5 | -5.1 | -8.6 | -11.4 | -7.8 |
| | 2021-2040 | -8.7 | -9.4 | -5.3 | -12.2 | -16.9 | -8.5 | -13.5 | -20.6 | -9.8 |
| **in relative terms** [%, compared to reference] | 2021-2030 | -33.4% | -38.4% | -29.5% | -29.4% | -36.9% | -25.0% | -26.8% | -35.2% | -24.2% |
| | 2021-2040 | -59.7% | -64.7% | -36.6% | -39.4% | -54.6% | -27.4% | -28.9% | -44.0% | -20.9% |

Notes:
All scenarios assume full RES cooperation between the EU and its neighbours

## 3.3.2 Costs and Benefits of enhanced RES cooperation

As outlined beforehand, extended the geographical scope of RES cooperation to the EU's neighbours brings about monetary savings that can be expressed in terms of certificate price development. Benefits as well as costs associated with the use of renewables, in particular with renewable electricity, are influenced by RES cooperation. They are further measurable as changes in benefits – i.e. avoided fossil fuels and avoided $CO_2$ emissions –, in investments (i.e. capital expenditures) and in costs – i.e. support expenditures and additional generation cost on the other.

Next we make a comparison of the resulting changes in costs and benefits associated with renewable electricity use at regional level, i.e. for the EU28, the Western Balkans, Turkey and North Africa. Thereby, changes are induced by enhanced RES cooperation (when moving from RES cooperation at EU level only (EU only) to full RES cooperation between all assessed regions). Moreover, please note that in order to simplify a comparison between distinct categories, all values are expressed in monetary terms – i.e. for example "avoided fossil fuel" use is translated into "avoided expenses for fossil fuels" (with impact on a country's trade balance) through multiplication of annual energy quantities with corresponding fossil fuel price trend assumptions, done in a dynamic way. In contrast to fossil fuels, for avoided CO2 emissions a constant carbon value of 80 €/ton CO2 is used for the monetary expression – in accordance with the approach taken for the assessment of environmental co-effects, cf. section 4.1.

## ***European Union***

As can be seen in Figure 53, an EU plus (full cooperation between EU28 Member States and Third countries) scenario leads to avoided fossil fuels in all different RES target cases, i.e. for the weak, moderate and strong RES target at EU level in the medium term. Specifically, for the strong RES target, 1.8 billion € could be saved, for the moderate target a slightly lower amount of 1.4 billion € annually and in the weak target case 0.3 billion € per year remain. In the longer term, this picture changes: for the weak target, fossil fuel use would have to increase between 2021 and 2040. Namely, fossil fuels to an amount of 1.2 billion € per year would have to be purchased annually. Concerning avoided $CO_2$ emissions, costs that occur are quite low for the EU28 Member States in the full cooperation scenario. In the longer term, up to 2040, monetary benefits occur for the weak, moderate and strong target case.

Capital expenditures can be lowered substantially with full cooperation compared to the EU only (reference) scenario. With a strong target, 22 billion € can be saved annually. A moderate target induces lower capital expenditures in comparison to the reference case of 15.7 billion €. Even a weak RES target still leads to minus 7.1 billion € capital expenditures annually, or 20.6% less compared to the reference case.

The same pattern can be observed for support expenditures, whereas at a lower level. As discussed at the end of the previous section (, support expenditures decrease substantially in the medium term, e.g. when assuming a strong RES target, 8.6 billion € can be saved annually up to 2030. Up to 2040, savings even increase up to 13.5 billion € per year. For the moderate and weak target, savings are lower but still visible with amounts of 6.0 and 12.2 billion € and 4.2 and 8.9 billion € respectively up to 2030 and 2040.

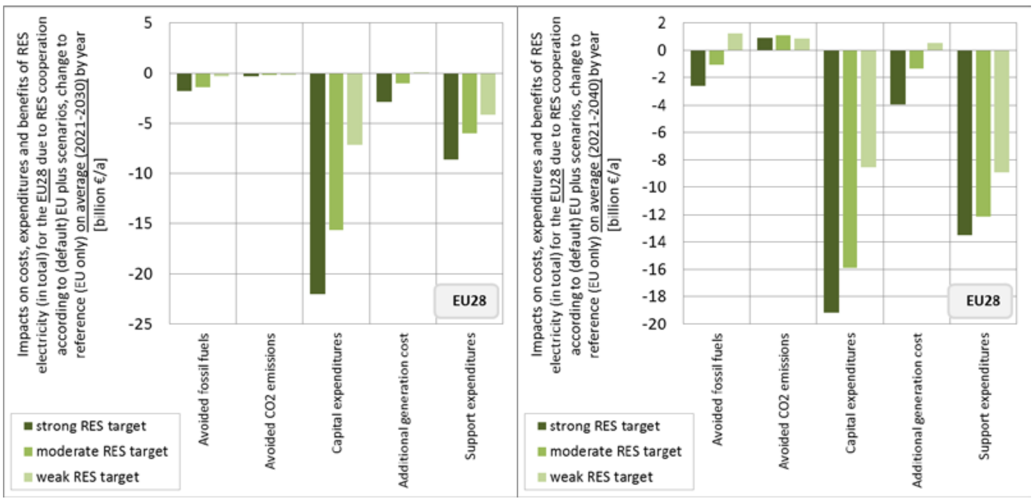



**Figure 53: Impacts of enhanced RES cooperation on costs and benefits of renewable electricity for the EU28 in the medium (2021-2030) and long term (2021-2040) for a weak, strong and moderate RES target.**

Additional generation costs fall for the strong and moderate RES target in the medium and long term perspective. Specifically, a decrease of 2.9 billion € per year for the strong target and 1 billion € per year for the moderate target can be observed in the medium term (up to 2030). When a weak RES target is assumed at EU level, these costs increase slightly compared to the reference (EU only scenario). In the medium term perspective (2021-2030) this means additional generation costs of 0.1 billion € per year. In the longer term (2021-2040) the increase is higher, namely amounting to 0.5 billion €/a.

## ***Turkey***

In Turkey, the costs and benefits evolve in the following way. Under a strong RES target, in the medium term, substantial savings occur in terms of avoided fossil fuels and avoided $CO_2$ emissions. Expressed as monetary values, these amount to around 2 billion € each per year.  For a moderate target, the amount falls, namely to 1.3 and 1.5 billion € respectively. In terms of capital expenditures, Turkey would have to expect additional expenditures of around 4.7 billion € per year in the mid-term. In the long term perspective, nevertheless, looking at the right hand side of Figure 55, the capital expenditures decrease whereas the benefits in terms of avoided fossil fuels and $CO_2$ emissions increase. This shows that while in the beginning additional expenditures are quite substantial, the overall benefits are sustainable and at a constant level in the long term perspective.

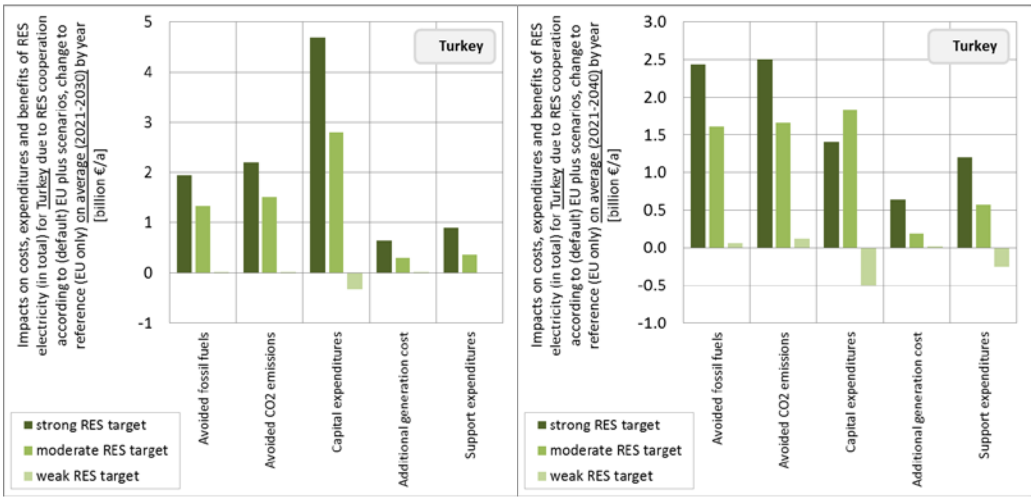



Figure 54: Impacts of enhanced RES cooperation on costs and benefits of renewable electricity for Turkey in the medium (2021-2030) and long term (2021-2040) for a weak, strong and moderate RES target.

The moderate target scenario exhibits lower capital expenditures at 2.8 billion €, which decrease to 1.8 billion € annually in the longer term. In comparison to the capital expenditures, additional generation cost as well as support expenditures are quite low. In the medium term, additional generation costs amount to 0.6 billion € for the strong target and to 0.3 billion € for the moderate target. In the longer term for the strong RES target, these costs stay at the same level, whereas they slightly decrease for the moderate target. Support expenditures amount to 0.9 billion € annually (strong target) or 0.4 billion € annually (moderate target) in the medium term. The long term scenario exhibits higher support expenditures in the strong and moderate target scenario (1.2 billion € and 0.6 billion € per year respectively). The weak RES target scenario hardly exhibits any changes when it comes to additional generation costs or support expenditures. The only visible change occurs for support expenditures in the long term – a weak target for RES leads to decreasing support expenditures (annually 0.3 billion €).

## ***Western Balkans***

The Western Balkan region exhibits a slightly different pattern in the development of costs and benefits. Avoided expenses for fossil fuels range from 0.3 (strong target for RES at EU level) to 0.2 billion € (moderate and weak target) annually for the medium term perspective. In the long term, benefits from avoided fossil fuels increase for a strong RES target and decrease for a weak target. Specifically, a strong target leads to 0.34 billion € per year, whereas a weak target induces a mere 24 million € annually. Looking at avoided $CO_2$ emissions shows a similar development. Whereas in the medium term, benefits range between 0.3 (strong target) and 0.2 billion € (medium and weak target), the long term perspective shows that a strong and moderate RES target lead to sustainable benefits up to 2040, whereas a weak RES target has only little effect when one looks at a broader time frame.

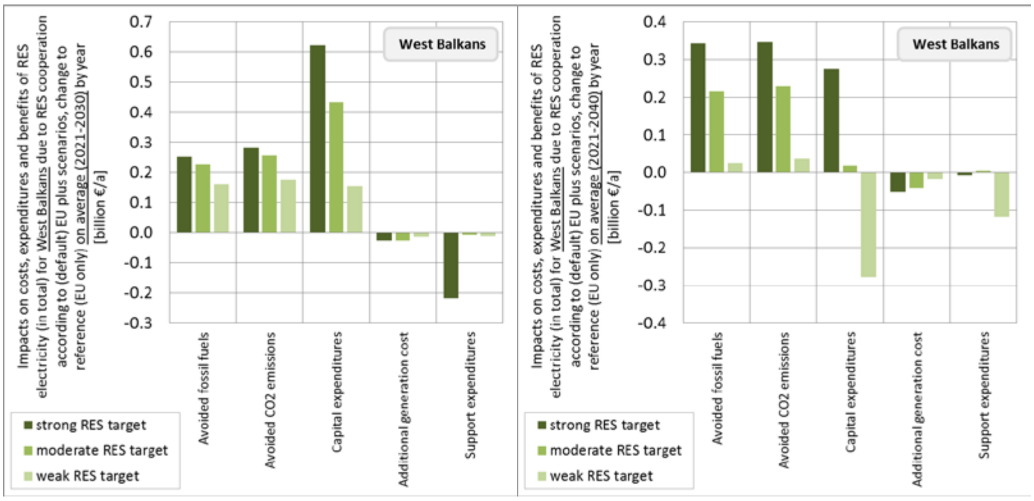



**Figure 55: Impacts of enhanced RES cooperation on costs and benefits of renewable electricity for the Western Balkans in the medium (2021-2030) and long term (2021-2040) for a weak, strong and moderate RES target.**

Looking at expenditures resulting from RES electricity deployment induced through RES cooperation between the EU28 Member States and the Western Balkans, the medium term shows an increase in capital expenditures of roughly 0.6 billion € annually for the strong target, whereas support expenditures decrease by more than 0.2 billion €. For the moderate and weak RES target scenarios, the capital expenditures also increase by 0.4 and 0.14 billion € per year respectively up to 2030.

Support expenditures do not exhibit any significant changes throughout that period of time. In the long term perspective a strong RES target still exhibits substantially increased capital expenditures by roughly 0.3 billion € annually. A weak RES target on the other hand shows a decrease in roughly that dimension, whereas a moderate RES target hardly changes capital expenditures in the long term. Support expenditures decrease only slightly through cooperation under a strong RES target in the long term as compared to the more significant decrease in the medium term. Again, the moderate target seems to come with basically unchanged expenditures, whereas the weak RES target leads support expenditures to be around 0.1 billion € lower annually.

Generation costs decrease under all scenarios and, not surprisingly, the most significantly when looking at a strong RES target. Under a strong target and in the long term perspective, generation costs decrease by 50 million € annually. In the medium term, the savings amount to roughly half of that value.

### ***North Africa***

In North Africa, in the medium term, benefits from avoided fossil fuels are basically the same for each target, i.e. the strong moderate and weak RES target induce 1.6 to 1.5 billion € annual savings each. The avoided $CO_2$ emissions lead to similar benefits: the savings amount to between 1.8 and 1.7 billion € per year. In the longer term (up to 2040), the targets still do not induce a large bandwidth of savings. Specifically, savings range from 3.5 (strong target) to 3.6 billion € (weak target) for avoided fossil fuels and from 3.4 (strong target) to 3.6 billion € (weak target) for avoided $CO_2$ emissions.

Capital expenditures on the other hand vary greatly depending on the underlying target. A strong target requires additional capital expenditures of 9.3 billion € per year in the medium term. For a moderate target, this amount falls to 6.3 billion € annually and for a weak RES target, it amounts to 2.5 billion € annually in the medium term. In the longer term perspective, the expenditures are lower but show a similar pattern of namely 8.2 billion € per year for a strong, 6.1 billion € per year for a moderate and 4.1 billion € for a weak target. One can observe, that while expenditures are lower in the long term perspective for the most ambitious RES target, are hardly unchanged for the moderate target and increase in comparison to the medium term perspective for the weak target.

Generation costs decrease in the medium term by 0.4 billion € per year for all targets. In the long term, the decrease is getting smaller, amounting to annually 0.2 billion € for the strong and moderate and to 0.3 billion € for the weak target. Support expenditures on the other hand increase slightly in the medium term, amounting to annually 0.4 billion € for the strong RES target and 0.2 billion € for the moderate. There are no noteworthy support expenditures to be seen for the weak target in the medium term. In the long term, support expenditures decrease for all target scenarios in comparison to the reference case. Concretely, they fall by 0.4 billion € annually for the strong, by 0.9 billion € annually for the moderate and by 1.5 billion € annually for the weak target case.

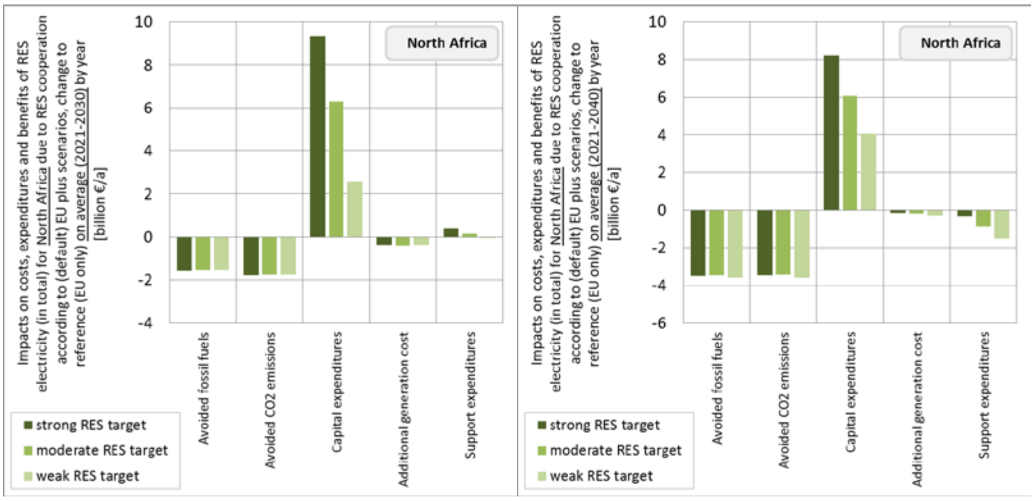



**Figure 56: Impacts of enhanced RES cooperation on costs and benefits of renewable electricity for North Africa in the medium (2021-2030) and long term (2021-2040) for a weak, strong and moderate RES target.**

## ***Sensitivity variants on regional specifics***

Table 16 (below) depicts the costs and benefits for all assessed cases. The values shown are deviations from the reference case (EU only) and are shown in billion €/a. In the left column, the EU plus default case as well as the Turkey and North Africa sensitivity are shown for a weak RES target (27%). The middle column depicts the moderate and the right hand column the strong target.

Looking at the first category exemplarily, avoided fossil fuels, for instance, in the medium term (up to 2030) perspective, the Turkey sensitivity leads to increased expenditures for the EU28 Member States in comparison to the reference case, whereas the EU plus default case as well as the North Africa sensitivity induce savings – the latter case substantially higher savings than the former. This is true for all target scenarios. For Turkey, the situation evolves differently: in the weak target scenario, nothing changes in comparison to the reference case, whereas in the non-affiliation case a slight amount can be saved. In the “North Africa moderate grid expansion” case, on the other hand, expenditures for Turkey increase in comparison to the reference case for the weak target scenario. For a moderate target scenario, costs increase, as well as for the North Africa variant. In the non-affiliation case, a slight decrease can again be seen. For the strong target case, this development continues.

**Table 16: Impacts of enhanced RES cooperation on costs, expenditures and benefits of RES electricity for all assessed scenarios, depicted in billion € per year as change compared to the reference (EU only) case**

| **Costs, expenditures and benefits** of RES electricity (in total) according to assessed scenarios, **change compared to reference** (EU only) **on average by year** | | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** |
|---|---|---|---|---|---|---|---|---|---|---|
| RES target (ambition level): | | **weak RES target** | | | **moderate RES target** | | | **strong RES target** | | |
| **Avoided fossil fuels [billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | -0.34 | 0.23 | -0.94 | -1.39 | 1.09 | -2.25 | -1.78 | 1.63 | -2.12 |
| | 2021-2040 | 1.24 | 2.02 | -0.17 | -1.06 | 3.03 | -3.49 | -2.61 | 2.74 | -4.00 |
| Turkey | 2021-2030 | 0.00 | -0.02 | 0.35 | 1.33 | -0.03 | 1.77 | 1.95 | -0.06 | 2.03 |
| | 2021-2040 | 0.07 | -0.43 | 0.40 | 1.61 | -0.60 | 2.58 | 2.43 | -0.72 | 2.80 |
| West Balkans | 2021-2030 | 0.16 | 0.14 | 0.18 | 0.23 | 0.17 | 0.25 | 0.25 | 0.21 | 0.28 |
| | 2021-2040 | 0.02 | -0.02 | 0.11 | 0.22 | 0.07 | 0.31 | 0.34 | 0.15 | 0.43 |
| North Africa | 2021-2030 | -1.54 | -1.54 | -1.54 | -1.55 | -1.55 | -1.54 | -1.57 | -1.58 | -1.57 |
| | 2021-2040 | -3.58 | -3.50 | -3.70 | -3.45 | -3.45 | -3.45 | -3.48 | -3.50 | -3.48 |
| **Avoided $CO_2$ emissions [billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | -0.18 | 0.33 | -0.61 | -0.16 | 1.55 | -0.77 | -0.39 | 2.36 | -0.82 |
| | 2021-2040 | 0.87 | 1.48 | 0.02 | 1.09 | 3.75 | -0.54 | 0.90 | 4.98 | -0.40 |
| Turkey | 2021-2030 | 0.01 | -0.04 | 0.40 | 1.51 | -0.09 | 2.00 | 2.20 | -0.14 | 2.29 |
| | 2021-2040 | 0.12 | -0.48 | 0.40 | 1.66 | -0.71 | 2.62 | 2.50 | -0.86 | 2.86 |
| West Balkans | 2021-2030 | 0.18 | 0.16 | 0.20 | 0.26 | 0.19 | 0.28 | 0.28 | 0.23 | 0.31 |
| | 2021-2040 | 0.04 | -0.01 | 0.12 | 0.23 | 0.09 | 0.32 | 0.35 | 0.17 | 0.44 |
| North Africa | 2021-2030 | -1.75 | -1.74 | -1.74 | -1.76 | -1.76 | -1.75 | -1.78 | -1.79 | -1.77 |
| | 2021-2040 | -3.58 | -3.49 | -3.65 | -3.44 | -3.45 | -3.40 | -3.44 | -3.47 | -3.41 |
| **Capital expenditures [billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | -7.10 | -8.03 | -6.29 | -15.66 | -18.12 | -14.26 | -22.05 | -27.62 | -19.14 |
| | 2021-2040 | -8.56 | -9.46 | -6.80 | -15.90 | -20.03 | -12.30 | -19.18 | -26.42 | -14.45 |
| Turkey | 2021-2030 | -0.34 | 2.05 | 0.56 | 2.80 | 6.15 | 3.76 | 4.69 | 10.51 | 4.89 |
| | 2021-2040 | -0.49 | 1.32 | 0.82 | 1.83 | 4.72 | 3.22 | 1.41 | 7.18 | 2.67 |
| West Balkans | 2021-2030 | 0.15 | 0.11 | 0.23 | 0.43 | 0.21 | 0.53 | 0.62 | 0.37 | 0.72 |
| | 2021-2040 | -0.28 | -0.30 | -0.13 | 0.02 | -0.23 | 0.24 | 0.28 | -0.09 | 0.47 |
| North Africa | 2021-2030 | 2.54 | 1.21 | 1.59 | 6.31 | 5.15 | 4.85 | 9.33 | 8.22 | 7.44 |
| | 2021-2040 | 4.06 | 2.52 | 0.51 | 6.08 | 5.19 | 3.01 | 8.23 | 7.41 | 4.76 |
| **Additional generation cost [billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | 0.10 | 0.28 | -0.06 | -1.02 | -0.54 | -1.18 | -2.87 | -2.42 | -2.77 |
| | 2021-2040 | 0.51 | 0.73 | 0.48 | -1.35 | -0.77 | -1.70 | -3.93 | -3.73 | -3.77 |
| Turkey | 2021-2030 | 0.00 | -0.01 | 0.05 | 0.29 | 0.11 | 0.40 | 0.64 | 0.31 | 0.67 |
| | 2021-2040 | 0.02 | -0.02 | 0.05 | 0.19 | 0.02 | 0.31 | 0.64 | 0.16 | 0.70 |
| West Balkans | 2021-2030 | -0.01 | -0.01 | -0.01 | -0.03 | -0.04 | -0.02 | -0.03 | -0.04 | -0.02 |
| | 2021-2040 | -0.02 | -0.02 | -0.01 | -0.04 | -0.06 | -0.04 | -0.05 | -0.08 | -0.04 |
| North Africa | 2021-2030 | -0.36 | -0.35 | -0.31 | -0.40 | -0.41 | -0.35 | -0.36 | -0.39 | -0.31 |
| | 2021-2040 | -0.27 | -0.25 | -0.16 | -0.19 | -0.22 | -0.14 | -0.16 | -0.17 | -0.12 |
| **Support expenditures [billion €]** | | | | | | | | | | |
| EU28 | 2021-2030 | -4.20 | -4.39 | -3.74 | -5.98 | -7.56 | -5.08 | -8.60 | -11.45 | -7.77 |
| | 2021-2040 | -8.91 | -9.49 | -5.54 | -12.16 | -16.89 | -8.46 | -13.50 | -20.62 | -9.74 |
| Turkey | 2021-2030 | 0.00 | 0.14 | 0.07 | 0.35 | 0.37 | 0.49 | 0.89 | 0.64 | 1.02 |
| | 2021-2040 | -0.26 | 0.14 | 0.34 | 0.57 | 0.63 | 1.22 | 1.20 | 1.15 | 1.87 |
| West Balkans | 2021-2030 | -0.01 | -0.02 | 0.00 | -0.01 | -0.08 | 0.02 | -0.22 | -0.22 | -0.20 |
| | 2021-2040 | -0.12 | -0.13 | -0.03 | 0.00 | -0.14 | 0.10 | -0.01 | -0.16 | 0.09 |
| North Africa | 2021-2030 | -0.04 | -0.07 | -0.01 | 0.17 | 0.10 | 0.21 | 0.38 | 0.28 | 0.42 |
| | 2021-2040 | -1.53 | -1.58 | -1.25 | -0.88 | -1.18 | -0.63 | -0.35 | -0.74 | -0.13 |

Notes:

All scenarios assume full RES cooperation between the EU and its neighbours

In accordance with literature external cost of 65 €/t $CO_2$ are used to express the avoidance of CO2 emissions monetarily

Virtual vs. physical trade of renewable electricity:

- For West Balkans virtual trade is assumed in all (default and) sensitivity scenarios
- For Turkey virtual trade is the default option, only in the sensitivitey case related to Turkey physical trade is presumed (since not part of the EU/EC)
- For North Africa physical trade is assumed in all (default and) sensitivity scenarios

In the Western Balkans, all variants and all different targets lead to higher costs in terms of avoided fossil fuels in the medium term perspective. The lowest increase can be observed for the Turkey sensitivity, followed by the default case and then the “North Africa moderate grid expansion” scenario. This picture is also consistent over all three scenarios. Looking at North Africa, one can see that whichever sensitivity case is analysed, savings in terms of avoided fossil fuels stay the same. These savings are constant over the weak and the moderate RES target and only increase slightly for a strong overall RES target. These values give insight on the distributional effects, i.e. how costs, expenditures and benefits are differently distributed over the regions and how they change with the different scenarios and decisions for policy ambition. The same area of the table also shows the long term (up to 2040) perspective for avoided fossil fuels, directly below the columns that depict the medium-term values. Additionally, avoided $CO_2$ emissions, capital expenditures, additional generation cost and support expenditures are depicted for all sensitivities and all target scenarios and can be read and interpreted the same way as the avoided fossil fuels. Furthermore Annex Table 1 gives insight into the absolute values underlying these differences – and furthermore also shows the values for the reference case (EU only) that serves as comparison in all of the presented scenarios.

## 3.4 Key results of the complementary power-system analysis

Complementary to techno-economic assessment as discussed above, grid and transmission needs or constraints, respectively, together with the physical integration possibilities are evaluated from a technical perspective in a power-system analysis, done by use of TU Wien's HiREPS model. As described in section 2.2.1 in further detail, the Green-X modelling of future RES deployment and related costs and benefits by country serves as basis for this analysis. For practical reasons, due to limitations in computing times, the power-system analysis is however limited to the cases of strong and weak RES deployment. Thus, with HiREPS we analyse the interplay between supply, demand and storage in the electricity sector on an hourly basis for the given years (2030, 2040).

Next we present key results of the power-system analysis, discussing the interplay of supply and demand, in particular the resulting generation mix, the resulting market values for variable and dispatchable RES and expected electricity price developments as well as expansion needs and related costs with respect to the transmission grid.

### 3.4.1 Generation mix according to different scenarios

In Figure 57 the energy generation mix is given for four key scenarios of the integrated assessment: the reference (EU only) scenarios and the default full RES cooperation (EU plus) scenarios, referring to a weak and a strong RES target by 2030 and beyond. According to Green-X modelling as discussed in previous sections of this report, in the EU plus scenarios a certain fraction of the demand for renewable electricity is not covered through domestically (i.e. within the EU) generated RES-E, but physically imported or statistically accounted for. In the EU plus scenarios it is assumed that Turkey becomes a member of the Energy Community (or the EU) and by this is getting eligible to statistical transfer of surplus RES. Therefore some of the RES exported from North Africa is integrated into Turkey and statistical transfer is then used to account this RES to the overall EU target.

Key results related to the electricity generation mix at regional level are:

- As a consequence from above, in the EU plus scenarios the fossil electricity generation within the EU28 is 102 TWh (120 TWh) larger than in the EU only (reference) scenarios under a weak (strong) RES target. This can be seen in Figure 57 where the generation mix at EU28 level is shown for all four key scenarios. The additional fossil generation stems mostly from natural gas combined cycle power plants, because the available base load capacity (lignite, coal, nuclear) is almost fully utilised in all 2040 scenarios.
- In Turkey an increase of domestic RES generation can be observed in Figure 58 under a strong RES target when moving from the EU only to the EU plus (full cooperation) scenario whereas a decrease is applicable under a weak RES target. Moreover, massive imports of RES-E generation from North Africa are apparent in the case of full RES cooperation (EU plus), more or less independent from the underlying ambition level for RES (i.e. weak or strong target). Notably, the magnitude of imports is larger under a weak RES target.
- For the Western Balkans the physical export of (renewable) electricity to EU28 increases under a strong RES target compared to the weak target scenarios (see Figure 59). In turn, lignite-fired power generation declines by about 45 TWh, corresponding to 45% of the regions gross electricity demand. For RES generation a similar pattern than in Turkey is applicable if EU plus scenarios are compared to EU only cases: an increase occurs under a strong RES target whereas a decline is notable under a weak RES target.
- North Africa shows the most pronounced increase in RES if EU plus scenarios are compared to EU only scenarios. Moreover, natural gas represents the key option for balancing power in that region.

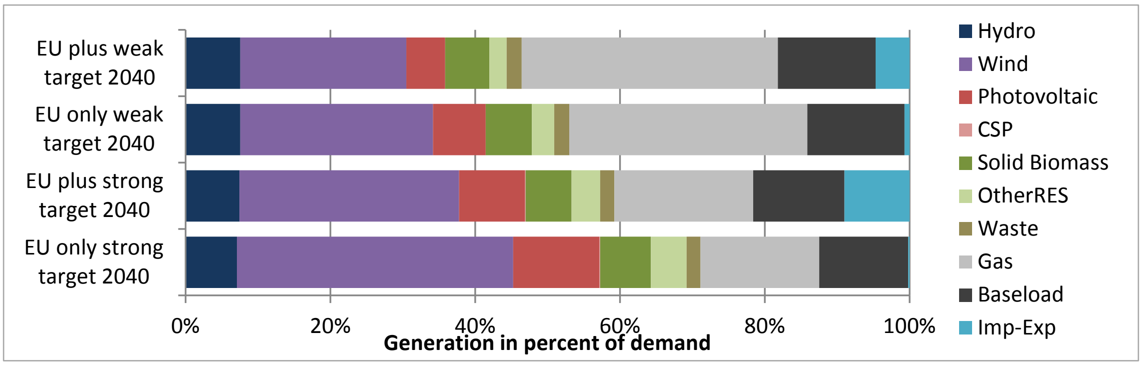



**Figure 57: Electricity generation mix at EU28 level in 2040 according to selected EU plus and EU only scenarios, following a weak or a strong RES target**

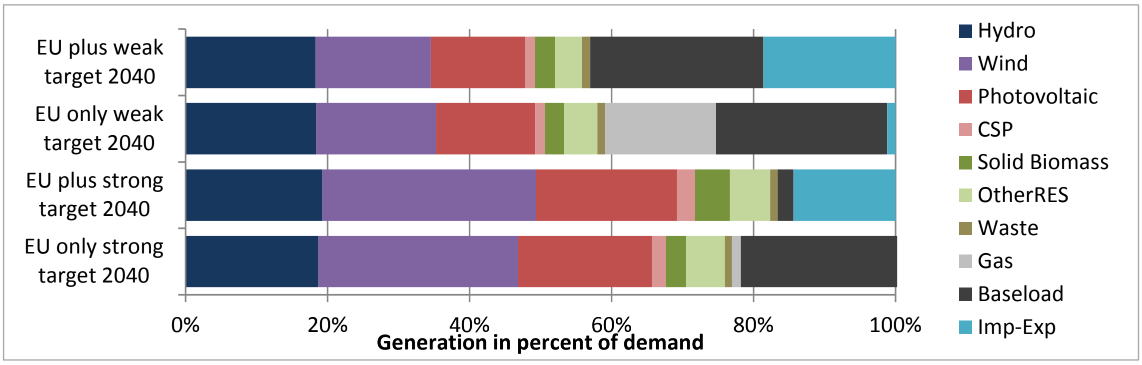



**Figure 58: Electricity generation mix of Turkey in 2040 according to selected EU plus and EU only scenarios following a weak or a strong RES target.**

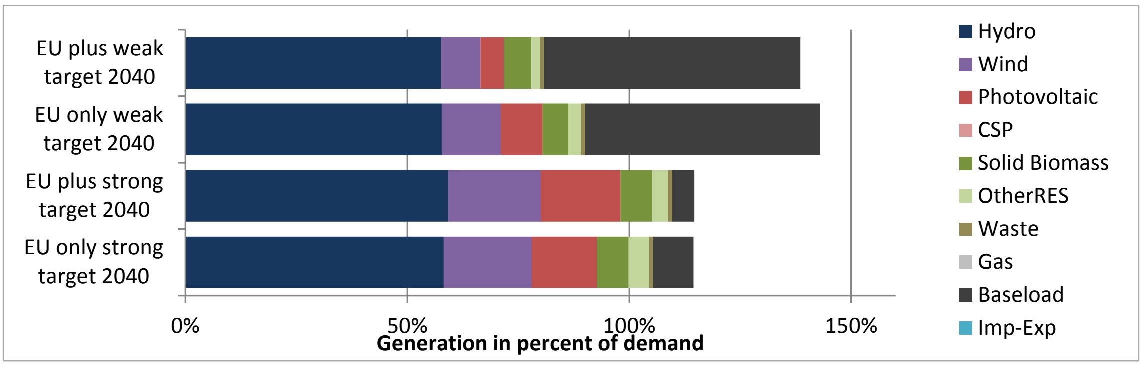



**Figure 59: Electricity generation mix in the Western Balkan region in 2040 according to selected EU plus and EU only scenarios following a weak or a strong RES target.**

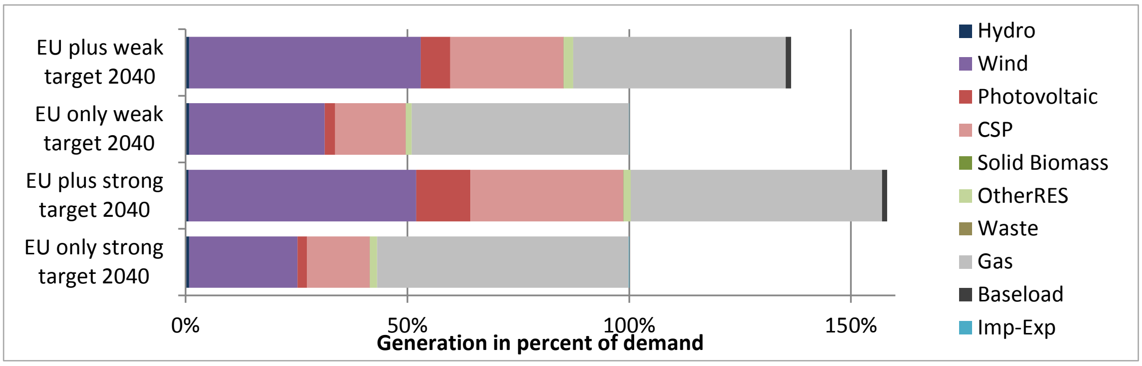



**Figure 60: Electricity generation mix in North Africa in 2040 according to selected EU plus and EU only scenarios following a weak or a strong RES target.**

Complementary to above, in Figure 61 and Figure 62 changes in the hourly electricity supply patterns at EU28 level are shown for one week in July for the EU plus and the EU only scenarios, referring to the year 2040 and to the in terms of impacts most challenging option of striving for a strong RES target. The black line depicts the electricity demand at EU28 level. If the generation exceeds the electricity demand, then exports into neighbouring regions occur. Notably, an increase of electricity generation from natural gas is applicable in the EU plus scenario compared to the EU only scenario.

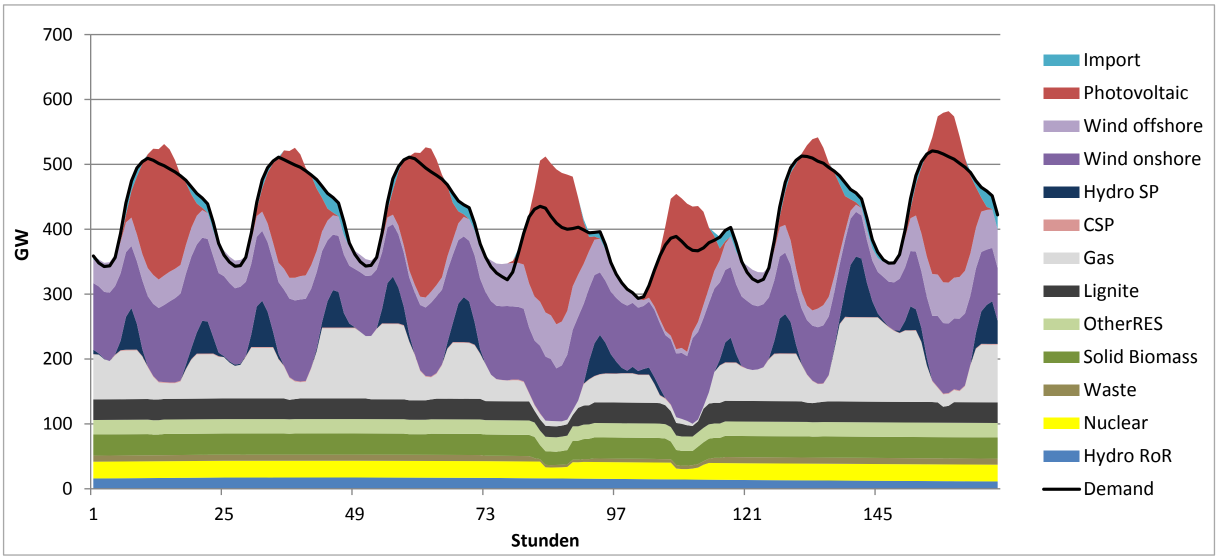



**Figure 61: Hourly electricity supply and demand in the EU28 in 2040 according to the EU only (reference) scenario assuming a strong RES target by 2030 and beyond.**

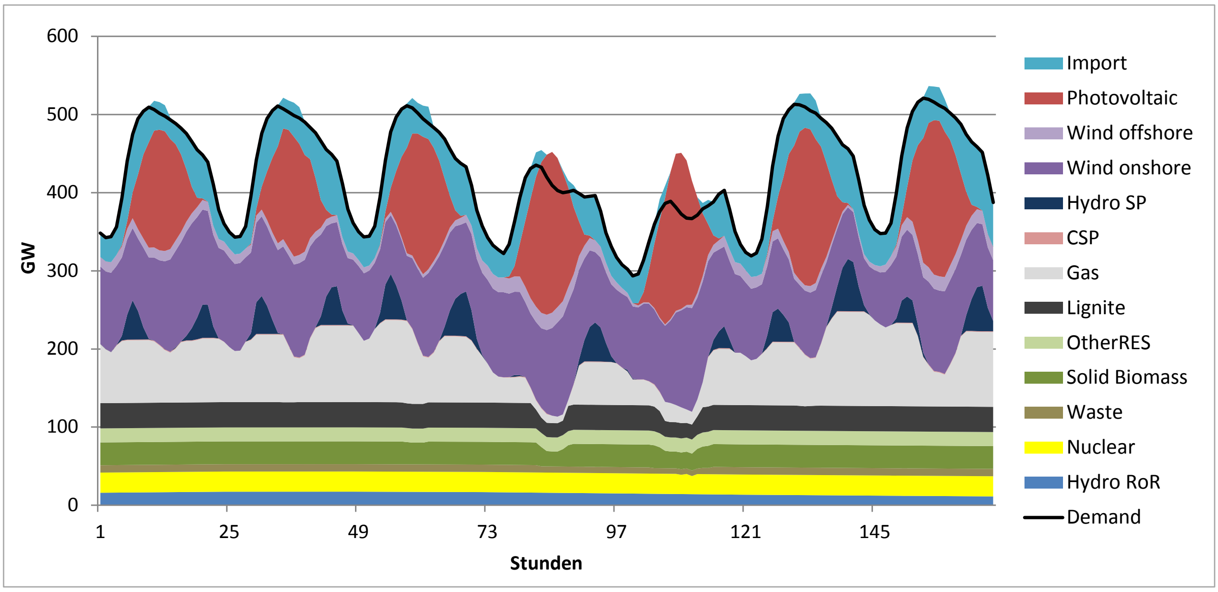



**Figure 62: Hourly electricity supply and demand in the EU28 in 2040 according to the EU plus (full cooperation) scenario assuming a strong RES target by 2030 and beyond.**

### 3.4.2 RES market values and electricity prices

All countries with physical export requirements under the “cooperation umbrella” (i.e. North Africa and, in an own sensitivity variant, Turkey) show significantly lower electricity prices – because of a high share of additional generation stemming from renewable sources. As a consequence, under a strong RES target electricity prices in

2030 in assessed North African countries are 30% lower in the EU plus scenario compared to the reference (EU only) case. Turkey, with price decreases in magnitude of 21%, and Greece as the first importer from Turkey, facing a decline of prices by 8%, have significantly lower electricity prices in the sensitivity variant of the EU plus scenarios assuming that Turkey will not be affiliated to the EU/EC.

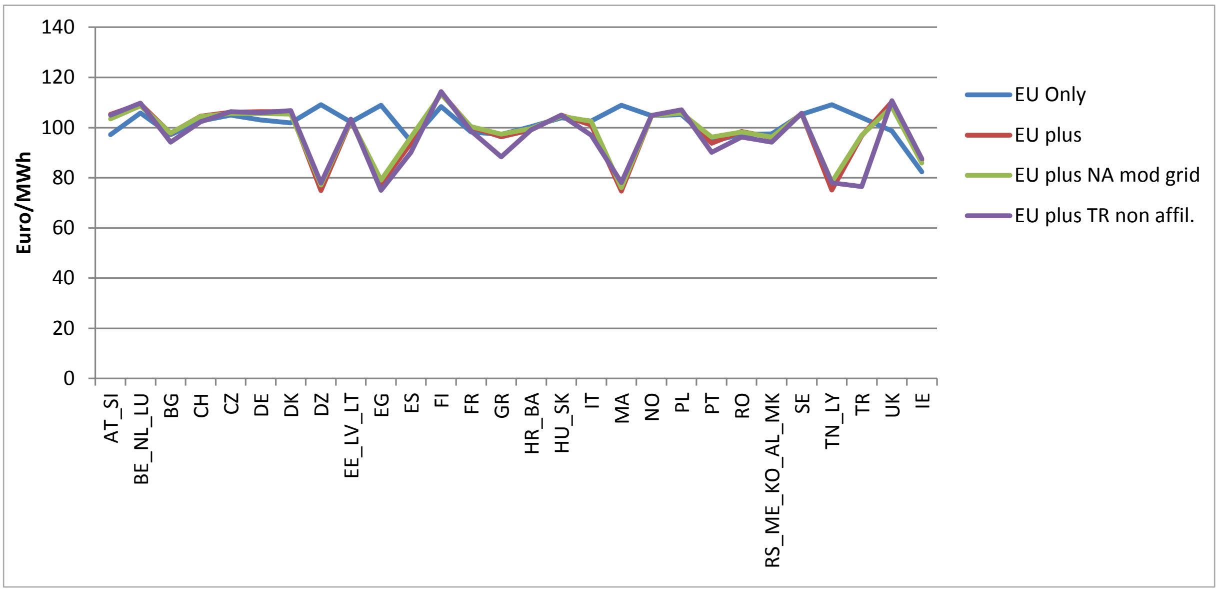



**Figure 63: Mean simulated electricity spot market price according to selected EU plus and EU only scenarios following a strong RES target.**

Figure 65 gives an overview on the changes of electricity prices in selected countries due to a switch from EU only to the EU plus scenario. The error bars represent the electricity prices in the EU only scenario, the full bars the prices that occur in the case of full RES cooperation (EU plus scenarios). The countries are selected and sorted according to the impact on prices. It can be seen that prices do not "collapse" in European countries despite the fact that no additional grid investments have been assumed besides the TYNDP 2014. Moreover, in some countries, for example in the UK, Austria and Slovenia, electricity prices even increase due to increased RES cooperation. However, in North Africa prices decrease significantly. To clarify, note that impacts on non-RES based generation expansion have not been considered in the modelling.

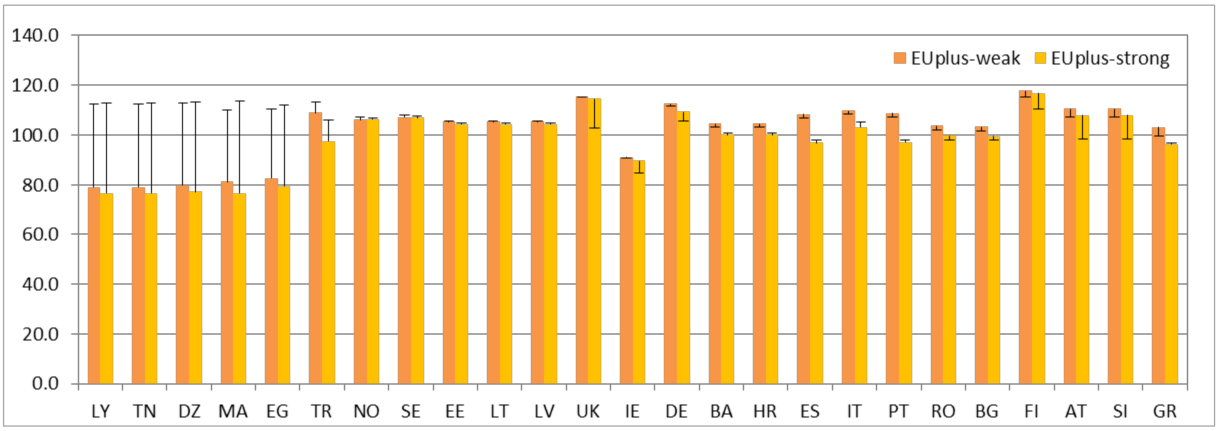



**Figure 64: Mean annual electricity prices for selected countries in the EU plus scenario for different RES ambition levels. The error bars indicate the price in the EU only scenario.**

Notes: The countries are sorted according to their impact on electricity prices (compared to the EU only case). Error bars indicate the price in the EU only scenario.

The mean electricity price at EU28 level by 2040 in the EU plus scenario is 2.6% higher than in the EU only scenario under a strong RES target. PV and wind show comparatively similar regional market value patterns. As a consequence of decreased corresponding renewables deployment, the market value of wind and photovoltaic power is in 2040 4.3% and 7.3% higher on EU average in the EU plus scenario than in the EU only scenario following a strong RES target. Note that related market values of wind and solar PV power are shown in Figure 65.

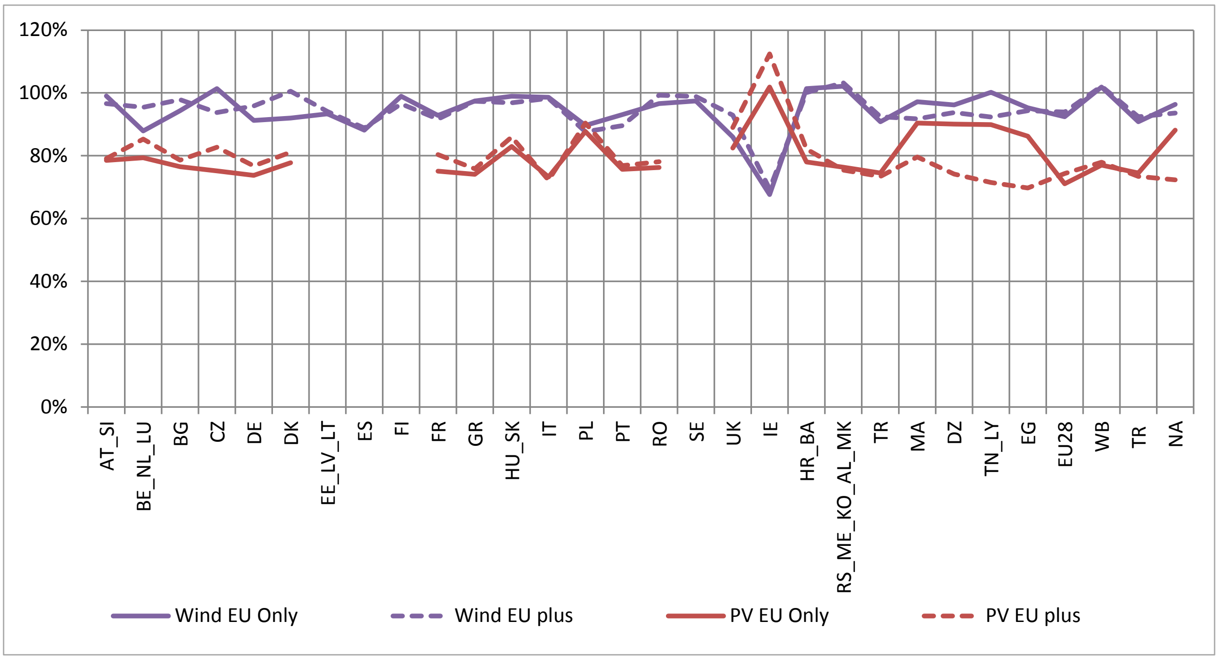



**Figure 65: The market value of photovoltaic and wind power in % of the average electricity price of the country/cluster.**

### 3.4.3 Transmission grid expansion needs

In Figure 66 the additional required HVDC grid capacity extensions, necessary to import the calculated amounts of RES electricity into the EU, are shown for all assessed full cooperation (EU plus) scenarios, i.e. the default cases of full RES cooperation and both sensitivity variants related to regional specifics (in Turkey and in North Africa) – for a weak and a strong RES ambition post 2020. Based on Green-X figures on RES deployment and exchange the HiREPS model endogenously derives for each assessed scenario the least-cost grid extensions required to transfer the calculated amounts of RES to the EU. Grid extensions are assumed of being exclusively HVDC links. Furthermore, the paradigm of dedicated CSP-HVDC links directly connected between the CSP plants to European load centres have been modelled in the sensitivity variants for North Africa (*EU plus, North Africa: delayed AC grid expansion).* Details on this perspective can be also found in the BETTER reports of the North African case study (cf. Trieb et al. (2015)).

It can be seen that strong HVDC export lines go from Egypt to Turkey, whereas only weaker HVDC lines determine the export to Greece. The reason is that in all scenarios – with the exception of the sensitivity variant for Turkey, named as "*EU plus, Turkey: non affiliation to EU"* scenario – it is assumed that Turkey is part of the Energy Community/EU post 2020. Therefore in these scenarios some of the RES generation exported from North Africa is integrated into the Turkish grid and statistically transfer is used to correctly account this RES amount to the EU28 target.

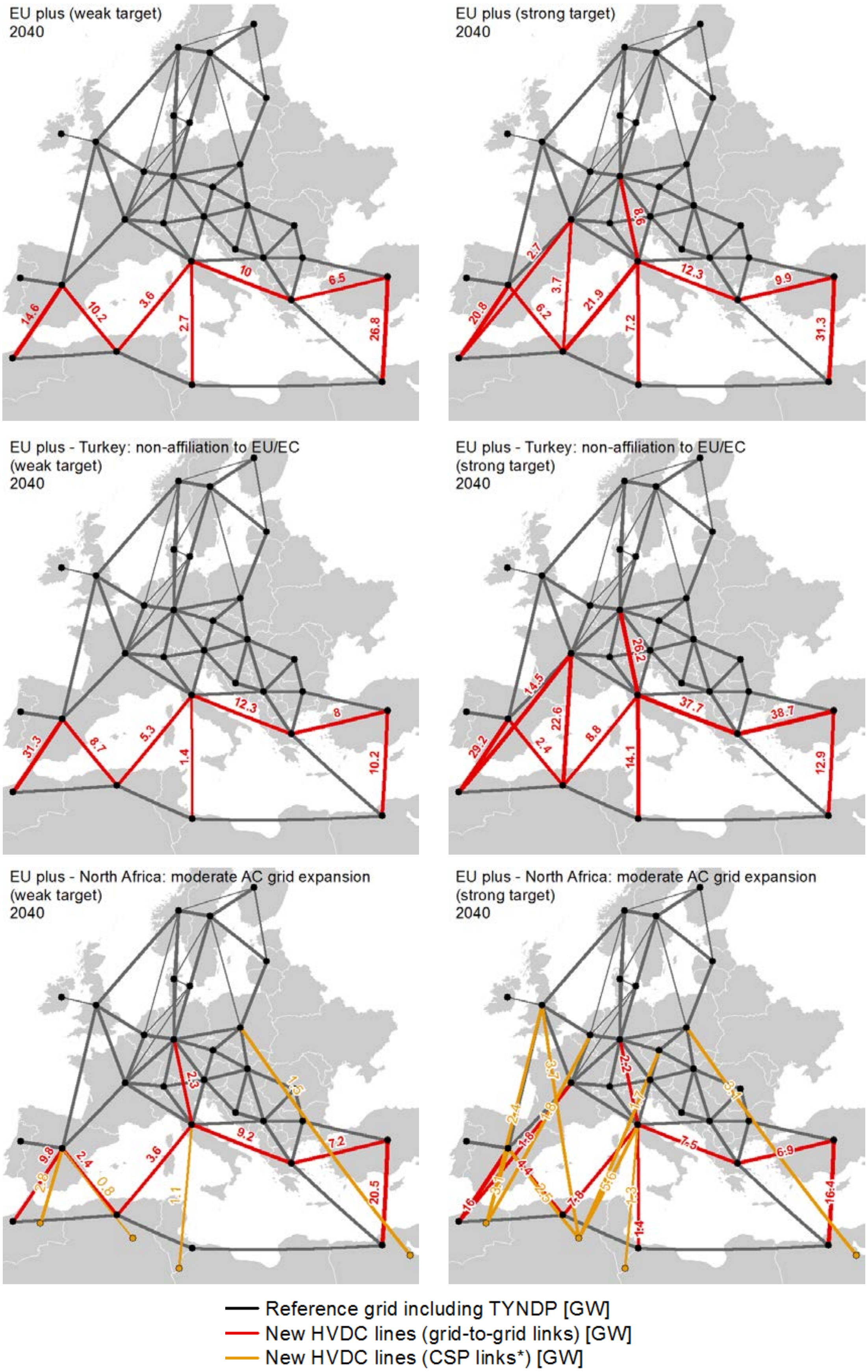



**Figure 66: Required investments in new HVDC lines for importing RES electricity in the different integrated assessment scenarios.**

In general it can be seen, that the necessary grid extensions are quite manageable compared to "supergrid" scenarios assuming a totally different architecture of the overall EU-MENA grid infrastructure in much bigger dimension. The additional grid extension costs and related data are shown in Table 17.

**Table 17: Grid expansion and costs for all assessed EU plus scenarios according to a weak or strong RES target**

| | HVDC new installed capacity [GW] | Capacity kilometer [GW_km] | Annual discounted grid expansion costs billion($10^9$) Euro | Specific import capacity costs [€/MWh] | Mean line utilization [%] | Physically imported RES into EC [TWh] |
|---|---|---|---|---|---|---|
| EU plus (weak target 2030) | 40 | 40062 | 1.4 | 11.8 | 58.4% | 122 |
| EU plus (strong target 2030) | 71 | 80434 | 3.0 | 14.3 | 66.3% | 210 |
| EU plus (weak target 2040) | 74 | 78021 | 2.9 | 9.9 | 63.2% | 296 |
| EU plus (strong target 2040) | 124 | 146850 | 5.5 | 11.8 | 69.7% | 464 |
| EU plus - Turkey: non affiliation to EU/EC (weak target 2040) | 77 | 80753 | 3.0 | 9.7 | 67.5% | 312 |
| EU plus - Turkey: non affiliation to EU/EC (strong target 2040) | 202 | 252879 | 8.9 | 12.8 | 71.7% | 695 |
| EU plus - North Africa: moderate grid expansion (weak target 2040) | 60 | 66474 | 2.4 | 12.4 | 57.7% | 196 |
| EU plus - North Africa: moderate grid expansion (strong target 2040) | 90 | 123391 | 4.5 | 15.5 | 65.0% | 291 |

The costs of the individual HVDC lines are estimated based on a line by line estimation using the case study report for North Africa. The specific import capacity costs (i.e. annual discounted costs/annual physical import volume) are in the range 9.7-15.5 €/MWh for all scenarios. The absolute annually discounted grid expansion costs for the strong target scenarios in Table 17 vary by a factor of 2. The reason for these differences in absolute grid expansion costs is that in the "*EU plus - Turkey: non affiliation to EU/EC (strong target 2040)*" a reduced domestic RES target of Turkey is presumed, and, consequently, the need for physical export from Turkey in this scenario strongly increases the required physical RES export volume into the European Union and Energy Community (i.e. the analysed Western Balkan countries).

For all assessed scenarios the simulated grid expansion costs in the timeframe up to 2040 correspond to 5.1-7.4% of the total investments in new RES plants in the period 2021 to 2040. Again, an exception to that is the "*EU plus - Turkey: non affiliation to EU/EC (strong target 2040)*" scenario where grid expansion costs equal to about 14% of the total RES-related investments in new power plants in the period 2021 to 2040.

The simulations give a rough indication about the infrastructure requirements and corresponding costs to import the RES electricity shares resulting from the integrated assessment scenarios to the EU. In the corresponding Green-X scenarios these costs have been incorporated, respectively related assumptions aligned. In practice that means that in all default scenarios in Green-X modelling the assumption is taken that North African RES producers aiming for the export market (i.e. RES cooperation with the EU/EC) in future years have to cover the large part of the identified grid expansion costs – as default the assumption is taken that as a rule of thumb two thirds of the identified grid expansion costs are borne by the RES producers whereas the remainder (of one third of the total is socialised). Please note that light is shed on these aspects also in a complementary sensitivity assessment, see section 3.5.

The curtailment of wind and photovoltaic and CSP electricity generation is modest in all scenarios. By 2040 in the EU only scenario referring to a strong RES target, the countries with the strongest curtailment (4-6%) for wind or photovoltaics are Spain, Portugal, the Western Balkans countries and Ireland. In the corresponding EU plus scenario the countries with the strongest curtailment (4-6%) for wind or photovoltaics are Morocco, Algeria and

Ireland. Notably, in the EU plus scenario the curtailment of wind and photovoltaic is reduced on average by 0.6% compared to the EU only scenario because of improved allocation signals within the underlying least-cost RES cooperation approach. The specific grid extension costs range between 8 and 10 €/MWh. These numbers only represent discounted installation costs and costs for O&M. Additional compensations payments are not considered therein.

## 3.5 Complementary sensitivity analyses

Since modelling exercises are subject to the quality and correctness of the assumptions and input data two complementary sensitivity analyses have been performed: As shown in Figure 6 (cf. section 2.2.2), one sensitivity assessment is related to the assumptions on grid costs in the case of physical electricity transfer from North Africa to the European Union whereas the other serves to assess the importance of each case region related to RES cooperation, assuming, in contrast to default, a limitation of RES cooperation to only one neighbouring region/country.

### 3.5.1 Sensitivity assessment on the impact of grid costs on RES cooperation

As mentioned earlier it is necessary to build and extend grids substantially to enable the assessed cooperation. The power-system analysis done by use of the HiREPS model gives a rough indication about these infrastructure requirements and corresponding costs to import identified RES electricity volumes to the EU, cf. section 3.4.3. As default in Green-X modelling we take the assumption that large parts of these costs have to be borne by the respective RES producers. In practice that means that in all default scenarios we assume that North African[42] RES producers aiming for the export market (i.e. RES cooperation with the EU/EC) in future years have to bear the largest part of the identified grid expansion costs – as default we estimate that as a rule of thumb two thirds of the identified grid expansion costs are borne by the RES producers whereas the remainder (of one third of the total is socialised).

Thus, the estimations of grid expansion costs are one of the key input factors in modelling of RES cooperation with non-EU countries. Grid expansion costs itself are subject to various input factors like topography, land use, labour costs and material prices. Therefore a sensitivity analysis is performed, in which a more conservative approach is taken on the possible height of these costs, leading to a significant increase of overall costs to be borne by RES producers that aim for physical export to Europe. More precisely, in our “high grid costs” sensitivity variant we assume that additional compensations payments related to land use are incorporated (in accordance with DLR’s assessment of these costs, cf. Trieb et al. (2015)). Moreover, we assume here that the total grid expansion costs (and not only two thirds of them) have to be factored in by the RES producer. As a consequence that means that grid-related costs for RES producers have been doubled compared to default.

This sensitivity analysis is done for the EU plus (full cooperation) scenarios assuming a weak and a strong RES ambition post 2020. Table 18 below summarises the results of this analysis.

In general, the results of the sensitivity analysis show the expected effect: If grid costs are increasing the electricity transfer between the EU28 and North Africa will decrease, since overall it will be cheaper to produce part of the needed RES generation within Europe. Exactly this effect can be seen in Figure 67, where the RES generation in Europe will increase in both assessed scenarios in 2030 as well as in 2040. More precisely:

- For the scenario with a weak European RES target, the EU28 will import approximately 9% less electricity by 2030 and 20% less energy by 2040. Even more interesting is the fact that until 2040 Turkey and Western Balkans will change from being electricity importers to electricity exporters.
- In the scenario with a strong European RES target, this effect is less drastic. In 2040 the EU28 will import only 2% less electricity than in the default scenario. All other three regions keep being net exporters of RES electricity but the export volume will decline between 1.6% (North Africa) and 9.2% (West Balkans).

Comparing the effect of the higher grid costs in the two scenarios it appears at first glance surprising that the reduction of RES generation in North Africa, which is caused by the higher grid costs and, consequently, the re-

[42] In the sensitivity variant on regional specifics related to Turkey this is also valid for Turkish RES-E producers aiming to export their green electricity to the EU/EC.

duced exports to Europe and the other two regions, is higher in the weak than in the strong RES target scenario (see Figure 67). Reason for that is the fact that for reaching an ambitious RES target as presumed in the strong target case North African RES producer prevent their competitive advantage compared to European "high cost" RES producers (like offshore wind at moderate sites) even if grid-related costs have doubled (i.e. increased from about 12 to ca. 22 €/MWh on average). In contrast to above, the doubling of these costs for North African RES producers has more severe impacts if only the "long hanging fruits" are needed to achieve the given targets (as this is the case under a weak RES target of striving for 27% RES by 2030).

**Table 18: Sensitivity analysis on the impact of grid costs on RES cooperation: Electricity exchange between regions by 2030 and 2040 according to assessed cases**

| **Import (-) / Export (+) of RES generation** (within the RES-E trading regime) by 2030 and 2040 according to **sensitivity scenarios (high grid cost)** | | *default case (EU plus)* | **EU plus - high grid cost** | high grid cost: change to default | | *default case (EU plus)* | **EU plus - high grid cost** | high grid cost: change to default | |
|---|---|---|---|---|---|---|---|---|---|
| | RES target (ambition level): | **weak RES target** | | in absolute terms | in relative terms | **strong RES target** | | in absolute terms | in relative terms |
| **in absolute terms [TWh/a]** | | | | | | | | | |
| EU28 | 2030 | -116.9 | -106.3 | 10.6 | -9.1% | -296.0 | -276.6 | 19.4 | -6.6% |
| | 2040 | -337.4 | -269.3 | 68.1 | -20.2% | -539.1 | -527.8 | 11.2 | -2.1% |
| Turkey | 2030 | -5.7 | 9.5 | 15.2 | n.a. | 67.9 | 67.9 | 0.0 | 0.0% |
| | 2040 | -23.0 | 1.8 | 24.8 | n.a. | 43.1 | 40.6 | -2.5 | -5.9% |
| West Balkans | 2030 | 7.1 | 8.0 | 0.9 | 13.1% | 10.7 | 10.9 | 0.2 | 2.1% |
| | 2040 | -0.5 | 3.9 | 4.4 | n.a. | 10.7 | 9.7 | -1.0 | -9.2% |
| North Africa | 2030 | 115.3 | 88.5 | -26.8 | -23.3% | 216.5 | 197.1 | -19.3 | -8.9% |
| | 2040 | 360.9 | 263.6 | -97.3 | -27.0% | 485.2 | 477.6 | -7.6 | -1.6% |

Notes:
All scenarios assume full RES cooperation between the EU and its neighbours
Virtual vs. physical trade of renewable electricity:
- For West Balkans and Turkey virtual trade is assumed in all (default and) sensitivity scenarios
- For North Africa physical trade is assumed in all (default and) sensitivity scenarios. Accordingly, (transmission) grid costs come into play
N.a. ... not applicable

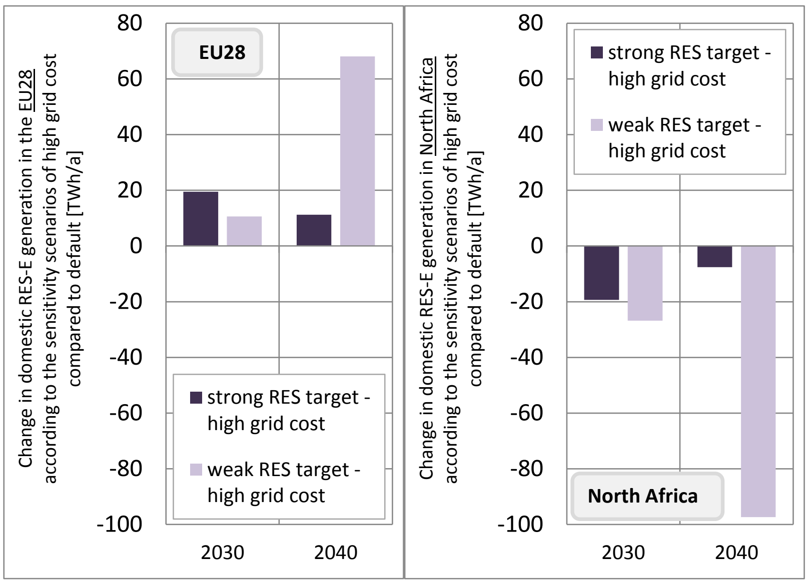



**Figure 67: Sensitivity analysis on the impact of grid costs on RES cooperation: Change in domestic RES-E generation in the EU28 (left) and in North Africa (right)**

Figure 68 depicts the change of the RES-E certificate price according to the different scenarios. Looking at the left side of Figure 68, which shows the results of the sensitivity analysis for the weak EU target scenario, it can be seen that the certificate price for the EU plus region increases by only 10% even though the grid costs doubled, which means they are still far below the price of an EU only scenario. The right side of Figure 68, which illustrates the results of the strong RES target scenario, shows that the green certificate price for RES-E will not increase at all despite the higher grid costs. The explanation for this is that North African RES producers affected by the grid cost increase are not the marginal producers under this setting. Thus, certificate prices are then determined by an even more costly renewable option in Europe, Western Balkans or Turkey.

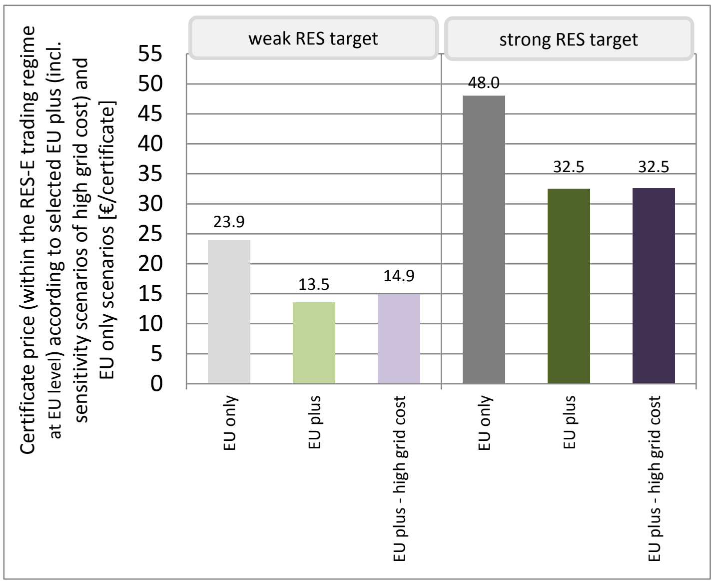



**Figure 68: Sensitivity analysis on the impact of grid costs on RES cooperation: Comparison of average (2021-2040) certificate prices for RES-E (at EU level) according to assessed cases**

## 3.5.2 Sensitivity assessment on a regional focus in RES cooperation

In the following, sensitivities to the assessed cooperation scenarios are depicted, showing how cooperation would change if instead of engaging in full cooperation, the EU 28 Member States would instead engage in trade with only one of the three assessed partner regions – i.e. either with Turkey, North Africa or the Western Balkans. The three sensitivity scenarios are consequently named “EU plus – Turkey only”, “EU plus – Western Balkans only” and “EU plus – North Africa only”. The different outcomes in terms of import and export of RES generation are depicted for the 2030 and 2040 perspective in Table 19, assuming a moderate RES target.

Thus, it can be seen that not surprisingly, the “EU plus –North Africa only” scenario has the largest impacts on trade in RES because the volumes of electricity are substantially higher than those that could be provided by Turkey or the Western Balkan region. Notably, this affects also significantly the savings related to RES cooperation with EU neighbours as can be seen in Figure 69 where certificate price are depicted according to assessed cases.

**Table 19: Sensitivity analysis on a regional focus in RES cooperation: Electricity exchange between regions by 2030 and 2040 according to assessed cases**

| **Import (-) / Export (+) of RES generation** (within the RES-E trading regime) by 2030 and 2040 according to **sensitivity scenarios (regional focus in RES cooperation)** | | *default case (EU plus)* | EU plus - Turkey only | EU plus - Turkey only: change to default | | EU plus - Western Balkans only | EU plus - Western Balkans only: change to default | | EU plus - North Africa only | EU plus - North Africa only: change to default | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RES target (ambition level): **moderate RES target** <br> **in absolute terms [TWh/a]** | | | | in absolute terms | in relative terms | | in absolute terms | in relative terms | | in absolute terms | in relative terms |
| EU28 | 2030 | -224.0 | -98.5 | 125.5 | -56.0% | -18.6 | 205.4 | -91.7% | -193.9 | 30.1 | -13.5% |
| | 2040 | -469.5 | -140.6 | 329.0 | -70.1% | -26.5 | 443.1 | -94.4% | -445.0 | 24.5 | -5.2% |
| Turkey | 2030 | 40.3 | 98.5 | 58.2 | 144.2% | | | | | | |
| | 2040 | 47.5 | 140.6 | 93.0 | 195.6% | | | | | | |
| West Balkans | 2030 | 9.7 | | | | 18.6 | 9.0 | 92.8% | | | |
| | 2040 | 5.9 | | | | 26.5 | 20.5 | 346.3% | | | |
| North Africa | 2030 | 173.3 | | | | | | | 193.9 | 20.5 | 11.8% |
| | 2040 | 416.0 | | | | | | | 445.0 | 29.1 | 7.0% |

Notes:
All scenarios assume full RES cooperation between the EU and its neighbours (but limited to the focal country/region in the sensitivity cases)
Virtual vs. physical trade of renewable electricity:
- For West Balkans and Turkey virtual trade is assumed in all (default and) sensitivity scenarios
- For North Africa physical trade is assumed in all (default and) sensitivity scenarios. Accordingly, (transmission) grid costs come into play

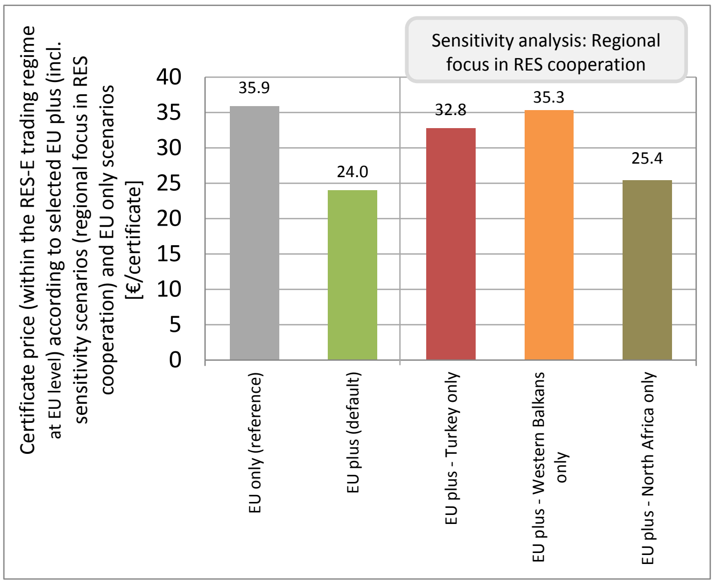



**Figure 69: Sensitivity analysis on a regional focus in RES cooperation: Comparison of average (2021-2040) certificate prices for RES-E (at EU level) according to assessed cases**

# 4 Co-effects of RES cooperation between the EU and its neighbours

This chapter complements the model based assessment with an assessment of co-effects including impacts on environmental aspects, energy security and macro-economic aspects. Existing data bases regarding co-effects from energy supply on air pollutants ($SO_2$, NOx, NMVOC, dust and CO) of different energy technologies are applied at the European and third countries level based on the scenarios of task 4.1. For including energy security aspects in the integrated assessment indicators selected and further developed in WP2 of the BETTER project are applied. In addition in a brief manner macroeconomic impacts in both Europe and third countries such as potential impacts on the economy as well as on employment due to the enhanced expansion of RES in third countries are assessed.

## 4.1 Environmental co-effects of RES cooperation with assessed neighbouring countries

Aim of this section is to quantify annually occurring emissions of GHGs and local air pollutants (NOx, SO2, CO, NMVOC and Dust) which are caused in switching from EU only to the EU plus scenario. Both scenarios are compared regarding two different (strong and weak target) assumptions by calculating changes in primary energy. Based on changes in primary energy, emission factors considering only direct emissions have been assigned to each energy source (technology). The allocation of emission factors to primary energy changes quantifies annually occurring emissions of local air pollutants representing environmental external effects of the switchover from EU only to EU plus.

### 4.1.1 Methodology for calculating environmental external effects

The methodology used in this study to quantify environmental co-effects which are caused due to passing from the EU only to the EU plus scenario is divided into two main components (see figure below).

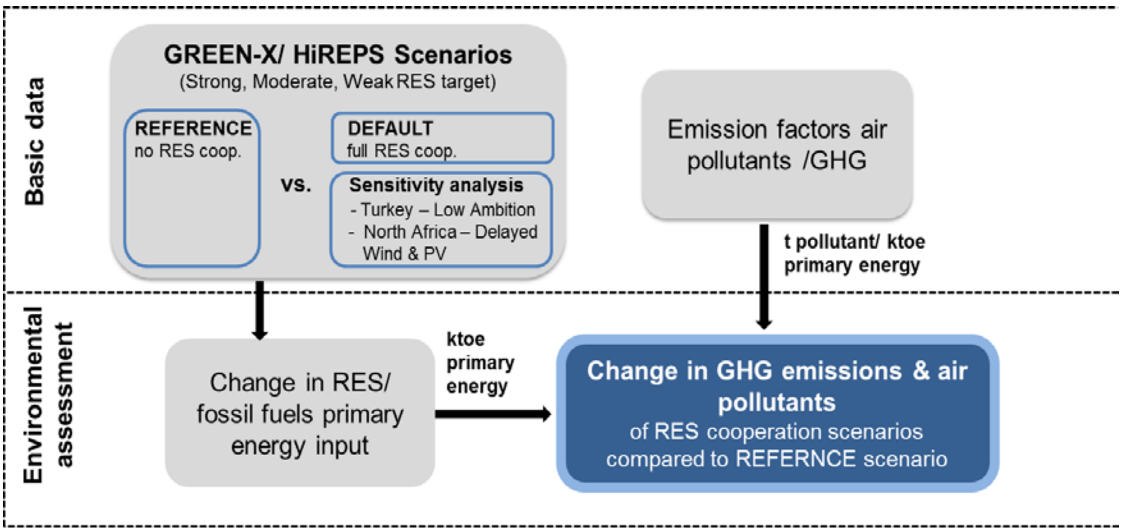



Figure 70: Methodology for calculating external environmental effects

The first component of the applied methodology (basic data) focuses on the selection of basic information necessary in quantifying changes in GHG emissions and air pollutants. Within the second component (environmental assessment) changes in RES/ fossil fuels primary energy input based on the switch from “EU only” to “EU plus" are calculated and assigned to emission factors per unit of energy output of a specific technology. Resulting emission changes linked to the switch from "EU only" to "EU plus" represent the environmental benefits or disadvantages for involved regions if cooperation in renewable production between third countries and the European Union is undertaken.

***Basic data***

Underlying scenarios/ changes in primary energy output

Quantification of changes in RES/ fossil fuel primary energy input caused by switching from "EU only" to "EU plus" is partly based on the results of the Green-X model (RES) and partly on results gained by use of the HiREPS model (fossil fuels). Both models deliver data for ktoe/TWh primary energy of specific RES/ fossil fuel technologies estimated to be present in each scenario (EU only, EU plus, sensitivity analysis) for each region (European Union, North Africa, Turkey, Western Balkan). The Green-X model which is an energy system model that offers a detailed representation of RES potential and related technologies in Europe and in the analysed neighbouring countries, provides estimates on ktoe primary energy of renewables for a long time period. Additionally, the HiREPS model (highly resolved European power system investment planning and supply security simulation and optimization model) provides in its results among others changes in primary energy estimates for fossil based energy sources as this is not detailed modelled in Green-X.

Within the Green-X model, RES data are given for each year assessed (2015-2040, partly 2015-2045). On the contrary, data of fossil based energy sources given by the HiREPS model are not available for each single year. Data on fossil fuels primary energy input for missing years have therefore been interpolated (assessment period: 2030 and 2040).

Emission factors

To quantify annual occurring domestic effects on greenhouse gas and local air pollutant emissions, technology-specific emission factors for each pollutant are linked to ktoe primary energy. The used emission factors per ktoe primary energy are based

- for GHG on data given in the 2006 IPCC Guidelines – default emission factors for Tier 1 approach[43]
- for air pollutants on most current information used from
    - the EMEP/EEA emissions inventory guidebook 2013[44] (RES-E technologies causing certain direct emissions and RES-H (excl. biogas)/ fossil fuel technologies)
    - the ETC/AAC Technical Paper 2009/18 published by the European Topic Centre on Air and Climate Change[45] for biogas and
    - on own calculations based on an Austrian national study on biofuels[46] for RES-T.

Within this analysis only direct emissions of energy technologies are considered, thus renewables causing external effects through direct air pollutant emissions are limited to few technologies. For those RES technologies

[43] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, available under: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

[44] European Environment Agency (2013): EMEP/EEA air pollutant emission inventory guidebook 2013, Technical report No 12/2013; available under: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

[45] Fritsche, Rausch (2008): Life cycle analysis of GHG and air pollutant emission from renewable and conventional electricity, heating and transport fuel options in the EU until 2030. ETC/ACC Technical Paper 2009/18, European Topic Centre on Air and Climate Change, The Netherlands, June 2009; available under: http://acm.eionet.europa.eu/reports/docs/ETCACC_TP_2009_18_LCA_GHG_AE_2013-2030.pdf

[46] Hofbauer et al. (2008): FT-Treibstoffe aus Biomasse in Österreich – Biomassepotential, Technologien und ökonomische und ökologische Relevanz, 2. Ausschreibung der Programmlinie Energiesysteme der Zukunft, Endbericht, 15.12.2008

which cause certain direct emissions as well as for selected fossil-based energy sources environmental co-effects have been calculated.

The table below presents used emission factors which have been linked to RES technologies which cause certain direct emissions. The same information is provided also for fossil based energy sources. Besides GHGs, local air pollutants which have been considered include NOx, SO2, NMVOC, Dust as well as CO. GHG emissions related to renewables only correspond to related CH4 and N2O emissions at combustion, as CO2 emissions for bioenergy are usually considered of being zero.

**Table 20: GHG/air pollutant emission factors linked to renewable and fossil based energy sources**

| | Air pollutants | | | | | GHG (*) | Energy conversion efficiency |
|---|---|---|---|---|---|---|---|
| | NOx | $SO_2$ | NMVOC | Dust | CO | $CO_{2eq}$ | |
| | [t pollutant/ ktoe primary energy] | | | | | [t $CO_{2eq}$/ ktoe primary energy] | % |
| RES-E | | | | | | | |
| Biogas | 3.48 | 1.30 | 0.10 | 0.18 | 3.48 | 0.65 | |
| Solid biomass | 1.67 | 0.27 | 0.10 | 3.60 | 1.88 | 28.26 | |
| Biowaste | 1.67 | 0.27 | 0.10 | 3.60 | 1.88 | 28.26 | |
| RES-H | | | | | | | |
| Biogas (grid) | 3.48 | 1.30 | 0.10 | 0.18 | 3.48 | 0.65 | |
| Solid biomass (grid) | 1.67 | 0.27 | 0.10 | 3.60 | 1.88 | 28.26 | |
| Biowaste (grid) | 1.67 | 0.27 | 0.10 | 3.60 | 1.88 | 28.26 | |
| Solid biomass (non-grid) | 1.26 | 0.33 | 0.84 | 16.75 | 41.87 | 107.39 | |
| RES-T | | | | | | | |
| 1st generation biofuels | 3.18 | 0.02 | 0.39 | 0.024 | 2.46 | 16.39 | |
| 2nd generation biofuels | 2.53 | 3.78 | - | 0.025 | 3.42 | 13.12 | |
| Biofuel import | 3.18 | 0.02 | - | 0.024 | 2.46 | 16.39 | |
| Fossils | | | | | | | |
| Coal | 8.75 | 34.33 | 0.04 | 0.48 | 0.36 | 3389.17 | 0.38 |
| Lignite | 10.34 | 70.34 | 0.06 | 0.49 | 0.36 | 4249.02 | 0.36 |
| Gas | 3.73 | 0.01 | 0.11 | 0.04 | 1.63 | 2351.97 | 0.6 |
| Oil | 5.95 | 20.72 | 0.10 | 1.48 | 0.63 | 3251.01 | 0.45 |
| Waste | 3.39 | 0.45 | 0.31 | 7.20 | 3.77 | 78.29 | 0.2 |

(*) GHG emissions related to renewables only consider direct emissions of N20 and CH4 (converted into CO2eq). Direct CO2 emissions are considered as zero.

## ***Environmental assessment***

Aim of the environmental assessment is to quantify annually occurring emissions of GHG and local air pollutants (NOx, SO2, CO, NMVOC and dust) which are caused by switching from the EU only to the EU plus scenario. Based on changes in primary energy, emission factors considering direct emissions have been assigned to each energy source (technology). The allocation of emission factors to primary energy changes quantifies annually occurring emissions of GHGs and local air pollutants representing environmental external effects of the switch-over from EU only to EU plus.

In switching from EU only to EU plus, RES expansion is partly displaced/ relocated from the European Union to third countries. Thus also emissions caused by RES technologies are more or less reallocated from the European Union to assessed neighbouring countries – an effect that reduces emissions within the EU. Additionally an increased utilizable RES potential of the EU due to absorbing RES potential of third countries may lead to an increase of renewables in EU gross final energy consumption and consequently decrease fossil energy need. This is decreasing GHG and air pollutant emissions of the European Union even further. In third countries fossil based emissions are also expected to be reduced as renewables instead of fossil based energy sources are expanded. However as an increased use of RES can also induce emissions (mainly of local air pollutants due to e.g. combustion of biomass) overall emissions may not decrease as much as expected depending on the energy mix. Additionally, depending on several other factors such as e.g. varying energy demand, also technology shifts may affect the outcome. The amount of emission savings or even an increase in emissions is therefore strongly dependent on specific RES/fossil technologies.

### 4.1.2 Results on environmental co-effects induced by full RES cooperation with third countries

Impacts are shown for switching from the EU only to the EU plus scenario. Both scenarios are compared regarding two different (strong and weak target) assumptions by calculating changes in primary energy and corresponding changes in annually occurring emissions of GHG and local air pollutants. Findings are presented in an overall comparison of EU and third countries. In doing so, we move from a separate examination of renewables and fossils to an overall picture of external effects emerging from both. Impacts of renewables are shown for a period of 30 years (2015-2045), whereas impacts of fossils as well as the combined picture are presented for a period of 10 years (2030-2040).

Additionally, results always consider how the magnitude of external effects responds on different RES target settings of the European Union, comparing the “strong” (32.5% RES-share at EU level in 2020) with the “weak” (27% RES-share at EU level in 2020) target case. In graphs ktoe primary energy and t pollutants linked to the European Union (EU) are depicted as fully filled, the same categories linked to third countries (TC) are depicted as striped.

***<u>Renewables</u>***

Results on renewables are based on Green-X model results and are given for each year of a time period of 30 years (2015-2045).

<u>Strong target</u>

Considering the “strong target” scenario, in switching from EU only to EU plus, especially renewables such as wind offshore, wind onshore, PV, biogas (RES-E) and solid biomass (RES-E) are (relatively) decreased in the European Union. Instead, in third countries mainly RES-technologies such as PV, CSP, solid biomass (RES-E), wind offshore and wind onshore are expanded. The amount of RES expansion reduced in the European Union is thereby higher as the amount of RES increased in third countries. Regarding RES technologies which cause certain direct emissions, more solid biomass (RES-E) and biogas (RES-E) in the European Union is reduced as it is in turn expanded in third countries. RES technologies which cause certain direct emissions in the European Union are therefore more or less replaced by “cleaner” technologies in third countries, resulting in an overall emission reduction when switching from the EU only to the EU plus scenario if only renewables are considered (see Figure 71, Figure 72). Additionally, solid biomass (RES-H, non-grid) in the European Union is estimated to fluctuate and EU biofuel import is calculated in some points in time to be higher in the EU plus as in the EU only scenario. These specific characteristics are later identified as having high influence on emission changes (see Figure 73).

Changes in ktoe primary energy due to the switch from EU only to EU plus are displayed in the figure below. Main technologies of both regions (EU and TC) which are estimated to increase by switching from EU only to EU plus, are highlighted in green in the legend. Main technologies estimated to decrease by switching from EU only to EU plus are highlighted in red in the legend. Technologies marked black in the legend are either shifted on a minor level only or even do not appear within the assumptions/scenario.

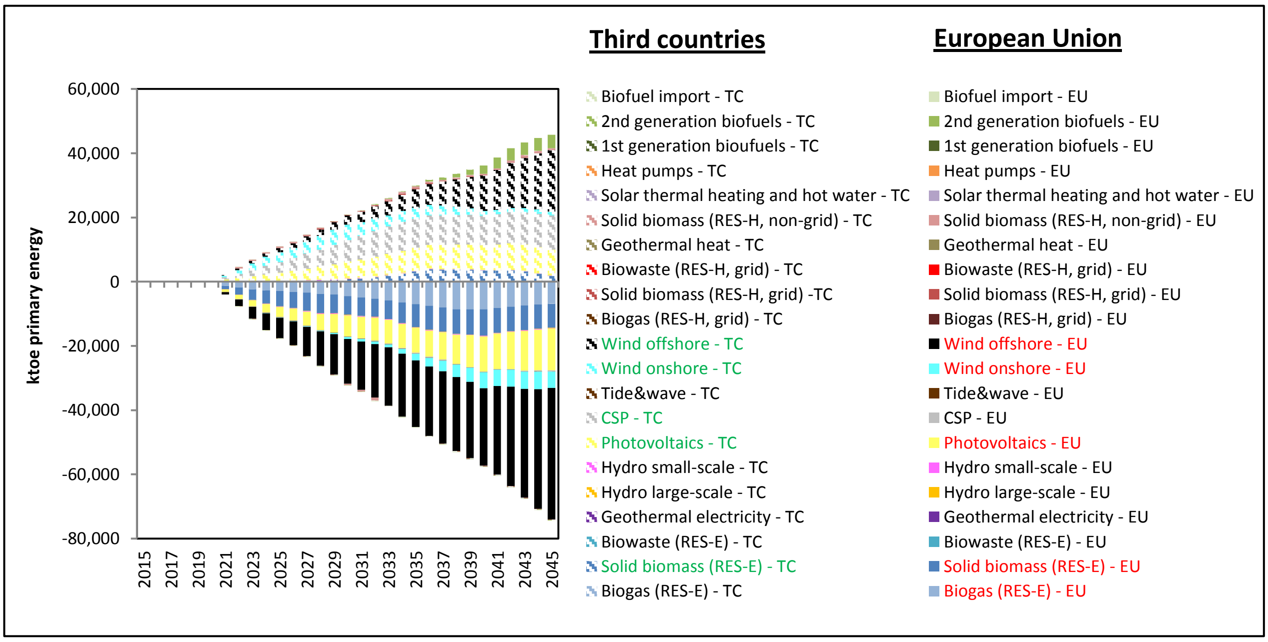



**Figure 71: Changes in ktoe primary energy: EU only → EU plus (STRONG TARGET) – all RES**

Changes in ktoe primary energy linked to RES technologies which cause certain direct emissions are shown in the figure below:

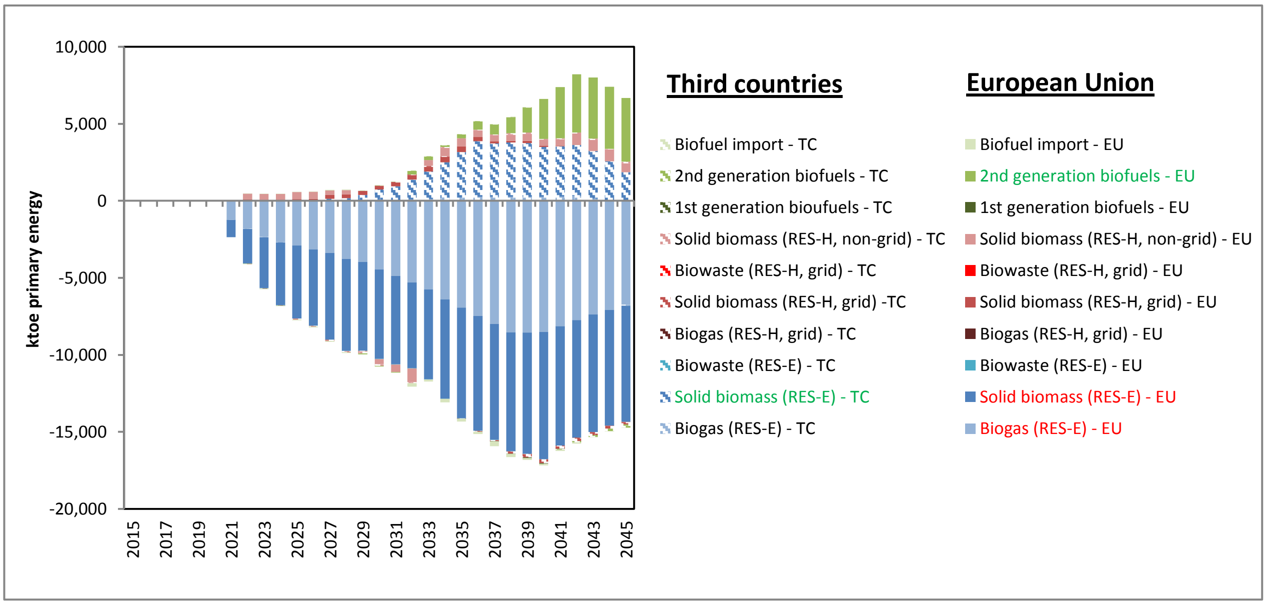



**Figure 72: Changes in ktoe primary energy: EU only → EU plus (STRONG TARGET) – RES technologies which cause certain direct emissions**

**Note:** Fluctuations, mainly noticeable regarding solid biomass (RES-H, non-grid) and biofuel import, are caused due to uncertainties as well as overlaps of underlying modelling data sets. E.g. on dynamics in cost development (overlaps of different cost curves result in intersection points which allow fluctuations of ktoe primary energy), market development or closing and opening of sites at different points in time.

In allocating emission factors to primary energy changes, GHG (not $CO_2$, but $CH_4$ and $N_2O$ from combustion) as well as air pollutant emissions are quantified, representing environmental effects of the switchover from EU only to EU plus. These environmental effects for the strong target assumption are illustrated in Figure 73.

In switching from EU only to EU plus, significant emission savings are achieved in the European Union, thus mainly regarding GHGs ($CH_4$, $N_2O$), but also regarding local air pollutants. In EU's neighbouring countries on the contrary, GHG ($CH_4$, $N_2O$) and air pollutant emissions increase. The increase of emissions in third countries is mainly based on a corresponding increase in solid biomass (RES-E) in the region, However, as more RES technologies causing certain direct emissions are reduced in the European Union as in turn are expanded in third countries, emission increases in third countries are still outweighed by EU emission savings.

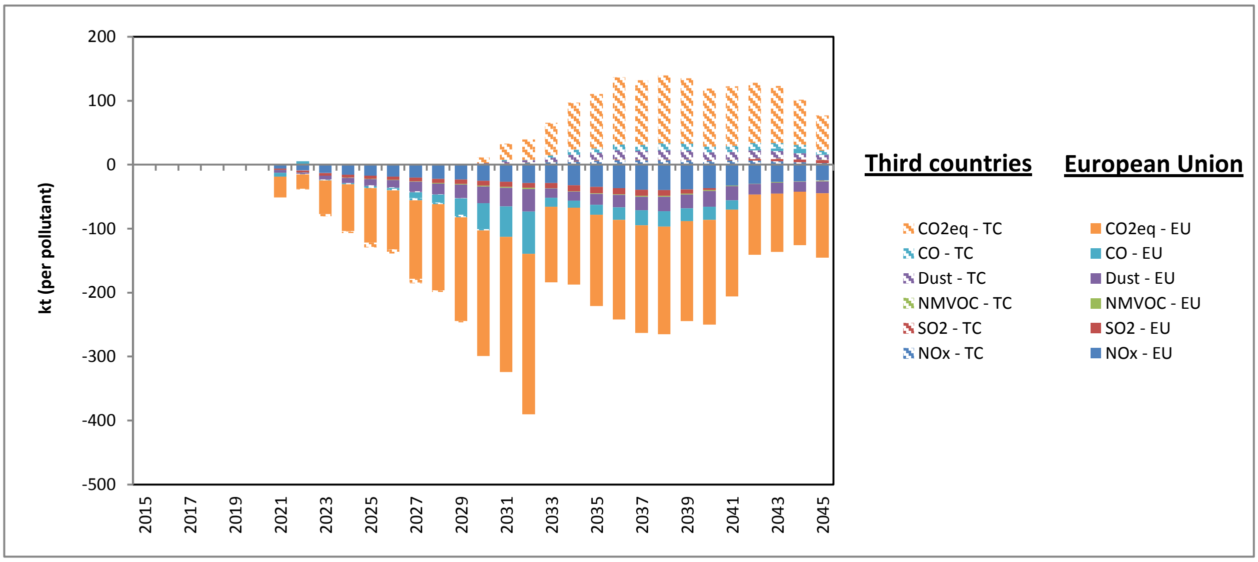



**Figure 73: Emission changes: EU only → EU plus (STRONG TARGET)**

**Note**: As especially solid biomass (non-grid, RES-H) – due to e.g. the absence of purge techniques which are only available for industrial sites – is having high emission factors regarding GHG as well as air pollutant emissions (see Table 20), the fluctuation of this technology (explained in Figure 72) are highly noticeable in emission changes. The effect is also increased by fluctuations of ktoe primary energy linked to biofuel import, although those category not having as high emission factors as solid biomass (non-grid, RES-H).

Weak target

Considering the "weak target" scenario, generally less ktoe primary energy of RES is shifted as in the "strong target" scenario. Regarding the European Union, switching from EU only to EU plus leads to a decrease in wind onshore, wind offshore, PV, solid biomass (RES-E) as well as biogas (RES-E). Instead in third countries mainly wind offshore and PV is expanded. However again, much more ktoe primary energy of RES is decreased in the EU as it is in turn increased in third countries by switching from EU only to EU plus. In the weak target scenario, only few RES technologies causing certain direct emissions are estimated to be expanded in third countries.

Changes in ktoe primary energy linked to the switchover from EU only to EU plus are displayed in the figure below. Main technologies of both regions (EU and TC) which are estimated to increase by switching from EU only to EU plus, are highlighted in green in the legend. Main technologies estimated to decrease by switching from EU only to EU plus are highlighted in red in the legend. Technologies marked as black in the legend are either shifted on a minor level only or are even not appearing within the assumption/scenario.

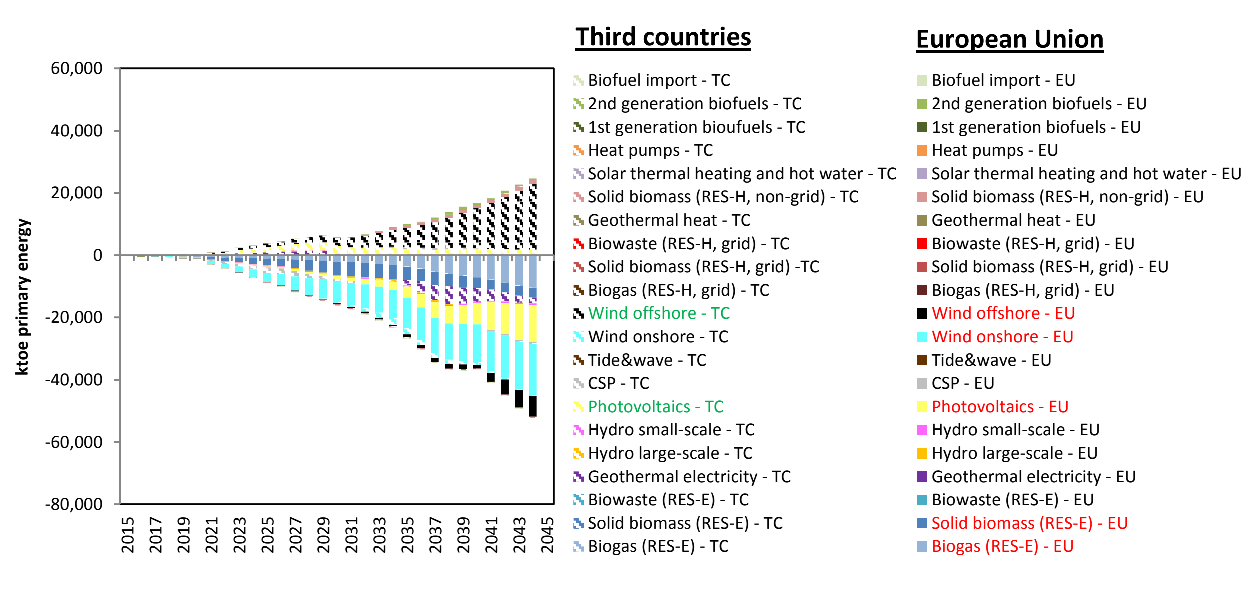



**Figure 74: Changes in ktoe primary energy: EU only → EU plus (WEAK TARGET) – all RES**

Looking at RES technologies which cause certain direct emissions only (see Figure 75) it is clearly noticeable that besides solid biomass (RES-E) any noticeable technologies causing certain direct emissions are expanded in third countries by switching from EU only to EU plus.

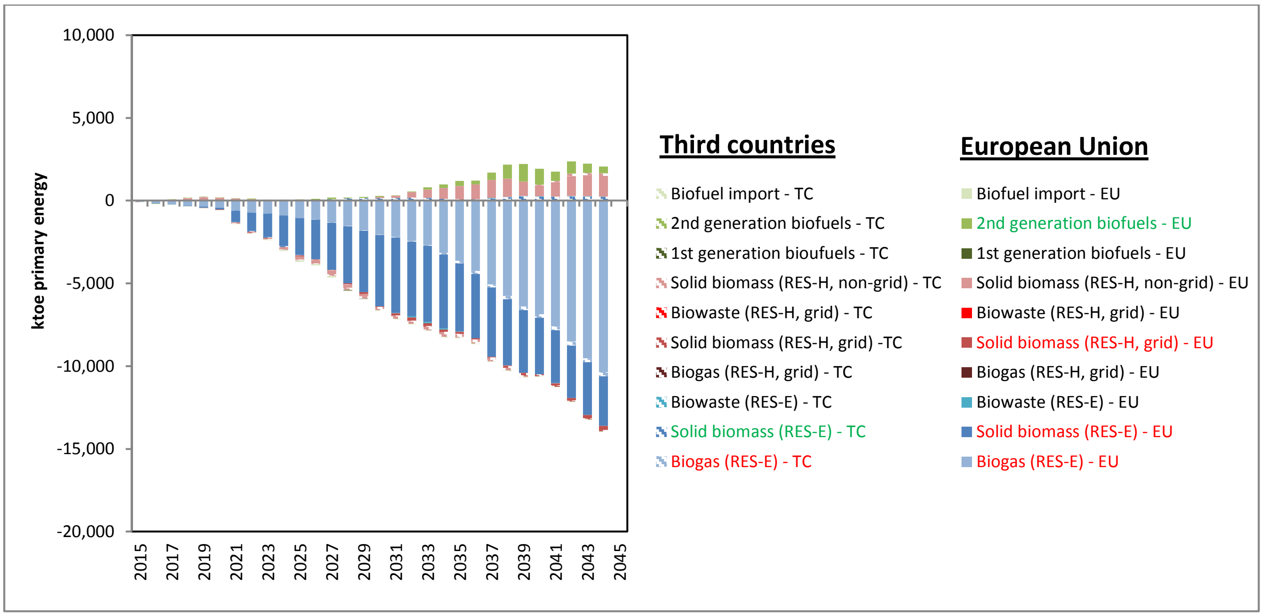



**Figure 75: Changes in ktoe primary energy: EU only → EU plus (WEAK TARGET) – RES technologies which cause certain direct emissions**

**Note:** Fluctuations, mainly noticeable regarding solid biomass (RES-H, non-grid) and biofuel import, are caused due to uncertainties as well as overlaps of underlying modelling data sets. E.g. on dynamics in cost development (overlaps of different cost curves result in intersection points which allow fluctuations of ktoe primary energy), market development or closing and opening of sites at different points in time.

Alike in the strong target case, solid biomass (RES-H, non-grid) is estimated to fluctuate in both regions in the European Union as well as in third countries. In third countries solid biomass (RES-H, non-grid) is estimated to be higher in the EU plus as in the EU only scenario in later years of the analysis. Thus, solid biomass (RES-H, non-grid) is together with solid biomass (RES-E) mainly responsible for third countries higher emissions in EU plus in later years of the analysis (~2030-2045, see Figure 76). Solid biomass (RES-H, non-grid) is also fluctuating in the EU and in earlier years of the analysis estimated to be lower in the EU plus as in the EU only scenario but estimated as being higher in the EU plus as in the EU only scenario in later years of the analysis. Also these fluctuations are clearly noticeable in the shape of emission changes linked to the weak target assumption illustrated in Figure 76.

These fluctuations of solid-biomass (RES-H, non-grid) together with other inhomogeneity's of further RES technologies in both regions lead to the phenomenon of overall emission savings at the switchover from EU only to EU plus in earlier years, detached by an overall emission increase caused mainly due to third countries in later years (see Figure 76).

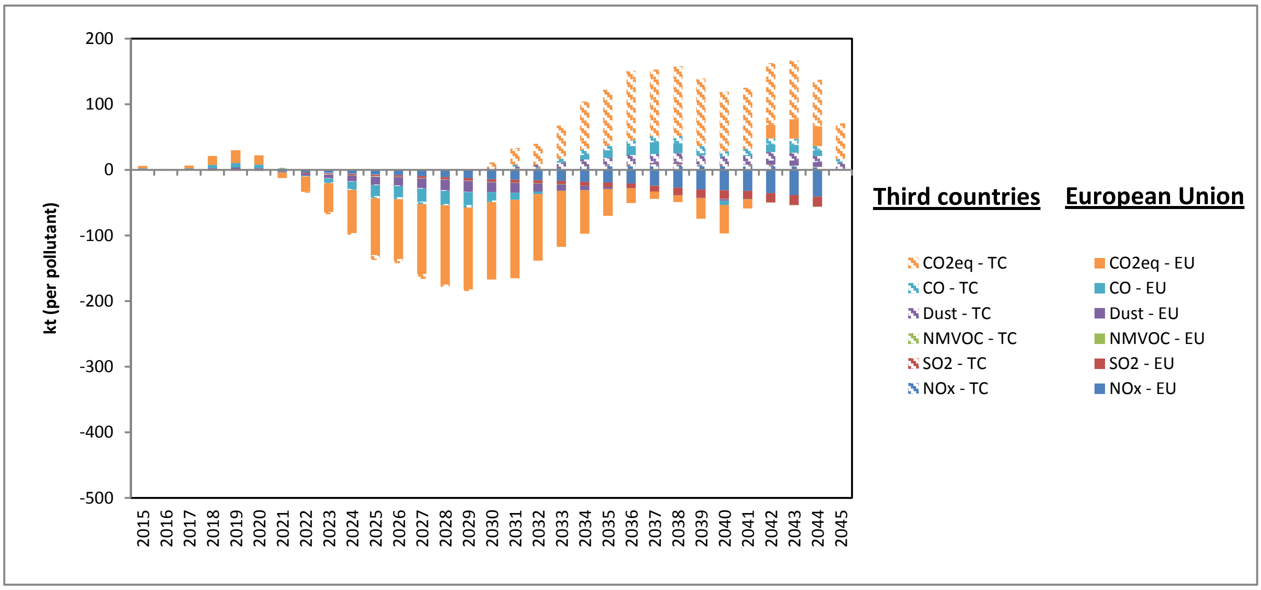



**Figure 76: Emission changes: EU only → EU plus (WEAK TARGET) - RES**

**Note**: As especially solid biomass (non-grid, RES-H) – due to e.g. the absence of purge techniques which are only available for industrial sites – is having high emission factors regarding GHG as well as air pollutant emissions (see Table 20), the fluctuation of this technology (explained in Figure 72) are highly noticeable in emission changes. The effect is also increased by fluctuations of ktoe primary energy linked to biofuel import, although those category not having as high emission factors as solid biomass (non-grid, RES-H).

Strong target/ weak target comparison

Mainly noticeable in comparing external environmental effects of the RES strong target with the weak target case is that the strong target case, at switching from EU only to EU plus, clearly results in overall emission savings. In the weak target case on the contrary, emission savings are only estimated to be achieved in earlier years of the analysis, in later years emissions are even estimated to increase in switching from EU only to EU plus. This is mainly based on strong fluctuations of solid biomass (RES-H, non-grid) and biofuel import in the EU, both significantly increasing in EU plus in comparison to EU only in later years of the analysis and resulting in overall significant decreases of EU emission savings.

## ***Fossil fuel based energies***

Results on fossils based energy sources are based on TU Vienna HiREPS model results and are given for 2030 and 2040 respectively. Data on fossil fuels primary energy input for missing years have therefore been interpolated (assessment period: 2030-2040).

Strong target

Considering fossil fuel based energy sources only, switching from EU only to EU plus leads in the strong target case to an increase of gas in the European Union. Also EU lignite and coal is estimated to be higher in the EU plus as in the EU only scenario; however the difference between the two scenarios is, especially regarding coal, estimated to decrease by time.

In third countries, fossil based energy sources are on the contrary estimated to decrease in switching from EU only to EU plus. Here it is estimated that by time especially more and more lignite is decreased in switching from EU only to EU plus. On the other hand, a declining trend in coal savings with years is noticeable, thus leading in 2038 even to more coal in the EU plus as in the EU only scenario in the third country region.

Changes in ktoe primary energy: EU only → EU plus are illustrated in the figure below. In an overall view reduced fossil based energy sources of third countries in switching from EU only to EU plus are almost the same size as increased fossil based energy sources in the EU.

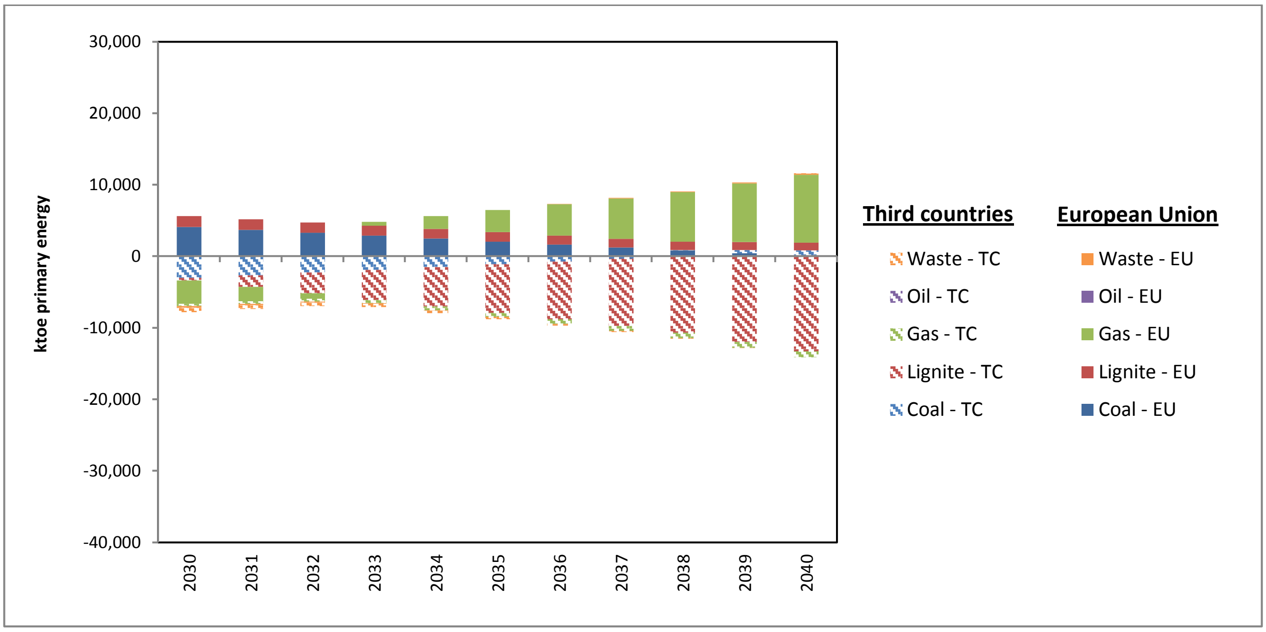



Figure 77: Changes in ktoe primary energy: EU only → EU plus (STRONG TARGET) – fossil based energy sources

Linking the above shown changes in ktoe primary energy to emission factors, it is noticeable that most emissions caused by fossil based energy sources are linked to GHGs and are on a much higher level than air pollutant emissions. Thus in the figures below fossil based emission changes induced from the switchover EU only → EU plus are once shown incl. $CO_{2eq}$ (left side) and once excl. $CO_{2eq}$ (right side).

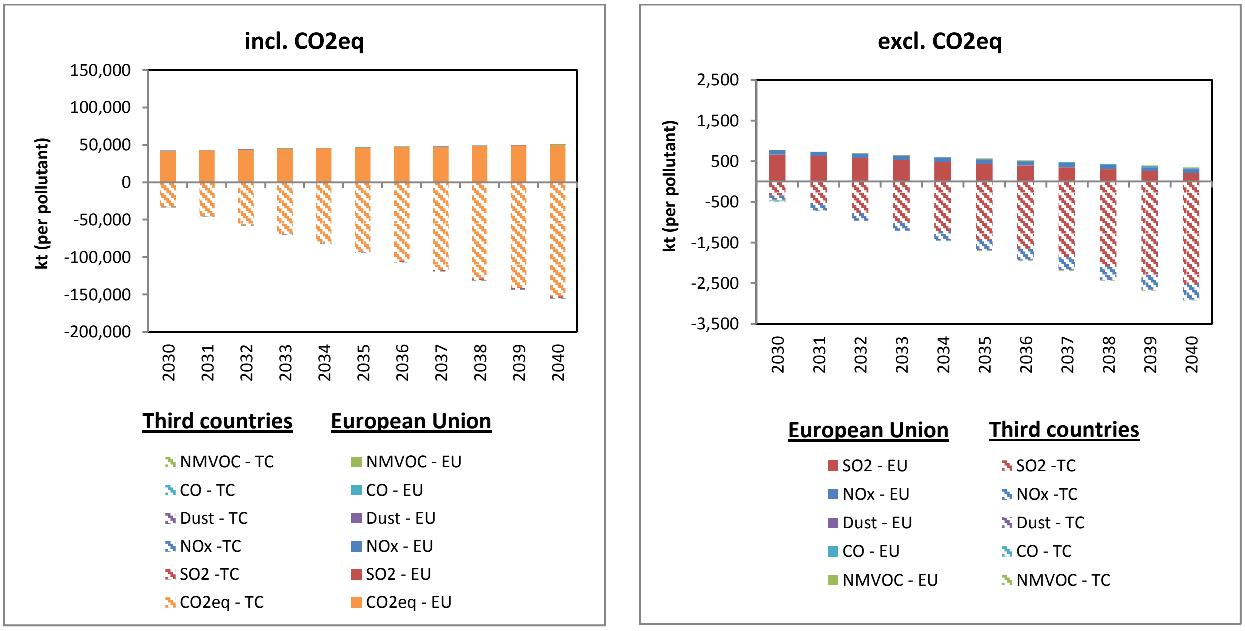



**Figure 78: Emission changes: EU only → EU plus (STRONG TARGET) – fossil based energy sources**

Generally, regarding the strong target case, in switching from EU only to EU plus and considering fossil fuels only, overall emission savings are achieved. This is mainly based on a decrease in fossil use in third countries. The estimated increase in fossil based energy sources in the European Union is indeed leading to increased emissions but not in the same magnitude as emission savings achieved in third countries. Also, emission savings are estimated to increase by time (see Figure 78).

Weak target

In the "weak target" scenario, switching from EU only to EU plus results in a complete different picture in ktoe primary energy changes of fossil based energy sources. In this case, especially changes in oil as well as waste are significant. In EU plus in comparison to EU only, oil is estimated to decrease in the European Union but to increase in third countries. Waste on the contrary is estimated to decrease in third countries but to increase in the European Union. Other fossil based energy sources such as lignite and coal are estimate do play a minor role, however lignite within the European Union is expected to decrease, whereas lignite in third countries is expected to increase.

Generally, alike in the strong target case, reduced fossil based energy sources in switching from EU only to EU plus are, independently from the corresponding region, almost about the same size as increased fossil based energy sources (in terms of energy unit).

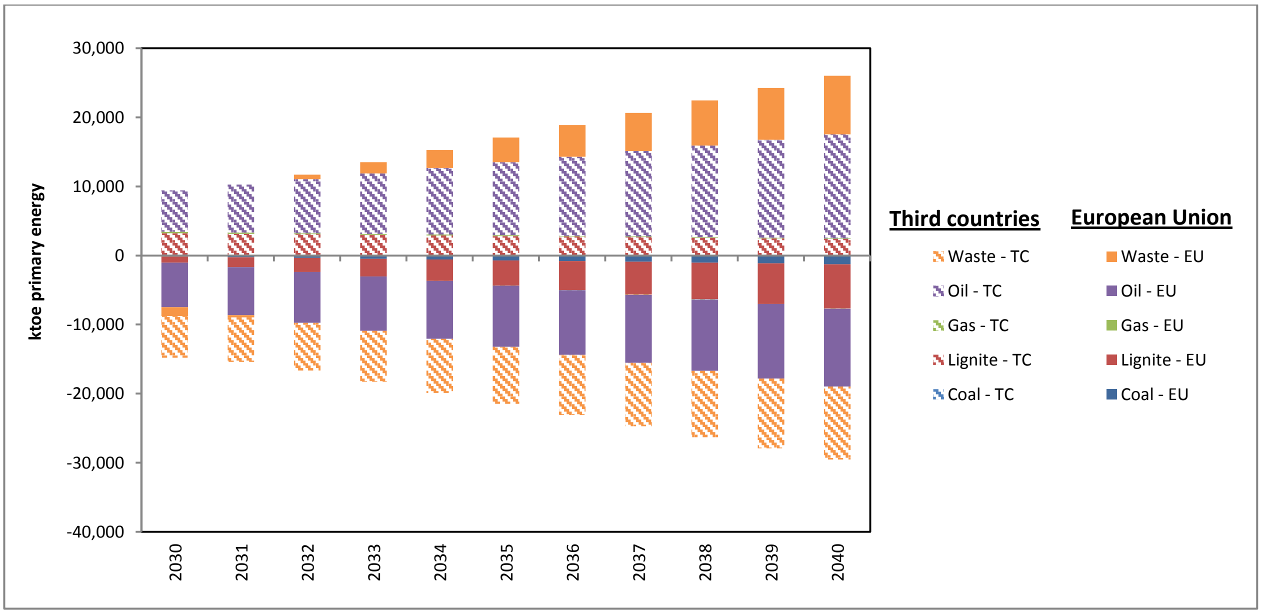
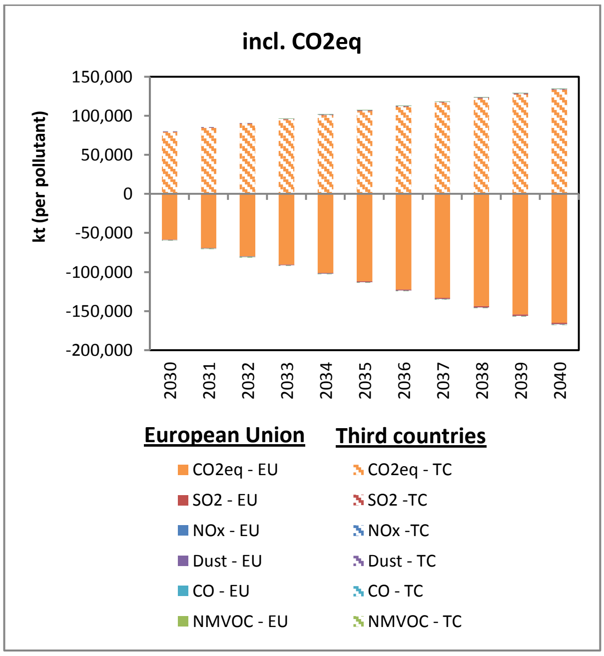



Figure 79: Changes in ktoe primary energy: EU only → EU plus (WEAK TARGET) – fossil based energy sources

This differing picture of changes in ktoe primary energy in the weak target case also leads to a totally differing picture in emission changes (see figures below).



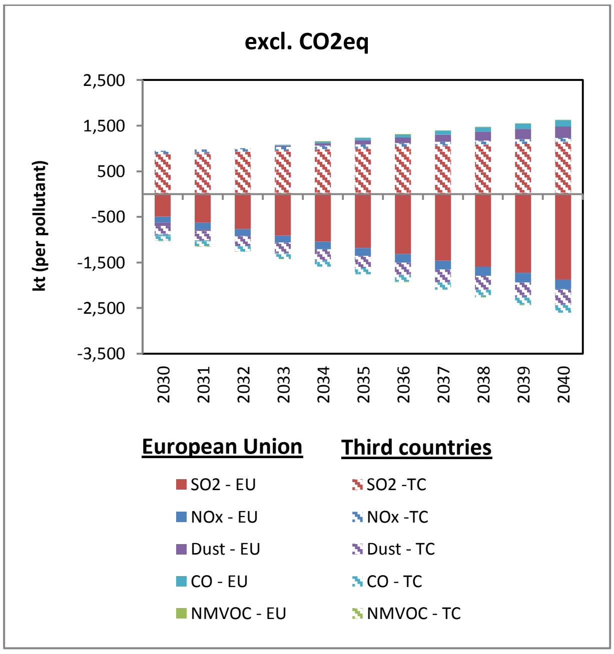




Figure 80: Emission changes: EU only → EU plus (WEAK TARGET) – fossil based energy sources

In an overall view, emission savings in switching from EU only to EU plus and considering fossil based energy sources only, are still prevailing, however not as much as in the strong target case. Also, in the weak target case third countries are mainly responsible for an emission increase in EU plus. The European Union on the other hand is mainly responsible for emission savings.

Strong target/ weak target comparison

Conspicuous in comparing the strong target with the weak target case regarding fossil fuels only is that the picture illustrating who is mainly responsible for emission savings and who is mainly responsible for emission increases changes completely. As in the strong target case, the EU is mainly responsible for emission increases in switching from EU only to EU plus and third countries are responsible for emission savings, it is the other way around regarding the weak target. Also, as in the strong target case mainly waste, coal and lignite are the most significant fossil based energy sources; these are oil, waste and lignite in the weak target case.

Also as in an overall picture the strong target case clearly concludes emission savings of the EU plus in comparison to the EU only scenario, this phenomenon is not as clear in the weak target case. However in contrast to the consideration "RES only", both target assumptions (strong target & weak target) in the consideration "fossil based only" lead to overall emission savings in switching from EU only to EU plus.

## ***RES/Fossil fuel based energies combined***

Strong target

Considering fossil fuel based energy sources and RES combined, in switching from EU only to EU plus generally more ktoe primary energy is reduced as being increased. Increased in EU plus are mainly renewables in third countries but also fossils in the European Union. Decreased are mainly renewables in the European Union but also fossils in third countries (see figure below).

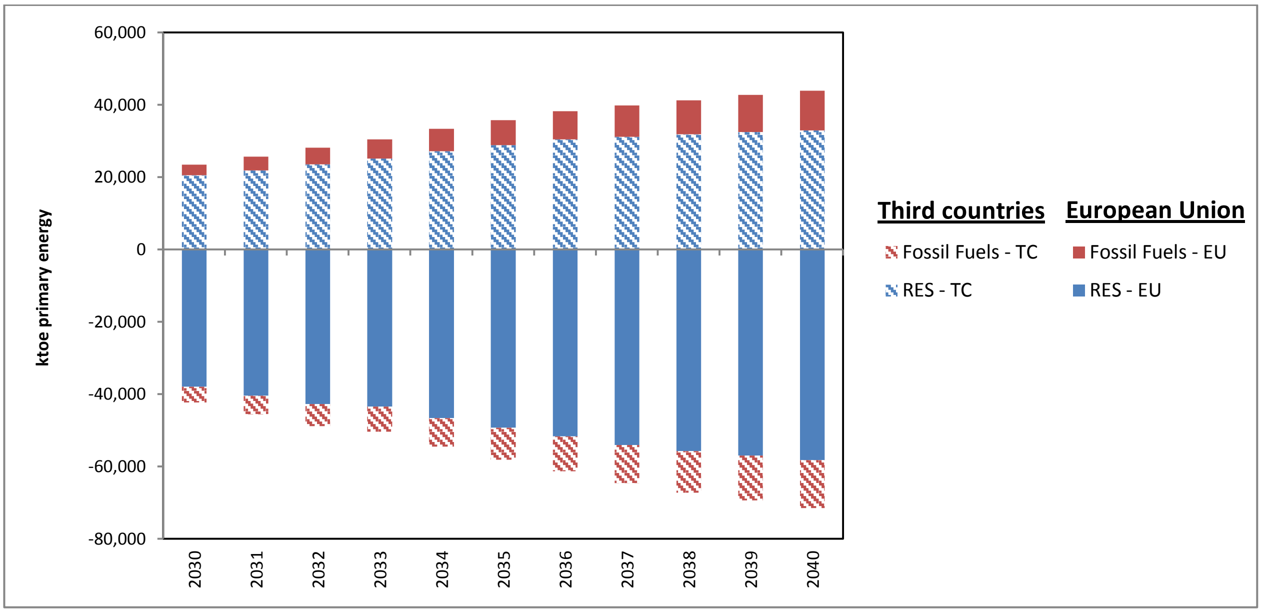
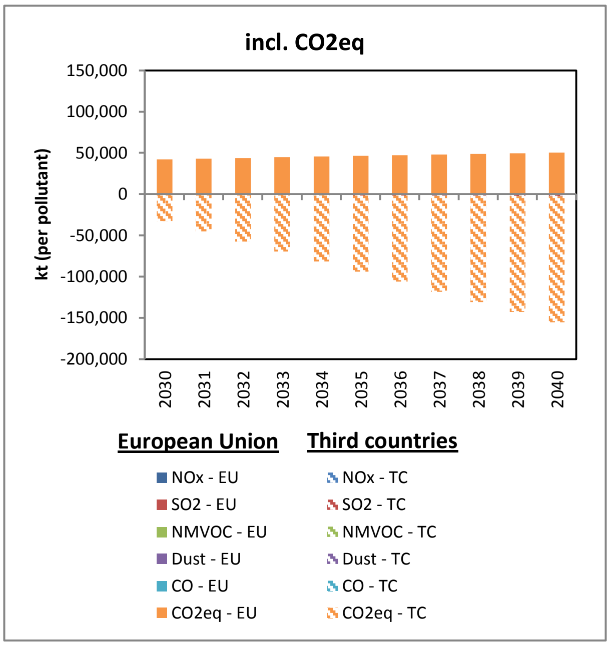



**Figure 81: Changes in ktoe primary energy: EU only → EU plus (STRONG TARGET) – RES & Fossil**

In allocating emission factors to changes in ktoe primary energy, the figures below show that mainly GHGs linked to fossils are responsible for changes in emissions. Local air pollutant emissions are playing a rather minor role, but not to forget that their harmfulness on the environment and therefore their respective costs can be several times higher as GHG emission impacts.



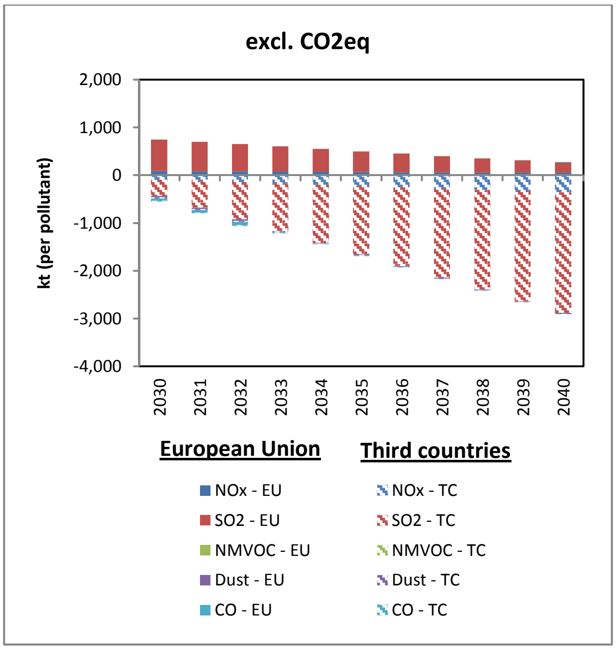




Figure 82: Emission changes: EU only → EU plus (STRONG TARGET) – RES & Fossil

In both cases, incl. $CO_{2eq}$ as well as excl. $CO_{2eq}$., switching from EU only to EU plus leads to overall emission savings, thus mainly linked to emission savings achieved in third countries. In the European Union switching from EU only to EU plus mainly leads to an increase in emissions, thus however not outweighing emission savings achieved in third countries.

Weak target

Considering the weak target assumption, more fossil fuel based energies as well as renewables are reduced in the EU in switching from EU only to EU plus as are calculated to increase in third countries. In comparison to the strong target assumption however, only the third country region is responsible for the increase in ktoe primary energy of both, renewables and fossil fuel based energies, in switching from EU only to EU plus. In contrast, ktoe primary energy reductions in switching from EU only to EU plus are estimated for the EU only (see figure below).

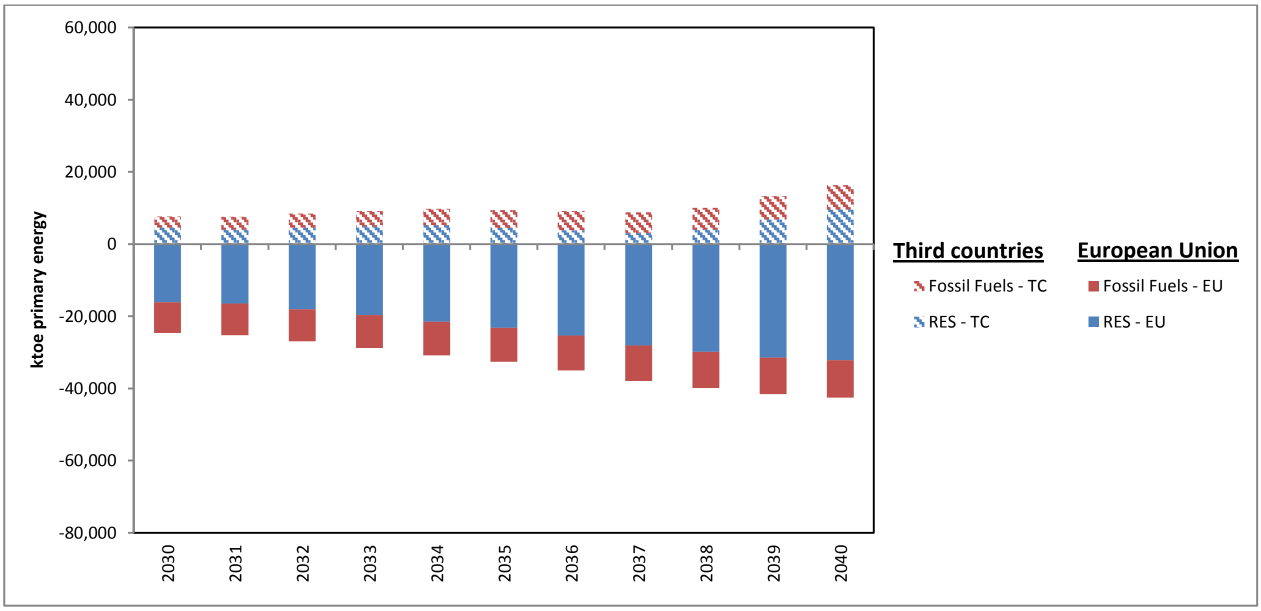



Figure 83: Changes in ktoe primary energy: EU only → EU plus (WEAK TARGET) – RES & Fossil

Also in the weak target case, mainly GHGs linked to fossils are responsible for changes in emissions. Quantities in air pollutant emissions play only a minor role. However the picture regarding emission savings and emission changes differs in comparison to the strong target case. In the weak target case mainly responsible for emission savings in switching from EU only to EU plus is the European Union. Mainly responsible for emission increases is the third country region (see figure below). This has been illustrated the other way round in the strong target case.

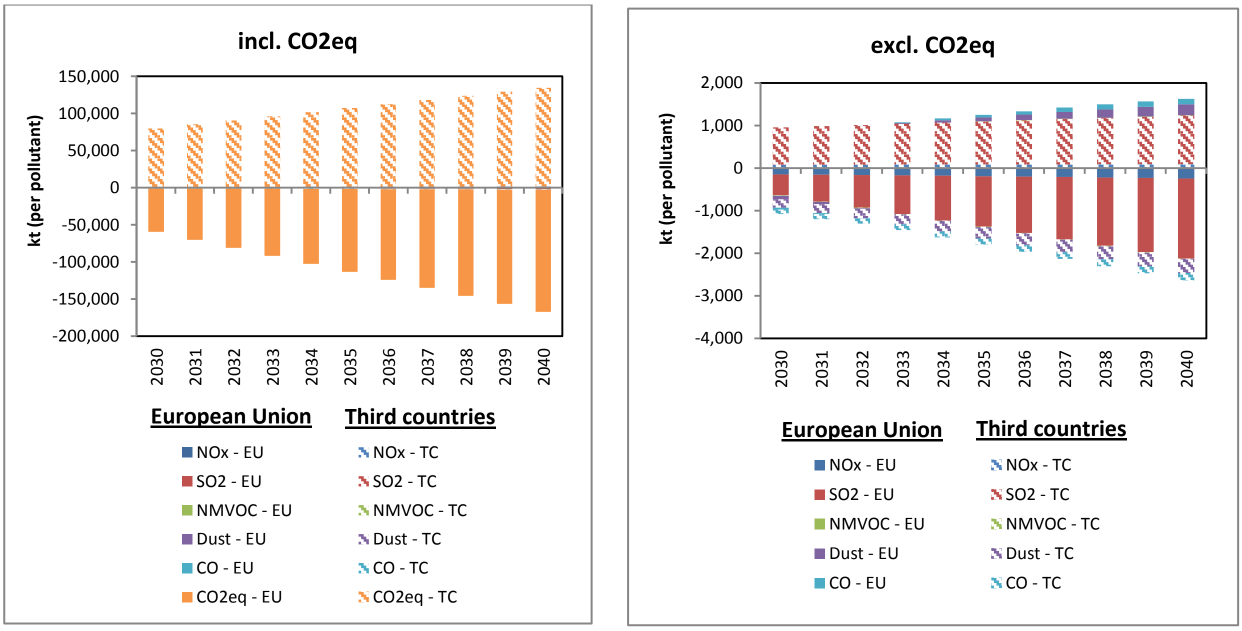



**Figure 84: Emission changes: EU only → EU plus (WEAK TARGET) – RES & Fossil**

Strong target/ weak target comparison

Comparing the strong and weak targets scenarios: Each scenario leads to different shifts of technologies when moving from EU only to EU plus and therefore different emissions patterns arise. Considering RES and fossils combined, overall emission savings achieved due to switching from EU only to EU plus are much more significant in the strong target as in the weak target case.

As in the strong target case, mainly in the European Union emission increases arise at switching from EU only to EU plus, it is the third country region in the weak target case. For emission savings achieved due to the switch from EU only to EU plus, mainly the third country region is responsible in the strong target case, the European Union in the weak target case.

### 4.1.3 Conclusions on environmental co-effects induced by full RES cooperation with assessed neighbouring countries

The analysis has shown that full RES cooperation with third countries leads to overall emission savings of greenhouse gases and air pollutants, independently from the European RES target setting (weak or strong). The amount of overall emission savings however is much more significant in the strong target case.

In addition, emission savings regarding both GHG as well as air pollutants induced by full RES cooperation with third countries are mainly observable regarding fossil based energy sources. Emission savings (GHG and air pollutant emissions) are not significant for renewables. Regarding renewables, emission savings strongly depend on shifted RES technologies which cause certain direct emissions. In both analysed assumptions the analysis shows that RES technologies such as biomass (RES-E) as well as biogas (RES-E) are estimated to be reduced in the European Union if it is switched from EU only to EU plus. RES technologies expanded/developed in the third country region instead are mainly “clean” technologies such as wind and solar which are not having direct emissions compared to substituted technologies in the EU that have direct emissions. This is also leading to overall emission savings regarding renewables only, however its magnitude is depending on shifted technologies and emission savings are not as significant as in the fossil case.

Therefore, from an environmental point of view, the analysis shows that full RES cooperation with third countries leads to emission savings and in turn to positive impacts on air quality and climate change. The magnitude of these positive environmental co-effects however is depending on different factors such as e.g. the level of the European RES target setting (strong, weak, etc.), the type of technologies shifted, specific third country regions in place for cooperation, etc.

## 4.2 Impact of cooperation on EU energy security

Closer cooperation regarding renewable energy between the EU and neighbouring regions may have impacts on the energy security of both, the EU and considered neighbouring regions. This section specifically assesses impacts on the EU's energy security when closer cooperating with the third country regions Western Balkans and Turkey.[47] For North Africa, the third case study region considered in the BETTER project, renewable electricity imports were compared to gas imports and published in the paper *"Lilliestam, 2013: Vulnerability to terrorist attacks in European electricity decarbonisation scenarios: Comparing renewable electricity imports to gas imports. Energy Policy Journal*".

As closer cooperation for increasing the EU's renewables share requires in most cases physical transfer of energy, this analysis focuses specifically on cooperation in the electricity system.

Lilliestam (2013) compares the Desertec scenario with the Global Energy Assessment (GEA) pathway as a representative of a scenario with high gas imports, most of which is used to generate electricity in Europe in gas power plants coupled with CCS. While North Africa given its size is the most important region (compared to the West Balkans and Turkey) that possibly impacts the energy security of the EU the paper concludes that the vulnerability of the import systems for electricity (Desertec) and gas (GEA) are low, as the systems are diversified and have considerable buffers. Forceful attacks are highly unlikely to cause spectacular (i.e. large and long-lasting) outages and severe damage, as system functionality can be restored quickly. The paper concludes that electricity imports are clearly more vulnerable than gas imports, as electricity systems are more brittle than gas systems and most importantly gas can be stored in meaningful amounts, whereas electricity cannot (Lilliestam, 2013).

### 4.2.1 Methodology and data

For analysing impacts on energy security several methods are available[48]. Taking existing approaches into account Lilliestam (2013) has proposed an indicator based approach also used in several recent and peer-reviewed analyses.[49] The main advantage of this approach is that it considers in a structured way all relevant aspects which describe impacts on energy security with manageable time efforts and data requirements.

The approach enables the analysis of impacts both for host and buyer countries of (renewable) energy deployment. For analysing energy security impacts of closer cooperation with the EU specific indicators are defined covering the aspects of:

***1.) Energy coercion:***

A very prominent aspect when discussing the issue of energy security is often how vulnerable an energy importer country is in a case where energy is used as a tool for coercion by the exporter country, i.e. to put economic, political, etc. pressure on the importer country. This aspect can be discussed by analysing the EU's (importer region) electricity import/ electricity transmission capacity compared to domestic capacities to compensate a certain stop in electricity delivery (via dispatchable backup generation in the EU).

[47] Impacts of closer cooperation for these third country regions are discussed in detail in respective third countries impact assessments.

[48] See Lilliestam (2013): Energy security and renewable electricity imports: the case of a supergrid connecting Europe, North Africa and the Middle East; Dissertation; Central European University Budapest.

[49] See e.g. Lilliestam, J., Ellenbeck, S. (2011): Energy security and renewable electricity trade – Will Desertec make Europe vulnerable to the "energy weapon"?; Energy Policy 39 (2011) 3380-3391. Lilliestam, J., Ellenbeck, S. (2012): Fostering Interdependence to Minimise Political Risks in a European-North African Renewable Electricity Supergrid; Expert View; Green, Vol. 2 (2012), pp. 105-109.

However, also exporter countries might depend on revenues from electricity exports. The question in that respect is how an exporting region/country depends on the revenues it gathers from electricity exports (e.g. in relation to its GDP or national budget).

***2.) Critical infrastructure failure:***

This aspect tackles the question whether electricity imports from considered third countries/regions to the EU could be reduced considerably by failure of certain infrastructures (e.g. transmission lines), for instance caused by extreme weather events or terrorism. An appropriate indicator for that is the number of transmission lines or number of chokepoints (= geographical dispersion of transmission lines).

***3.) Diversity:***

In order to make the energy system more secure against events one cannot foresee, diversifying the energy system might be one strategy. In order to display the diversification of the EU's electricity system the diversity of electricity exporter countries (importing to the EU) and the fuel diversity of the EU's electricity system describe this aspect.

***4.) Intermittency risk:***

The intermittency risk covers two aspects – the weather based and the third country/region based intermittency risk.

The importance of weather based intermittency risk from renewable energy power facilities on the functioning/stability of the EU's electricity system can be analysed by putting the magnitude of potentially fluctuating renewable energy based electricity in relation to dispatchable European generation capacity and the European peak load.

Third country/region based intermittency risk in turn covers the aspect of how likely it is that certain electricity production facilities in third countries/regions cannot deliver and how it impacts the EU's electricity system. Third country/region based intermittency risk is influenced by the age of the power plant fleet, their own electricity demand growth and the pace of investments into the fleet, etc.

Changes in indicators covering the above mentioned aspects are considered to appropriately display changes in energy security. A more detailed description of indicators is provided in Deliverable 2.5 "Indicators and Methodologies to Assess Key Issues for the Implementation of the Cooperation Mechanisms" provided by the BETTER project.[50]

Required data include status quo information about the current electricity system in both the EU and third countries (current generation capacities, fuel flows, electricity flows, peak loads, used generation technologies and fuel types, import diversity and share of domestic production/exploration of several fuels, transmission capacities) as well as projections of the energy system (renewable electricity generation capacities, energy demands and transmission capacities) in 2020 and 2030 provided by the Green-X and HiREPS models. Also economic information e.g. importance of energy trade for the domestic economy or the economies of the third country regions are included.

### 4.2.2 Impacts on EU's energy security due to closer cooperation with Western Balkan

Taking the unequal sizes of the electricity systems of the EU and the Western Balkan (WB) into account one could already assume that the EU's susceptibility to blackmail related to electricity imports from the Western

[50] Find this deliverable at http://www.better-project.net/content/d25-indicators-and-methodologies-assess-key-issues-implementation-cooperation-mechanisms

Balkans is highly limited. This is underpinned by – for the stability of the European electricity system – rather low thermal limit of electricity transmission lines of currently approx. 20.4 GW or 22.4 GW when PECIs are going to be built. This magnitude does not provide a sufficient leverage for using energy as a means for political pressure, considering the EU's peak load of approx. 581 GW. Around half of these transmission capacities go over Croatia, FYROM and Serbia. While Croatia is already part of the EU, others might join the EU in the future. Also, the Western Balkan countries do not only profit from an accelerated raise of their renewable energy potential (with therefore accelerated impacts on their employment and their national budgets a.o.). Some of the Western Balkan countries, specifically small ones, profit from hedging the risk of black outs/electricity supply shortages – e.g. caused by sudden technical failures of their (rather old) power fleet – by being incorporated within a bigger European electricity system. All these indicators point in the direction that energy coercion from the Western Balkans to the EU is neither likely to happen nor would have significant impacts. Also, as presented in the specific country case study reports, closer cooperation is mutually free of risk in that respect: Increasing cooperation will increase annual electricity import volumes to 42 TWh[51] from Western Balkan to EU in the best case. Potential future electricity export revenues of € 2.1 billion (assuming aforementioned electricity trade volumes and an average price of € 50/MWh) are rather small compared to the regions GDP of approx. US$ 91 billion in 2013[52]. That implies that also the Western Balkan region is not vulnerable to hypothetical export sanctions.

Infrastructure failure due to natural events or terrorism is another aspect of energy security. The Western Balkan region is connected to the EU via several transmission lines of 380 kV starting from different Western Balkan countries, 4 new PECIs are planned (see Figure 85). In case of intensified electricity trade some of these lines could be near to their safety limits. The HiREPS model assumes that in the future respective TSOs need to actively manage the power generation at all times in order to avoid an overloading of one or more lines. However, due to the geographically diversified grid systems for transmitting electricity to the EU, infrastructure failures due to single extreme weather events or terrorist attacks are assumed to be have limited impacts on the electricity export of the region and the EU's electricity system stability.

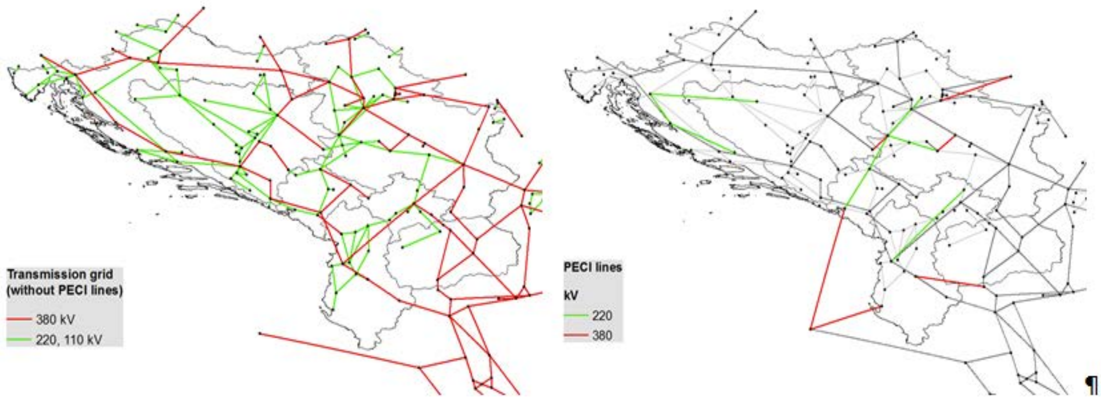



**Figure 85: Simulated transmission grid based on the ENTSO-E Grid Map; Left picture: existing transmission lines; Right picture: planned PECI lines; Source: HiREPS Simulation Model**

For improving the EU's energy security, it is valuable to both diversify the EU's fuel consumption as well as to diversify among the countries exporting energy/electricity to the EU. Currently the EU is not really an electricity importer – only 1,138 ktoe out of 238,892 ktoe final electricity consumption (data for 2013[53]) have been imported (net imports). For coal, more than half of the EU's gross inland consumption is imported (165,244 ktoe out of

[51] Modelling scenario "Strong target, NA delay
[52] http://data.worldbank.org/indicator/NY.GDP.MKTP.CD
[53] See http://ec.europa.eu/eurostat/web/energy/data/energy-balances

286,522 ktoe in 2013[54]), however, suppliers are geographically highly diversified worldwide. For natural gas, however, 2/3 of the EU's gross inland consumption (386,845 ktoe in 2013) is imported, approx. ¼ of gross final consumption is used as transformation input in conventional thermal power stations. Approx. half of the EU's natural gas imports originate from Russia (see Figure 86).

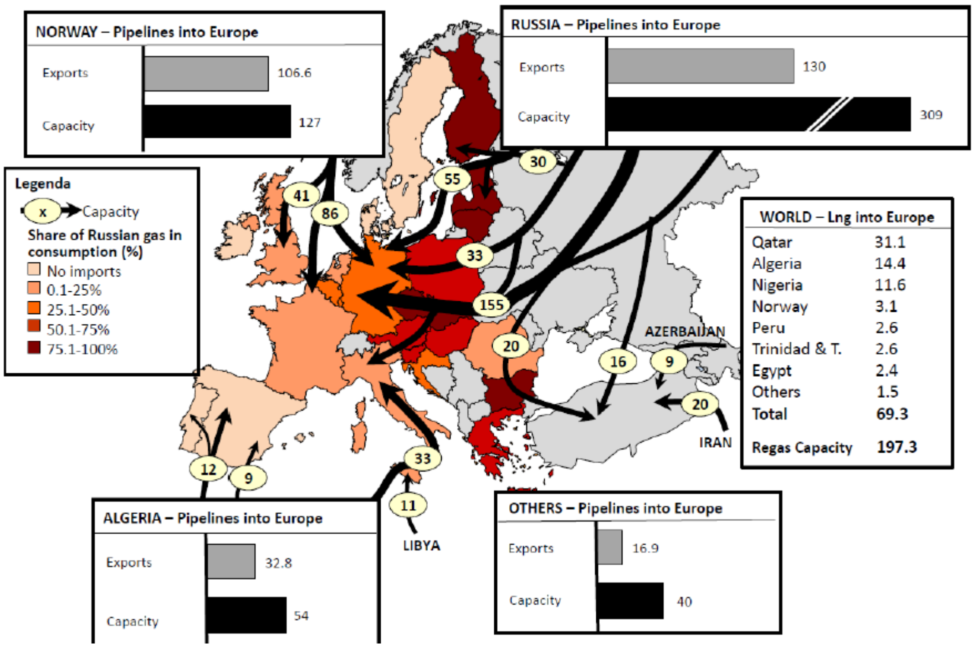



Figure 86: Natural gas import flows to Europe; Source: CIEP[55]

From the diversity aspect, an improvement of the EU's energy security by closer cooperation with the Western Balkans depends on the type of electricity imported: in case of base load imports, which are provided in the EU mainly by base-load renewables, nuclear and coal, energy security does not change as closer cooperation does not reduce critical import dependencies of the EU for its "base load fuels" (as coal suppliers are highly diversified). When importing peak load, however, a small but existent improvement of EU's energy security arises. As peak loads are provided in the EU – apart from renewables – mostly by gas fired power plants, providing peak load by RES from the Western Balkans reduces the EU's need of gas fired power and therefore reduces its import dependency from gas exporting countries with a high market share in the EU.

Especially when focusing on peak load weather based intermittency risks are highly relevant. However, taking into account the thermal limits of 22.4 GW of intended transmission lines in the near future compared to approx. 581 GW European peak load, weather caused reduced transmission will be manageable for the EU's electricity system.

However, a stronger focus should be on the intermittency risk caused by the Western Balkan countries. Although it is also valid at this stage that single failures or interruptions in electricity generation will not cause unmanageable problems for the EU's electricity system, there are certain aspects which need to be considered and solved in the future for improving the energy security both for the EU but also for single Western Balkan countries. Nearly all of the considered Western Balkan countries anticipate growth of electricity demand in the coming years by 12-27 %[56] (depending on considered scenarios). It is intended that capacities are strongly increased[57],

54 See http://ec.europa.eu/eurostat/web/energy/data/energy-balances
55 http://www.clingendaelenergy.com/files.cfm?event=files.download&ui=9C1DEEC1-5254-00CF-FD03186604989704
56 Source: Own calculations
57 Source: Expert information

however, investment barriers in some West Balkan countries make an achievement of required new investments challenging. Also in the coming future investments for revitalizing existing power facilities will be needed – the average age of the current fleet in the West Balkan countries is between 32 years in Bosnia and Herzegovina and 42 years in Montenegro[58] (see Figure 87).

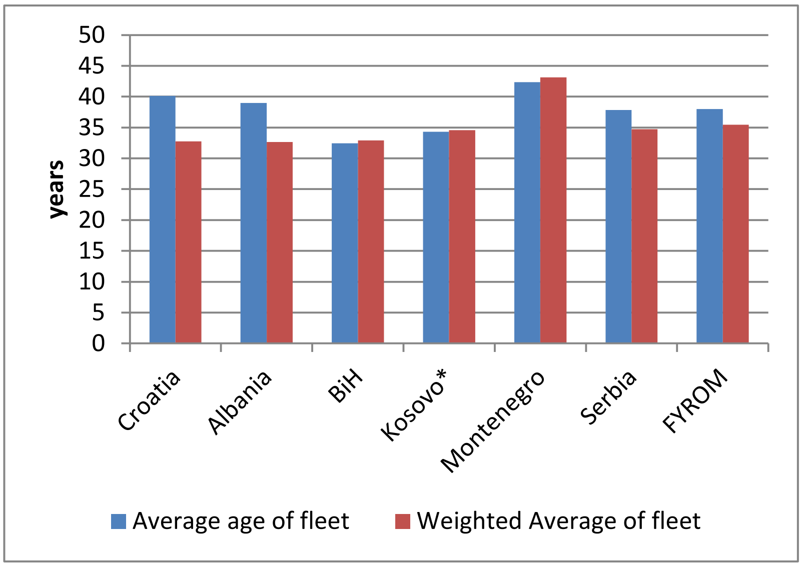



**Figure 87: (Weighted) average fleet of power generation facilities; Source: own calculation**

Thus, anticipated strong electricity demand growth, potential lack of investments and a rather old fleet of generation facilities would need to be considered for the EU's electricity supply security if the potential West Balkans electricity exports would not be small compared to the European electricity generation (EU's transformation output of 2,542 TWh[59] compared to potential future imports from the West Balkans of 42 TWh in the HiREPS/Green-X modelling scenario "Strong target, NA delay").

## ***Concluding:***

Current transmission capacities from Western Balkan countries to the EU as well as unequal sizes of the electricity systems of both regions (WB and EU) do not provide sufficient leverage to considerably affect the EU's energy security. Apart from that, most Western Balkan countries seek for a closer cooperation with the EU, also for hedging their electricity systems against infrastructure failures.

The EU and the Western Balkan region are connected through several transmission lines, geographically distributed over several West Balkan countries. This geographical diversification of transmission lines therefore does not lead at single unintended events (extreme weather events, terrorist attacks) totally interrupting the electricity trade between both regions.

Importing specifically peak load from the Western Balkans could substitute gas-fired power in the EU to a certain extent. This would improve the EU's energy security, as it makes the EU less dependent on natural gas, which needs to be imported to a considerable extent from only a few countries.

[58] Own calculations based on survey of existing power plants

[59] Based on http://ec.europa.eu/eurostat/web/energy/data/energy-balances ; transformation electricity output 218,618 ktoe in 2013 in EU; EURELECTRIC even states 3,082 TWh for EU27, http://www2.warwick.ac.uk/fac/soc/csgr/green/foresight/energyenvironment/2013_eurelectric_power_statistics__trends_2013.pdf , p., 11

Problematic – in relative terms – could be the rather old power plant fleet in the Western Balkans, the strong growth of the Western Balkans electricity demand and the investment barriers for building new power plants in certain parts of the Western Balkan region. This makes the Western Balkan region less reliable in being able to deliver agreed electricity to the EU, especially in case of extreme events (failure of power plants, sudden high domestic electricity demand e.g. for cooling, etc.)

| | |
|---|---|
| **Energy coercion** | |
| **Critical infrastructure failure (natural events, terrorism)** | |
| **Diversity** | |
| **Intermittency risk (weather based)** | |
| **Intermittency risk (Third country based)** | |
| | |
| **Cooperation perceivable improves energy security for EU/WB** | |
| **Cooperation has no impact on energy security for EU/WB** | |
| **Cooperation worsens energy security for EU/WB** | |

### 4.2.3 Impacts on EU's energy security due to closer cooperation with Turkey

As for the Western Balkan region also for Turkey capacities of electricity transmission lines to the EU are currently highly limited. Determined as maximum values by ENTSO-E, the Turkish electricity export capacity to the EU (more specifically to Bulgaria and Greece) is 300 MW (see Figure 88).

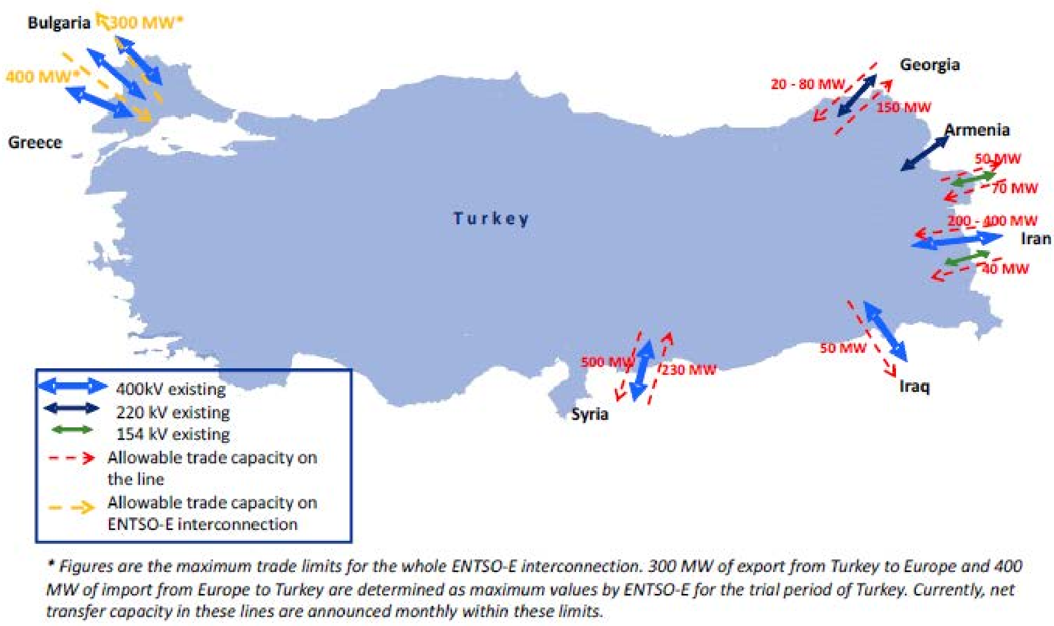



**Figure 88: International electricity transmission line capacities from Turkey**

This small transmission capacity does certainly not provide sufficient leverage for energy coercion to the entire EU. However, the question arises, whether Greece or Bulgaria as direct neighboring countries to Turkey could suffer from electricity supply interruptions from Turkey. The EU's concept of an "Energy Union" requires an interconnection ratio (= total capacities of interconnectors to a country/domestic generation capacities of that country) of at least 10 %, both Greece and Bulgaria will have an interconnection ratio of 10-15 % by 2020 (EN-

TSO-E). Taking into account installed capacities of 17.4 GW[60] and 13.8 GW[61] in Greece and Bulgaria respectively, the transmission capacity from Turkey amounts to about 2 % of the Greek or Bulgarian installed capacity. Moreover, the Bulgarian electricity system is characterised by an overcapacity in electricity generation with a peak load of 7.8 GW (in February 2012[62]). Furthermore, Greece imports less than 5 % of its electricity consumption; Bulgaria is even a net exporter of electricity.[63] This implies that the low electricity transmission capacities by far do not provide the leverage for energy coercion, neither for the EU as a whole nor for EU-MS directly bordering with Turkey.

The only minor transmission capacities between Turkey and the EU are also the reason why the EU's electricity system stability is not vulnerable to critical infrastructure failure – specifically of transmission lines from Turkey to the EU.

The EU's electricity generation is highly diverse. As mentioned also for the Western Balkans, only natural gas as input fuel for power plants EU leads to vulnerabilities because of its high import dependency and the low diversification of countries exporting natural gas to the EU. In that respect, closer cooperation with Turkey could reduce the EU's dependency of gas, if peak loads in the EU could increasingly be covered by RES-electricity from Turkey, thereby substituting EU's peak load generation – currently mainly provided by natural gas. That implies that existing domestic capacities in natural gas storage facilities could last longer in a case of gas supply shortages. Certainly this improvement of EU's energy security is only minor; however it could improve by increasing transmission capacities between the EU and Turkey.

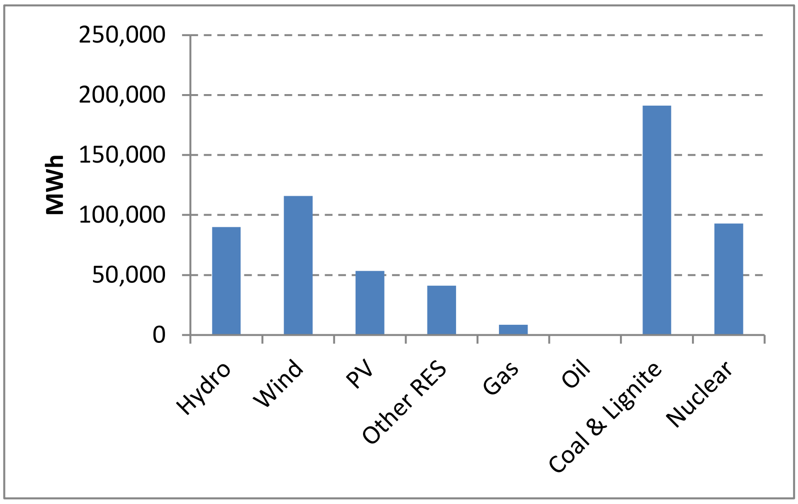



**Figure 89: Simulated mix of electricity generation in Turkey 2030, scenario SNP ave (Source: HiREPS)**

Weather based intermittency risk of electricity from renewables is certainly an issue to be handled by TSOs, however, the smaller transmission capacities the smaller the risk for the EU to be harmed by intermittency risks. Also from the viewpoint of exporting country based intermittency risk, i.e. a certain unreliability of the exporting county to be able to transmit electricity as agreed, closer cooperation with Turkey does not harm the EU's energy security. Firstly, HiREPS simulations show that the Turkish mix of electricity generation in 2030 switches significantly from gas to more hydro, wind and PV. Coal & lignite as well as nuclear power remain/become important (see Figure 89). This reduced dependency on natural gas in power generation certainly increases the Turkish energy security and therefore makes Turkey more reliable in being able to generate electricity as planned. Alt-

60 https://energypedia.info/wiki/Greece_Energy_Situation
61 http://ec.europa.eu/energy/sites/ener/files/documents/2014_countryreports_bulgaria.pdf
62 http://ec.europa.eu/energy/sites/ener/files/documents/2014_countryreports_bulgaria.pdf
63 https://www.entsoe.eu/Documents/Publications/Statistics/2013_ENTSO-E_Electricity%20in%20Europe.pdf

hough gas power in Turkey becomes less important, it is assumed that respective facilities remain available to a certain extent, potentially balancing certain weather based intermittency risks.

The growing Turkish economy[64] and living standards result also in increasing electricity demand. In the past Turkish investments in additional power generation capacities could keep pace with increasing electricity demand. According to expert information planned power generation capacities have always been a bit over the actual electricity demand growth. Therefore it is assumed that Turkey will be able to provide agreed amounts of electricity to be exported to the EU.

***Concluding:***

Currently only minor electricity transmission capacities between Turkey and the EU exist. Therefore closer cooperation with Turkey neither harms nor increases the EU's energy security to a perceivable extent.

Increasing these transmission capacities in the future will lead to more perceivable impacts on EU's energy security. However, even in that case the EU is not threatened by energy coercion because of the size of the EU's electricity system compared to the Turkish electricity system. Also the electricity system of EU-MS directly bordering with Turkey are not threatened by electricity delivery interruptions from Turkey as they sufficiently connected with other EU-MS or even have overcapacities in power generation facilities.

Increased import of peak load imported from Turkey increases the energy security of the EU, as European peak load is mainly covered by power from natural gas, which is imported to a considerable extent from only a few countries. Also Turkey as a potential electricity exporter to the EU is expected to be reliable in the future. On the one hand it is assumed that Turkey switches from currently high gas-dependency in power generation to renewables to a considerable extent, marginalising natural gas demand for power generation and therefore making itself less vulnerable to energy coercion. Still existing gas power facilities may serve as back-up to reduce weather based intermittency risk from renewables. On the other hand, investments into power plants kept pace with increasing electricity demand and this is also assumed in the future. This makes Turkey reliable in being technically able to deliver RES-electricity to the EU as required.

| | |
|---|---|
| **Energy coercion** | |
| **Critical infrastructure failure (natural events, terrorism)** | |
| **Diversity** | |
| **Intermittency risk (weather based)** | |
| **Intermittency risk (Third country based)** | |
| | |
| **Cooperation perceiveable improves energy security for EU/Turkey** | |
| **Cooperation has no impact on energy security for EU/Turkey** | |
| **Cooperation worsens energy security for EU/Turkey** | |

[64] See for instance http://www.tradingeconomics.com/turkey/gdp

## 4.3 Macro-economic impacts in the EU

The underlying analysis compares the cases where – on the one hand – only EU-MS cooperate for achieving their agreed RES-shares most cost-effectively, versus – on the other hand – EU-MS cooperate also with third countries. In other words, the underlying analysis compares the scenarios "EU only" with "EU+". Furthermore, economic impacts will be distinguished depending on the ambitions the EU has for increasing the RES-share in Europe by 2030 (strong target vs. weak target).

### 4.3.1 Types of impacts

- Investment and operating impacts: The potentially best known impacts from implementing technologies are direct impacts which arise from expenditures for investment and operation of facilities. Compared to an alternative use of such funds, namely consumption, expenditures in technologies/facilities lead to an increased capital stock, from which profits can be achieved, which once again can be invested with resulting impacts on employment and GDP.
- Impacts from financing expenditures for investment and operation: Obviously funds for investments and operation need to be provided within the economy. Used funds would not have been idle in the absence of RES-investments, they would have been invested somewhere else in the economy. Thus investing into RES-technologies results in respective lower investments/consumptions in other economic sectors (unless expenditures into RES are financed by new debts, whose repayment would lead to negative impacts in the future). These impacts could be seen as a kind of "counterbalance" to positive impacts from investments and operation of RES-facilities. Thus positive impacts from investment and operation of RES facilities are balanced by negative impacts from financing – the final impact depends on the intensity of RES investments of using domestic production factors and the ability for providing these RES-investments domestically compared to non-RES investments.
- Budgetary impacts: Closer cooperation with third countries intends to use more cost-efficient sites for electricity and heat production abroad for achieving efficiency gains. This leads to lower costs for providing the service "1 MWh of electricity or heat" than without cooperation. These savings increase the available budget of economic agents for non-energy related expenditures without forgoing on energy consumption in the same manner as without cooperation. Spending these savings (due to efficiency gains) leads once again to additional positive macro-economic impacts.
- Direct, indirect and induced effects: Macro-economic impacts do not only arise from initial changes in expenditures ("direct effects"). These expenditures lead – in a second round – to a change in investments by suppliers for RES technologies ("indirect effects"). Additional income due to the increased labour force also leads to economic impacts ("induced effects").
- Crowding out: The impacts of investments certainly depend on the degree of current use of existing capacities in the absence of RES-investments. This implies that increasing investments in times where production capacities (labour, production facilities) are used near to their capacity limits will crowd out other investments. Thus, final macro-economic impacts will be lower in a case where production capacities are near to their full use already compared to a case with a high degree of idle production capacities (e.g. high unemployment rate).

### 4.3.2 Method of approach

The macro-economic analysis is built on data on expenditures for RES when comparing the scenarios EU only and EU plus. Considered expenditures are changes in:

- Capital investment expenditures
- Fuel expenditures

- O&M expenditures
- Support expenditures

Based on information of expenditure changes a multiplier analysis is applied (see e.g. IRENA – Renewable Energy and Jobs, Dec. 2013). In this approach empirical information about achieved impacts on employment or GDP per unit of expenditures are used. Janssen and Staniaszek (2012) have reviewed 35 different cases of investments (mostly in the construction sector) in OECD countries, calculating the thereby achieved employment impacts per unit of investment. For governmental expenditures it is assumed that they are using domestic production factors more intensely than private investments. In addition to direct impacts it has to be considered that impacts of one annual investment last for many subsequent years (because of indirect and induced effects), whereas the bulk of effects appears in the first six years [see Kurzmann et al., 2007]. The extent of these subsequent impacts is based on Kurzmann et al. (2007). As indirect and induced job effects of one annual investment appear in addition to direct (as well as its indirect & induced) effects of investments in subsequent years, annual job effects are cumulated over time even if annual investments stay the same. Beyond a certain horizon of analysis, where no investments into RES are considered anymore, only indirect & induced (but no direct) effects last for some subsequent years.

The calculation of impacts on the GDP also follows the multiplier approach, for instance applied by Hansen and von Utfall Danielsson (2012). There the used multiplier is based on EU-specific data for gross value added per job and production per job (=productivity per job). A crucial leverage for impacts on both employment and GDP are country-specific import shares: Certain parts of expenditures will lead to domestic and therefore considered impacts. However, other parts of expenditures will flow out to other countries – these expenditures will certainly have an impact in these countries but are out of scope of national statistics and therefore not considered anymore in the analysis. The degree of how much of certain expenditures flow out of the country depends also on the size of a country: Expenditures in small countries, with a potentially limited variety of industries or limited capacities might flow out of the country to a bigger extent compared to countries having all industries at home with sufficient capacities. Therefore a positive relationship between the size of countries and the ability to provide goods and services by domestic production factors exists. The underlying analysis focuses on the system boundary “entire EU”, which means that rather little outflows of expenditures are assumed. Considering data of the EU’s trade balance shows that the relation between the performance of the EU’s economy (GDP 13.1 trillion € in 2013[65]) and imports to the EU (1.7 trillion € in 2013[66]) is approx. 9:1. Taking into account annual fluctuations and uncertainties this analysis therefore assumes potential outflows of 10 % of expenditures. In order to provide a comprehensive picture of macro-economic impacts in the EU caused by closer cooperation, the analysis will not only provide gross impacts of changed expenditures. This would miss out important parts of the entire picture. Thereby the analysis provides net impacts, considering also the financing part of expenditures (see also Breitschopf et al., 2013).

## ***Steps of the analysis***

Closer cooperation intends to use more efficient sites for RES-technologies outside the EU in order to achieve the RES-targets of EU-MS most cost-effectively. By “outsourcing” RES-investments into third countries, positive impacts will certainly appear in these countries. In a first step the macroeconomic effects are calculated under the assumption that expenditures for RES in the EU are lower in the EU due to cooperation. Funds not used for RES-investments in the EU are available for other consumption/investment leading to positive impacts on employment and GDP in the EU. Whether this alternative use of funds could outweigh negative impacts from lower investments into RES-technologies in the EU depends on how intensive these alternative investments use do-

[65] Based on Statistica http://de.statista.com/statistik/daten/studie/222901/umfrage/bruttoinlandsprodukt-bip-in-der-europaeischen-union-eu/
[66] Based on Statistica http://de.statista.com/themen/2340/aussenhandel-von-eu-und-euro-zone/

mestically available production factors (second step of the analysis). Within a sensitivity analysis we are showing these effects.

### 4.3.3 Results on "weak target" scenarios

This section shows calculated macro-economic impacts for the "weak target" if EU-MS closer cooperate with third countries (instead of only cooperating among themselves), i.e. the difference between EU only and EU plus.

As mentioned above in case of closer cooperation RES investments are spent to a certain extent in third countries. This implies lower investments into RES-technologies in the EU (compared to the scenario EU only).

Figure 90 shows the change in RES-expenditures in the EU for that case, including the sectors electricity, heat and transport. The change in expenditures does not only include capital expenditures, but also fuel and O&M expenditures, as well as public subsidies granted if RES-technologies were implemented domestically. It has to be pointed out explicitly that this does not mean that absolute investments into RES in the EU decline, rather it shows the difference in RES-expenses between the two scenarios EU only and EU plus (see Figure 90).

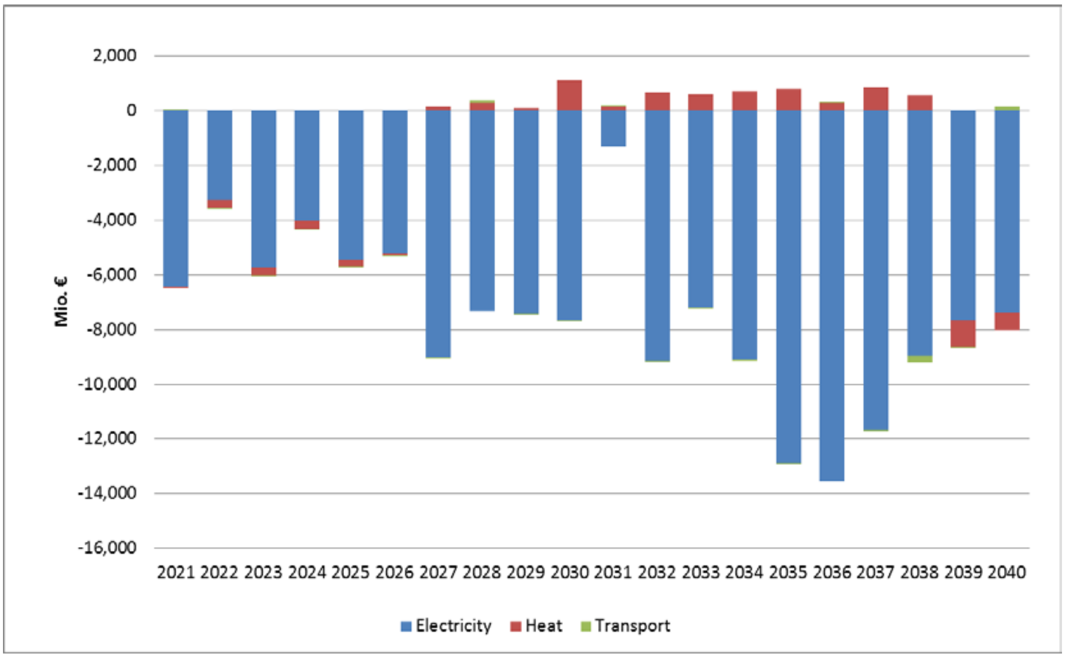



**Figure 90: Change in expenditures for RES-technologies at switching from scenario EU only to EU+, "weak target"**

It can be observed that the bulk of reduced expenses occurs in the electricity sector. Heat and transport play only a very minor role. This is not surprising, as at least for Turkey and North Africa physical transfer of RES-energy is required according to the Renewable Energy Directive (2009/28/EC).

These changes in expenditures lead in the EU (first step of the analysis) to possibly reduced impacts on employment (compared to the EU only scenario). The red line in Figure 91 shows that reducing expenditures in RES-technologies in the EU reduces possible future jobs by approx. 200,000 full-time job years annually on average (EU-wide), considering the time horizon until 2040. Although relatively reduced expenses in the EU plus scenario are rather similar in the time frame 2020-2040, possible negative job impacts are increasing due to indirect and induced effects.

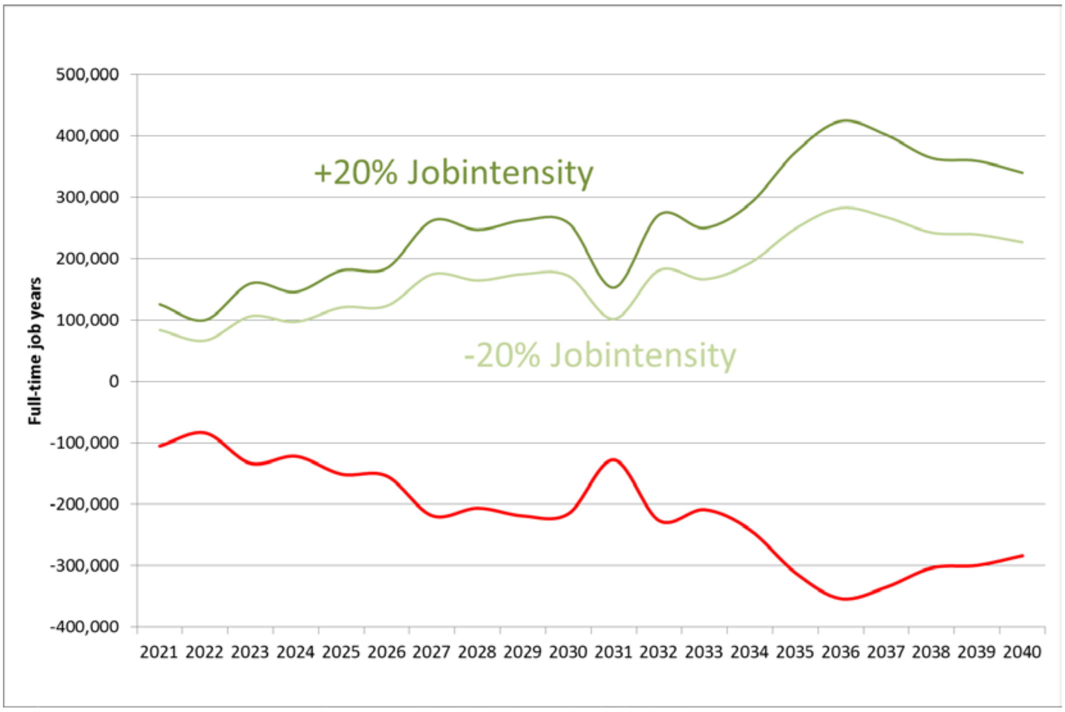



**Figure 91: Fulltime job years over time for the weak target**

RED LINE: Impacts of reduced employment effects due to the change in expenditures for RES-technologies when switching from scenario EU only to EU+; GREEN LINES: Employment effects resulting from investing saved expenses (second step of analysis) assuming +20% and -20% job intensity of alternative investments compared to RES-investments

However, as abovementioned, spending fewer funds for RES-technologies in the EU enables spending these funds for other investments/consumptions (second step of the analysis). The magnitude of employment effects of these saved funds depends on how they are used. In a sensitivity analysis, it has been estimated that saved funds are spent domestically in sectors which either use the production factor "labour" 20 % more intensive compared to producing and running RES-technologies, or 20 % less labour intensive. The job effects are shown by the two green lines in Figure 91.

Beyond that it needs to be considered that achieving RES-shares cheaper by cooperating with third countries leads to savings for EU consumers. These savings could also be spent by consumers, leading to additional positive employment effects in the EU.

Considering a second prominent macro-economic indicator, the Gross Domestic Product (GDP), similar directions of impacts can be anticipated. The blue line in Figure 92 shows once again the first step of the analysis, resulting in a lower GDP in the EU+ scenario compared to EU only.

These possible negative impacts might be compensated by using saved funds for alternative investments/consumption. The final impact, once again, depends on the grade of intensity of the use of domestic production factors relative to the respective intensities of RES-technologies' producing and operating sectors/industries. These impacts are shown by the dark green (+20%) and light green (-20%) line.

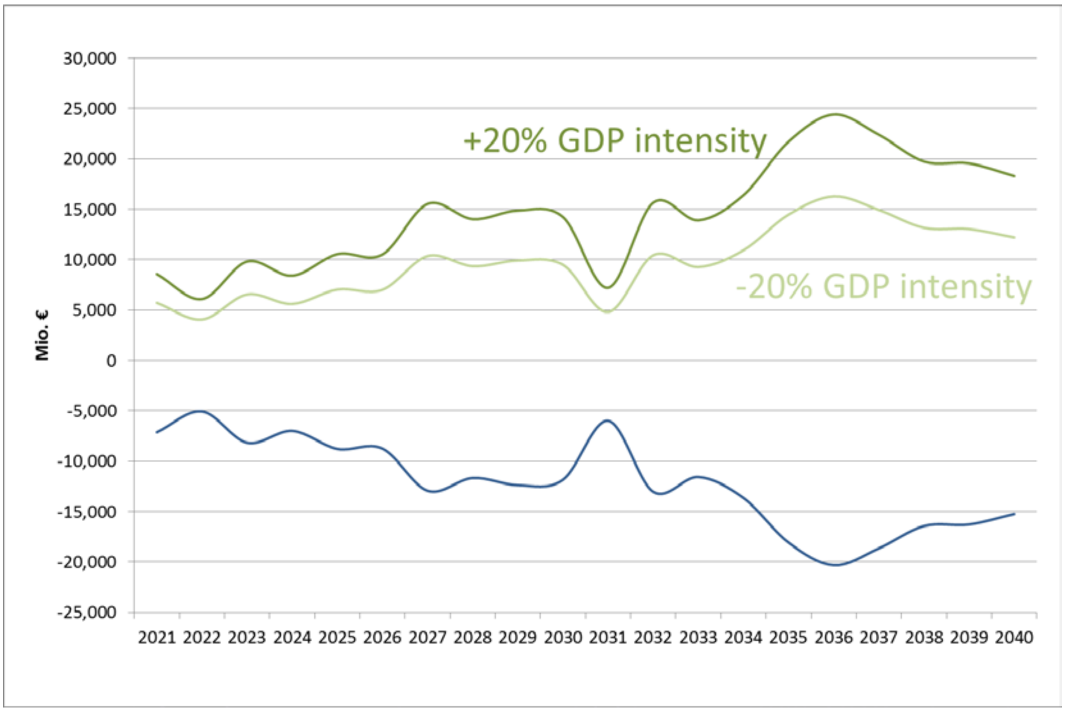



**Figure 92: Impacts on GDP for the weak target**

BLUE LINE: Effects of relatively reduced GDP due to the change in expenditures for RES-technologies when switching from scenario EU only to EU plus; GREEN LINES: GDP effects resulting from saved expenses (second step) assuming a +20/-20% intensive use of European production factors (labour, capital) of alternative investments compared to RES-investments

### 4.3.4 Results on "strong target" scenarios

This section shows calculated macro-economic impacts for the "strong target" if EU-MS cooperate more closely with the considered third countries (instead of only cooperating among themselves), i.e. the difference between EU only and EU+.

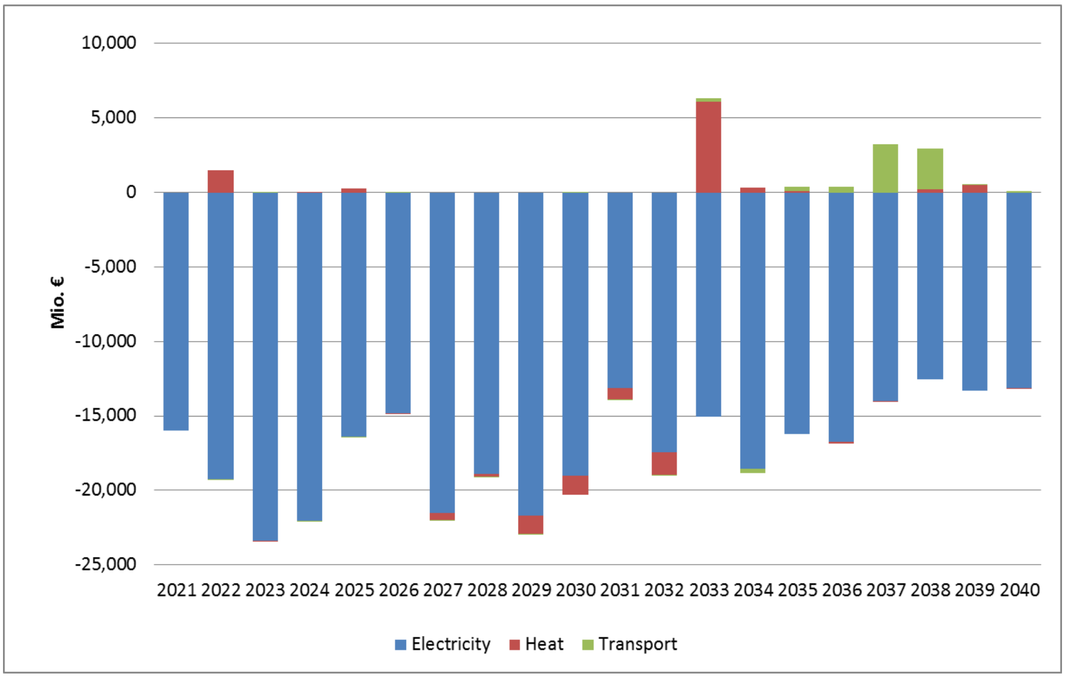



**Figure 93: Change in expenditures for RES-technologies at switching from scenario EU only to EU+, "strong target"**

The change in expenditures for RES-technologies when switching from scenario EU only to EU+ is until 2040 about double as big as in the case of a weak target. Changes in expenditures lead to effects on jobs and GDP as shown in the next two figures also for the strong target. Figure 94 and Figure 95 show that the job and GDP effects are more than twice as high for the strong target as in the case of a weak target.

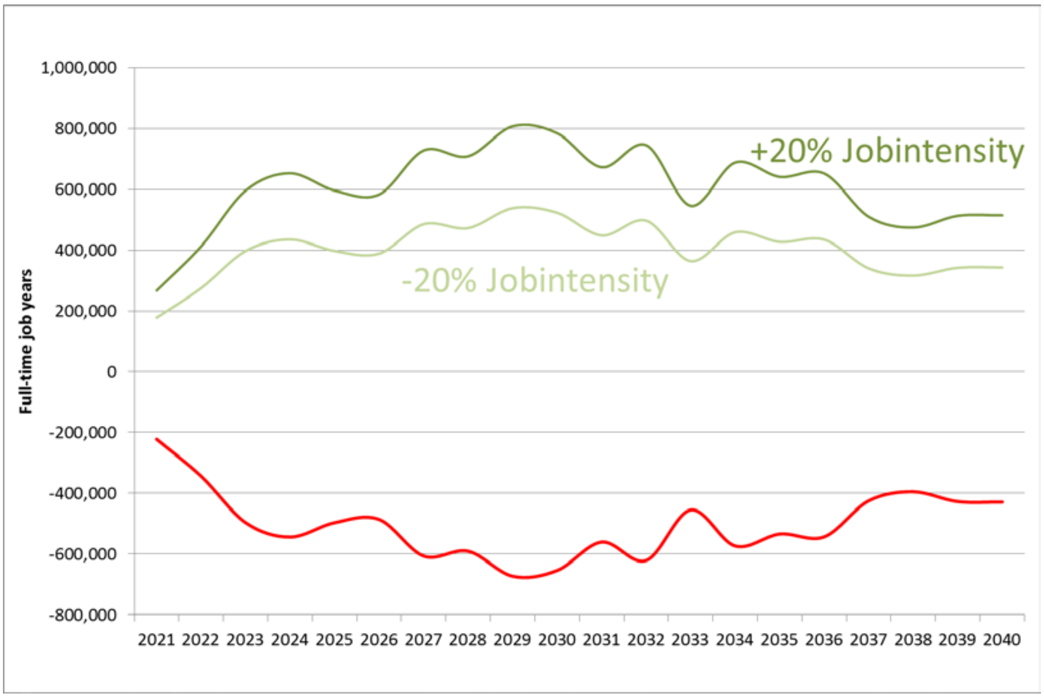



**Figure 94: Fulltime job years over time for the strong target**

RED LINE: Effects of reduced employment due to the change in expenditures for RES-technologies when switching from scenario EU only to EU+; GREEN LINES: Employment effects resulting from investing saved expenses (second step) assuming +20% and -20% job intensity of alternative investments compared to RES-investments

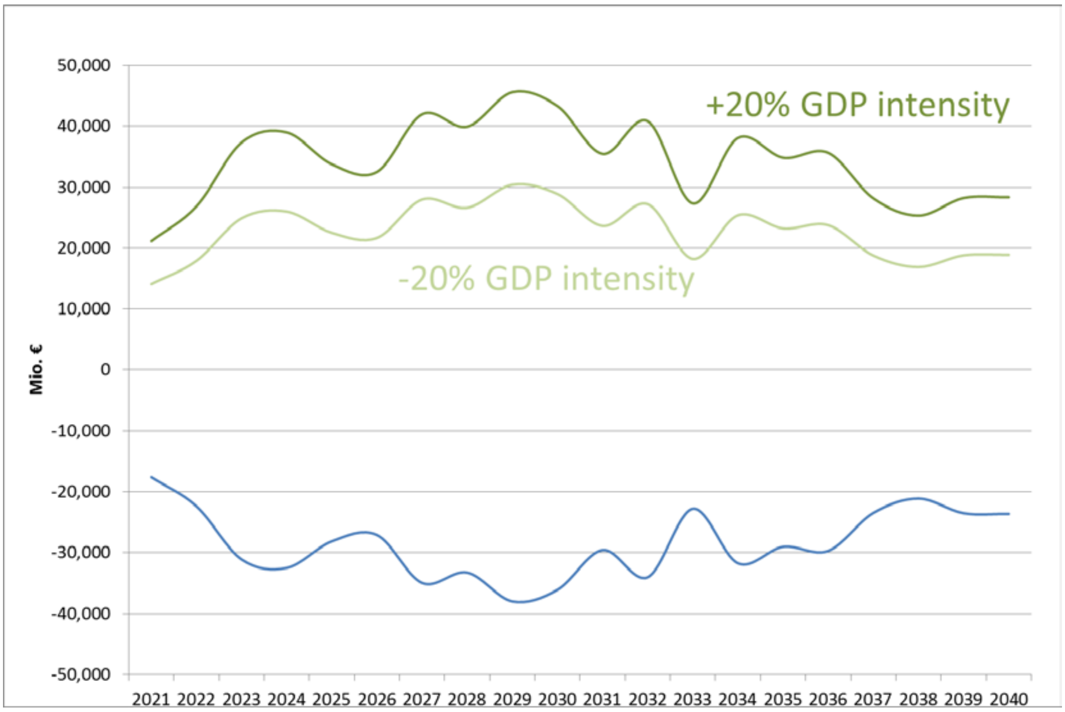



**Figure 95: Impacts on GDP for the strong target**

BLUE LINE: Effects of relatively reduced GDP due to the change in expenditures for RES-technologies when switching from scenario EU only to EU+; GREEN LINES: GDP effects resulting from saved expenses (second step) assuming a +20/-20% intensive use of European production factors (labour, capital) of alternative investments compared to RES-investments

### 4.3.5 Conclusions

The analyses show the magnitude of effects on job creation and GDP as the two most important macroeconomic indicators. It shows that the magnitude of macro-economic impacts is higher in the "strong target" assumption. Solely looking on impacts resulting from relatively lower RES-investments in the EU due to cooperation with third countries, certainly negative impacts have to be anticipated. However, in a comprehensive view considering freed up funds, in total also positive impacts are possible. Assuming for instance a 20% higher job- and GDP-intensity of alternative investments compared to RES-investments, an additional 100,000 jobs per year EU-wide could be created and GDP would rise by 5.7 billion € annually in the strong target scenario. In the weak target scenario, this assumption (i.e. 20% higher job- and GDP-intensity) would lead to 43,000 jobs per year and a 2.4 billion € higher GDP per year.

## 4.4 Summary of key findings of the assessment of co-effects

The energy security assessments showed that the impacts on energy security for the EU are low in the case of cooperation with the West Balkans and Turkey but the considered countries have an increase in energy security. Furthermore, the environmental co-effect assessment showed that full RES cooperation with third countries leads to overall emission savings of greenhouse gases and air pollutants, independent from the European RES target setting (weak or strong). The amount of overall emission savings however is much more significant in the strong target case. The macroeconomic analyses showed that the magnitude of macro-economic impacts is higher in the "strong target" assumption. Solely looking on impacts resulting from relatively lower RES-investments in the EU due to cooperation with third countries, certainly negative impacts have to be anticipated. However, in a comprehensive view considering freed up funds, totally also positive impacts are possible.

# 5 Discussion – Comparison with other studies

Compared to the literature on export and cooperation potentials concerning RES, one has to keep in mind that as mentioned earlier, this literature focuses almost exclusively on the MENA region as a cooperation partner for Europe. Nevertheless the comparison should provide some interesting insights on the robustness of our modelling outcomes – primarily concerning the cooperation potential with North Africa but also for the integrated assessment of a full cooperation scenario in general.

Furthermore, we compare the results of our integrated assessment with the country specific bottom-up perspective – i.e. the different outcomes for the three regions when assessed separately. Herewith, the analysis is underpinned with results from a different perspective which adds to the robustness and precision of the predictions. In the following we thus look into the different approaches and compare their assessed minimum and maximum possible outcomes.

As already presented graphically, the bottom-up assessment that was created for North Africa from results of Dii and DLR studies – described in the literature review in more detail – spans a huge bandwidth for RES-E potentials in the analysed countries. The different paths that resulted from the integrated assessment are within this bandwidth, but among the higher value scenarios. North Africa has a vast potential to develop RES-E. Nevertheless, the variety of scenarios and levels of RES-E deployment assessed by different studies show that the actual developments are dependent on a variety of factors. External factors as political uncertainty as well as the decision on which technology path should be followed (a CSP-only or CSP dominated solution or a more varied deployment of different technology options) strongly influence the development of RES-E in the region.

For Turkey, the bottom-up assessment predicted minimum values that were quite a bit lower for overall RES deployment, whereas the maximum possible values were more or less aligned with those of the integrated assessment. Overall, the different assessments did not contradict one another and thus provide robustness to the finding that substantial RES-E potential exists in Turkey and that export to EU28 Member States is feasible and beneficial. For the future RES deployment in Turkey, political decisions are crucial. Whether or not domestic potential will be developed depends largely on the decision if Turkey will become a member of the EU or the Energy Community. A membership would induce Turkey to align its goals on renewables development. If no accession takes place, it can be expected that RES deployment will not be high on the political agenda in Turkey. However the RES-E generation that would take place nonetheless could be largely used for exports to the EU28 Member States, as it would not be needed domestically to fulfil any kind of target.

In the Western Balkan case, the maximum feasible RES deployment assessed by the bottom-up analysis exceeds the maximum values of the integrated assessment. Nevertheless, the development path and the range of the different scenarios both predict similar increases up to 2040. The combination of results paints a consistent and encouraging picture for RES deployment in the region. As all Western Balkan countries are already in different stages of accession to the Energy Community, one could say that politically, the situation in this region seems to be the most predictable. Nevertheless, a lot of steps have to be undertaken to actually enable the development of the assessed levels of RES deployment and the according cooperation.

Aside of discussing the robustness of the scenario results, practical implications for cooperation on RES with the respective countries analysed are necessary to assess actual feasibility of the levels of RES deployment and the according export potentials described above. As shortly explained beforehand, for the short- and midterm perspective, the Western Balkans seem to be the most suitable cooperation partner. This is due to their level of accession to the Energy Community as well as the policies that are in place for RES deployment. As grid interconnections are still lacking, this cooperation is likely to take place virtually – i.e. statistical transfers are imaginable as to aid EU Member States in achieving their RES shares for 2020 and beyond. Furthermore, some countries in the region have concrete plans of integrating the cooperation mechanism into their NREAPS. Bilateral talks are furthermore taking place to initiate joint projects and concrete plans for grid extension and increased RES deployment exist for the period up to and beyond 2020 (Türk et al., 2015). Thus far, from a practical perspective cooperation seems feasible and beneficial in the near future.

Considering Turkey, there are still more barriers to be mitigated from a practical perspective. RES deployment is currently not moving very fast, as Turkish policy does not encourage construction by setting binding targets. Furthermore, licensing procedures and bureaucracy are substantial impediments towards joint projects under the cooperation mechanism. If these non-economic barriers were mitigated, wind onshore would be the most promising RE technology for cooperation between the EU and Turkey. As presented in the assessment results above and due to political uncertainties, joint projects with Turkey are a rather long-term option for EU28 Member States. In the short term, depending on the target assumed domestically as well as at EU level, Turkey could even become a net importer of RES-E (Ortner et al., 2015).

The case of the North African countries considered is also subject to some uncertainties. Whereas there is quite some heterogeneity among the countries, e.g. Morocco exhibits clear perspectives and a secure investment environment in comparison to other areas where the situation is less predictable. Overall, the case for RES deployment has to be made in the respective countries and the legal environment strengthened as to enable beneficial cooperation with the EU. Hence, as in the case of Turkey, North Africa seems more valuable as a cooperation partner in the mid- to long-term perspective. This observation can be confirmed by the results of the integrated assessment described beforehand (Trieb, 2015). This overview on policies and current non-economic impediments of RES deployment is of course not exhaustive.

# 6 Conclusions and Recommendations

Article 9 of EU Directive 2009/28/EC – the Directive on the promotion of the use of energy from renewable sources (RES Directive) –allows EU Member States to produce a certain share of the renewable energy to reach their national RE-target in another country. As thus far, this form of cooperation has not started off so far, the results discussed above are highly interesting as to what can be expected in the short and longer term perspective.

Overall, increasing RES deployment in the three analysed regions and initiating or intensifying cooperation with EU28 Member States leads to mutual benefits. Concretely, these benefits become apparent in terms of the EU Member States importing RES-E and adding on to their targets for RES deployment at a lower price as if they would have generated the electricity at home.

***<u>Limited hope for RES cooperation with EU neighbours in the 2020 context</u>***

Looking into the time horizon, the assessment of short term perspective for RES cooperation provides a less promising picture: Compared to the other cooperation mechanisms, additional barriers to the implementation of the cooperation mechanism between the EU and its neighbouring countries exist, including a higher degree of grid infrastructure requirements and long-lead times for doing so, some degree of geopolitical unrest, more complex financing schemes, differences in public acceptance, potential socio-economic and environmental impacts, existing laws and regulations (cf. Jacobsen et al., 2014 and Karakosta et al., 2013). Thus, the physical import requirement as postulated by Article 9 currently represents an additional hurdle as very limited interconnections exist between Europe and neighbouring countries, while the existing interconnection capacity within many Member States is also a limiting factor.

Moreover, since 2009 there have been various unforeseen events which have not been conducive for the implementation of cooperation mechanisms:

- Among others, events such as the Eurozone crisis have led to a reduction in energy demand – as a direct result of the slow-down of economic growth, indirectly making it easier for some EU Member States to achieve their 2020 RES target domestically.
- Secondly, the cost decline of domestically available RES-E in the EU (particularly for solar PV) has reduced the cost advantage of RES-E imports from neighbouring countries to the EU.
- Thirdly, following the Russia-Ukraine crisis, energy security concerns are now at the top of energy policy priorities. In this sense, following the Energy Union package in February 2015, the EU has taken steps to revitalise energy cooperation with neighbouring countries as a way to improve energy security (but mostly focusing on fossil fuels).
- In neighbouring countries, important events include episodes of civil unrest, such as the Arab Spring, which have led to higher country risks and financial costs, resulting in scepticism from foreign investors.

In accordance with above we have to conclude that at present, there is almost no demand for RES cooperation in general, and in particular for RES-E imports to the EU, as most Member States believe they can reach their 2020 RES target domestically while reaping the associated co-benefits (in terms of employment, supply security, etc.). On the other hand, neighbouring countries´ increasing internal electricity demand together with the need to reinforce their electricity system has limited their capacity to generate RES-E surplus that could potentially be exported to Europe in a short time frame (i.e. up to 2020).

The outcomes of the quantitative analysis done by use of the Green-X model confirm the pessimistic view on short-term (2020) prospects for RES cooperation with EU's neighbours. Due to the infrastructural constraints, RES cooperation with third countries is in the short term practically limited to the Western Balkan countries – all of them being Contracting Parties of the Energy Community. As modelling points out, under strong RES cooperation between EU and Western Balkans an ambiguous situation occurs where the future demand development in Western Balkan countries is the key determinant for the flow of exchange: assuming a low demand development, the Western Balkan region could become a net exporter, whereas in the case of a high demand growth the region would be a net importer. In practical terms, the possibilities for doing so appear however more limited – it would require immediate action and a rapid removal of non-economic barriers and, in turn, a new RES policy framework to be implemented in all analysed EU and neighbouring countries at short notice.

***Promising prospects for RES cooperation in the extended geographical context in the mid- (2030) to long-term (2040)***

The model-based assessment of prospects for RES cooperation in the enlarged geographical context shows that promising and economically viable opportunities exist to go for that. A large set of economically attractive sites for future RES developments can be identified within Europe and in neighbouring regions that are waiting to be exploited. According to our modelling works, it turns out that – if full RES cooperation across all assessed regions is aimed for in the medium to long term – among all assessed regions North Africa becomes the main focus region for cooperation. Of course, this is dependent on the form of deployment and the target set at EU level, which is shown in detail in the different sensitivity variants displayed.

**Disaggregating the picture by region**, the different regions show the following quantities of RES that could be exported.

- In Turkey, a strong and moderate target would lead to roughly the same exports of RES that amount to 47 or 43 TWh, respectively. A weak overall RES target would make Turkey a net importer even in the long term perspective up to 2040 (22 TWh of RES imports in 2040). In relative terms these scenarios make up a bandwidth of 5.9% (strong), 6.4% (moderate) or -3.1% (weak target).
- For the Western Balkans, the long-term (2040) perspective is as follows: a weak overall target would lead to net imports of 0.5 TWh of RES by 2040, or 0.5% of gross electricity demand. A moderate target changes the flow of RES and makes the Western Balkans an exporting region. Under this specific target they would export 5.9% of their gross electricity demand which amounts to a number of 5.9 TWh in 2040. Increasing the target for RES even further would increase exports by 5.2 percentage points up to a value of 10.7 TWh.
- North Africa, in the long- as well as in the mid-term is a clear RES exporting region, independent of the respective target set at EU-level. Assuming a strong target for RES at EU level, North Africa would export 485 TWh in 2040, 56% of its gross domestic electricity demand. A moderate target leads to an export of 415 TWh or 48% and a weak target to 360.7 TWh or 41.7% of gross domestic electricity demand.

The **monetary flows** resulting from this cooperation take place from the EU28 Member States to the three focus regions and take on quite substantial levels. In the medium term, i.e. 6.3 billion € would flow annually from the EU28 under a strong RES target by 2030 and beyond. This amount would be split among the partner regions. Namely, Turkey would receive an inflow of 1.6 billion € annually from this, the Western Balkans 0.2 billion € and North Africa 4.5 billion € respectively. A moderate target would lower the monetary transfers to an overall 3.3 billion € being transferred from the EU28 Member States to the partner regions. A weak target would decrease this amount even further such that 1.1 billion € would move from the EU to Turkey (a marginal amount of 5.3 million €), the Western Balkans (0.1 billion €) and North Africa (1 billion €). In the long term up to 2040, monetary transfers increase.

Turning the focus on the **economic impacts** of RES cooperation, significant savings become visible, manifested in a substantially lower support required for future RES expansion. Expressed in numerical terms, this would mean that under a strong future RES target (aiming for more than 32% RES by 2030) enhanced cooperation would yield in yearly savings of support expenditures for renewables at EU level in size of 13.5 billion €, or 29% compared to a reference track where RES cooperation is limited to EU Member States only. If a moderate RES target (i.e. 30% RES by 2030) is aimed, annual savings at EU level amount to 12.2 billion € on average throughout the whole assessment period, or 39% compared to reference. Assuming a low RES policy ambition (i.e. the current policy thinking, where a RES share of 27% is the set option for 2030) savings are smaller in absolute terms (8.7 billion € annually) but higher in relative terms (60% compared to the corresponding reference track).

**Regionally different impacts on benefits**, i.e. in terms of $CO_2$ avoidance and avoided fossil fuels, are furthermore quantifiable, **as are changes in costs** (i.e. support expenditures and system costs) **and investments** (i.e. capital expenditures). Capital expenditures (in total) can be lowered substantially with full cooperation compared to the EU only (reference) scenario, and a redirection of RES investments towards exporting regions is noticeable. Support expenditures in general are declining although a small increase of policy-related costs for RES in regions where large amounts of RES are deployed is applicable – at least in the medium term. Avoidance of fossil fuels and $CO_2$ is of course dependent on where the RES deployment takes place, i.e. these effects are mainly distributional. Assuming increased domestic RES deployment within the third countries thus leads to beneficial effects for the climate and local economy – which were assessed in more detail in an analysis of concomitant co-effects of RES cooperation.

The **technical perspective** is crucial to determine which export potential for RES can currently be realised (if physical transfer is necessary), but also to assess whether the grid in the respective focus regions is already prepared for the intake of an increased amount of RES electricity. Results from this perspective show that in general the necessary grid extensions are quite manageable compared to "supergrid" scenarios assuming a totally different architecture of the overall EU-MENA grid infrastructure in much bigger dimension. In the EU plus scenarios it is assumed that Turkey becomes a member of the Energy Union and by this allegeable to statistical transfer of surplus RES. Therefore some of the RES exported from North Africa is integrated into Turkey, and statistical transfer or proof through accompanying green certificates is used then to account this RES to the EU/EC target. As a consequence in the EU plus scenarios the fossil-based electricity generation in the EU28 is 102 (120) TWh larger than in the corresponding reference (EU only) scenarios under a weak (strong) RES ambition post 2020.

## ***Assessment of co-effects complements and confirms the modelling outcomes***

Complementary to the comprehensive modelling exercise an assessment of co-effects has been conducted, done in a quantitative and qualitative manner. Key findings of that are presented below.

**Environmental co-effects** were assessed by performing a switch from the EU only to the EU plus cooperation scenario. From this switch, significant emission savings are achieved in the European Union, thus mainly regarding GHGs ($CH_4$, $N_2O$), but also regarding local air pollutants. In third countries on the contrary GHG ($CH_4$, $N_2O$) and air pollutant emissions increase. The increase of emissions in third countries' is mainly based on a corresponding increase in solid biomass (RES-E) in the region, However, as more RES technologies causing certain direct emissions are reduced in the European Union as in turn are expanded in third countries, emission increases in third countries are still outweighed by EU emission savings. Overall, the analysis shows that full RES cooperation with third countries leads to overall emission savings of greenhouse gases and air pollutants, independently from the European RES target setting (weak or strong). The amount of overall emission savings however is much more significant in the strong target case.

**Impacts on EU energy security** are also a very influential factor in the decision process of engaging in cooperation, in choosing the partners and the dimension of the exchanged RES volumes. The energy security assessments show that the impacts on energy security for the EU are low in the case of cooperation with the Western Balkans and Turkey but the considered countries have an increase in energy security.

A **brief macroeconomic analysis** provides estimations of the magnitude of effects on job creation and GDP as the two most important macroeconomic indicators. It shows that the magnitude of macro-economic impacts is higher in the "strong target" assumption. Solely looking on impacts resulting from relatively lower RES-investments in the EU due to cooperation with third countries, certainly negative impacts have to be anticipated. However, in a comprehensive view considering freed up funds, in total also positive impacts are possible. In third countries, increased RES deployment obviously induces job creation in construction as well as operation and maintenance. This of course is dependent on local content of the used materials and on whether or not local workers are mainly employed for the respective tasks.

***In conclusion***, the results show a substantial export potential of RES with overall clear benefits in the assessed cases. At the same time, political, regulatory and technological barriers have to be mitigated and awareness for the advantages of RES created in the respective regions. Putting cooperation between the assessed regions and the EU28 Member States into action will aid in mitigating these barriers. It nevertheless requires concerted action from both sides to make large scale cooperation in RES deployment possible.

# 7 References

Breitschopf B., C. Nathani and G. Resch (2012): Employment Impact Assessment Studies – Is There a Best Approach to Assess Employment Impacts of RET Deployment?; RELP 2|2013, Journal Employment Impact Assessment Studies

De Jager, D., C. Klessmann, E. Stricker, T. Winkel, E. De Visser, M. Koper, M. Ragwitz, A. Held, G. Resch, S. Busch, C. Panzer, A. Gazzo, T. Roulleau, P. Gousseland, M. Henriet, and A. Bouille, 2011. Financing Renewable Energy in the European Energy Market. By order of: European Commission, DG Energy, 2011.

Dii, 2013. Desert Power: Getting Started. The manual for renewable electricity in MENA. Full Report.

DLR, 2009. Characterisation of Solar Electricity Import Corridors from MENA to Europe. Potential, Infrastructure and Cost.

Ernst & Young (2009): Cost and financial support for offshore wind, report prepared for the Department of Energy and Climate Change, London, United Kingdom.

European Commission (2004): The share of renewable energy in the EU. Communication from the Commission to the Council and the European Parliament, COM(2004) 366 final.

European Commission, 2011. Energy roadmap 2050 (COM/2011/885).

European Commission, 2013a. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Renewable energy progress report (COM/2013/175 final, 27 March 2013).

European Commission, 2013b. EU Energy, Transport and GHG Emissions Trends to 2050: Reference Scenario 2013. DG Energy, DG Climate Action and DG Mobility and Transport.

European Commission, 2014. IMPACT ASSESSMENT. Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030 (COM/2014/15 final).

International Energy Agency (IEA) (2013): World Energy Outlook – 2013 edition. IEA, OECD, Paris, France, 2013.

Jacobsen, H. K., Pade, L. L., Schröder, S. T., Kitzing, L., 2014. Cooperation mechanisms to achieve EU renewable targets, Renewable Energy, Vol. 63, pp. 345-352

Janssen and Staniaszek (2012): How Many Jobs? A Survey of the Employment Effects of Investment in Energy Efficiency of Buildings

Karakosta, C., Marinakis, V., Psarras, J., 2013. RES Cooperation Opportunities between EU and MENA Countries: The Case of Morocco, Energy Strategy Reviews, Vol. 2, Issue 1, pp. 92-99.

Krewitt, W., Nienhaus, K., Kleßmann, C., Capone, C., Stricker, E., Graus, W., Hoogwijk, M., Supersberger, N., Winterfeld, U., Samadi, S. (2009): Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply, final report on behalf of Umweltbundesamt, Berlin, Germany, 2009.

Kurzmann, R., Aumayr, C. (2007): Österreichische Beschäftigungs- und Wertschöpfungsmultiplikatoren. Eine Abschätzung der ökonomischen Effekte verschiedener Ausgabekategorien anhand des Modells MULTIREG; InTeReg Research Report Nr. 61-2007; ISSN 1810-6307; 05/2007

Martin Bo Hansen, Carl von Utfall Danielsson (2012): Copenhagen Economics; Multiple benefits of investing in energy efficient renovation of buildings

Ortner, A., G. Resch, M. Welisch, G. Totschnig, N. Caldes, C. De La Rua, A. Türk, 2015. D5.3: Case study report on prospects for RES cooperation with Turkey using the cooperation mechanisms. A report compiled within the IEE project BETTER, accessible at www.better-project.net.

Ragwitz, M. et al. (2005): FORRES 2020: Analysis of the renewable energy sources' evo-lution up to 2020. Report for the European Commission, Directorate General for En-terprise and Industry.

Ragwitz, M. et al. (2012): RE-Shaping: Shaping an effective and efficient European re-newable energy market. Report compiled within the European research project RE-Shaping under the Intelligent Energy for Europe programme, Karlsruhe, Germany, 2012.

Rathmann, M., D. De Jager, I. De Lovinfosse, B. Breitschopf, J. Burgers, J., and B. Weöres, 2011. Towards triple-A policies: More renewable energy at lower cost. Report compiled within the IEE project RE-Shaping (work package 7 (D16)), accessible at www.reshaping-res-policy.eu.

Resch G., M. Welisch, Ortner (2015). D6.2: Short term prospects for RES cooperation with Third countries. A report compiled within the IEE project BETTER, accessible at www.better-project.net. Vienna, Austria, 2015.

Resch G., T. Faber (2006). The Green-X database on RES potentials and costs in Europe – an introduction on approach and results. Vienna, Austria, 2006.

Resch, G. et al. (2009): Futures-e – Action plan on deriving a future European Policy for Renewable Electricity. Concise final report of the research project futures-e, with support from the European Commission, DG TREN, EACI under the Intelligent Energy for Europe programme. Vienna, Austria, 2009.

Trieb, F., Schillings, C., Pregger, T., O'Sullivan, M., 2012. Solar electricity imports from the Middle East and North Africa to Europe. Energy Policy 42, 341–353. doi:10.1016/j.enpol.2011.11.091

Trieb, Franz 2015. D3.3: Case study report on prospects for RES cooperation with North Africa using the cooperation mechanisms. A report compiled within the IEE project BETTER, accessible at www.better-project.net.

Tuerk, A., D. Frieden, D. Steiner, C. Fruhmann (JR), Z.Kordic, R. Pasicko (UNDP), A. Ortner, G. Resch, G. Totschnig (TU Wien), 2015. D4.3: Case study report on prospects for RES cooperation with the Western Balkans using the cooperation mechanisms. A report compiled within the IEE project BETTER, accessible at www.better-project.net.

V. Duscha, M. Ragwitz, B. Breitschopf, W. Schade, R. Walz, M. Pfaff, E. de Visser, G. Resch, C. Nathani, P. Zagamé, A. Fougeyrollas, B. Boitier (2014): EmployRES II – Employment and growth effects of sustainable energies in the European Union (Support Activities for RES modelling post 2020). Final report of a study done by order from the European Commission, DG ENER (Contract No. ENER/C1/428-2012), compiled under the lead of Fraunhofer ISI by TU Vienna (Energy Economics Group), SEURECO, Ecofys, Rütter + Partner. Fraunhofer ISI, Karlsruhe (Germany), 2014. Accessible at http://ec.europa.eu/energy/renewables/studies/renewables_en.htm.

Wiser, R., Barbose, G., Peterman, C., Darghout, N. (2009): Tracking the Sun II: The Installed Cost of Photovoltaics in the U.S. from 1998-2008, Lawrence Berkeley NationalLaboratory, LBNL-2674E.

# 8 Annex – Complementary modelling results

### Annex Table 1: Costs, expenditures and benefits of RES electricity (in total) according to assessed scenarios (in billion €)

| **Costs, expenditures and benefits** of RES electricity (in total) according to assessed scenarios | | *reference case (EU only)* | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** | *reference case (EU only)* | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** | *reference case (EU only)* | *EU plus (default case)* | **Turkey: non-affiliation to EU/EC** | **North Africa: moderate grid expansion** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RES target (ambition level): | **weak RES target** | | | | **moderte RES target** | | | | **strong RES target** | | | |
| **Avoided fossil fuels** [billion €] | | | | | | | | | | | | | |
| EU28 | 2021-2030 | 112.4 | 112.0 | 112.1 | 111.4 | 119.4 | 118.0 | 120.5 | 117.2 | 126.9 | 125.1 | 128.5 | 124.7 |
| | 2021-2040 | 141.7 | 142.9 | 143.3 | 141.5 | 157.6 | 156.6 | 160.7 | 154.1 | 173.6 | 171.0 | 176.3 | 169.6 |
| Turkey | 2021-2030 | 9.5 8.2 | 9.5 | 8.2 | 9.9 | 10.4 8.2 | 11.7 | 8.2 | 12.1 | 11.2 8.2 | 13.1 | 8.2 | 13.2 |
| | 2021-2040 | 12.5 10.1 | 12.6 | 9.7 | 12.9 | 14.3 10.1 | 15.9 | 9.5 | 16.9 | 16.0 10.1 | 18.4 | 9.4 | 18.8 |
| West Balkans | 2021-2030 | 2.7 | 2.8 | 2.8 | 2.9 | 2.8 | 3.0 | 3.0 | 3.0 | 2.9 | 3.1 | 3.1 | 3.2 |
| | 2021-2040 | 3.2 | 3.2 | 3.2 | 3.3 | 3.4 | 3.6 | 3.5 | 3.7 | 3.6 | 4.0 | 3.8 | 4.0 |
| North Africa | 2021-2030 | 5.2 | 3.7 | 3.7 | 3.7 | 5.2 | 3.7 | 3.7 | 3.7 | 5.3 | 3.7 | 3.7 | 3.7 |
| | 2021-2040 | 10.9 | 7.3 | 7.4 | 7.2 | 10.6 | 7.2 | 7.2 | 7.2 | 10.7 | 7.2 | 7.2 | 7.2 |
| **Avoided $CO_2$ emissions** [billion €] | | | | | | | | | | | | | |
| EU28 | 2021-2030 | 97.2 | 96.9 | 97.1 | 96.4 | 102.3 | 102.1 | 104.2 | 101.4 | 108.0 | 107.6 | 111.0 | 107.0 |
| | 2021-2040 | 104.7 | 105.8 | 106.1 | 104.7 | 114.2 | 115.6 | 118.8 | 113.6 | 123.6 | 124.7 | 129.7 | 123.1 |
| Turkey | 2021-2030 | 13.4 11.7 | 13.5 | 11.6 | 13.9 | 14.6 11.7 | 16.4 | 11.6 | 17.0 | 15.7 11.7 | 18.4 | 11.5 | 18.5 |
| | 2021-2040 | 16.0 13.0 | 16.1 | 12.4 | 16.5 | 18.1 12.9 | 20.2 | 12.0 | 21.4 | 20.2 12.9 | 23.3 | 11.9 | 23.7 |
| West Balkans | 2021-2030 | 3.8 | 4.0 | 4.0 | 4.0 | 3.9 | 4.3 | 4.2 | 4.3 | 4.1 | 4.4 | 4.4 | 4.4 |
| | 2021-2040 | 4.1 | 4.1 | 4.1 | 4.2 | 4.4 | 4.6 | 4.5 | 4.8 | 4.6 | 5.0 | 4.8 | 5.1 |
| North Africa | 2021-2030 | 7.2 | 5.1 | 5.1 | 5.1 | 7.2 | 5.0 | 5.0 | 5.0 | 7.3 | 5.1 | 5.0 | 5.1 |
| | 2021-2040 | 13.2 | 8.8 | 8.9 | 8.7 | 13.0 | 8.7 | 8.7 | 8.8 | 13.0 | 8.8 | 8.7 | 8.8 |
| **Capital expenditures** [billion €] | | | | | | | | | | | | | |
| EU28 | 2021-2030 | 34.4 | 27.3 | 26.3 | 28.1 | 49.2 | 33.6 | 31.1 | 35.0 | 65.4 | 43.3 | 37.9 | 46.2 |
| | 2021-2040 | 38.9 | 30.4 | 29.5 | 32.1 | 53.9 | 38.0 | 33.9 | 41.6 | 67.3 | 48.2 | 41.0 | 52.9 |
| Turkey | 2021-2030 | 6.2 3.0 | 5.8 | 5.0 | 6.7 | 8.3 3.0 | 11.1 | 9.1 | 12.1 | 10.6 3.0 | 15.3 | 13.5 | 15.5 |
| | 2021-2040 | 8.4 6.1 | 7.9 | 7.4 | 9.2 | 10.7 5.9 | 12.5 | 10.7 | 13.9 | 13.1 6.0 | 14.5 | 13.2 | 15.7 |
| West Balkans | 2021-2030 | 1.2 | 1.3 | 1.3 | 1.4 | 1.5 | 1.9 | 1.7 | 2.0 | 1.8 | 2.4 | 2.2 | 2.5 |
| | 2021-2040 | 1.3 | 1.1 | 1.0 | 1.2 | 1.6 | 1.6 | 1.4 | 1.8 | 1.8 | 2.1 | 1.7 | 2.3 |
| North Africa | 2021-2030 | 6.8 | 9.3 | 8.0 | 8.4 | 6.8 | 13.1 | 11.9 | 11.6 | 6.8 | 16.2 | 15.1 | 14.3 |
| | 2021-2040 | 11.1 | 15.2 | 13.7 | 11.6 | 10.7 | 16.8 | 15.9 | 13.7 | 10.7 | 18.9 | 18.1 | 15.5 |
| **Additional generation cost** [billion €] | | | | | | | | | | | | | |
| EU28 | 2021-2030 | 21.7 | 21.8 | 21.9 | 21.6 | 23.8 | 22.8 | 23.3 | 22.6 | 27.4 | 24.5 | 25.0 | 24.6 |
| | 2021-2040 | 15.1 | 15.6 | 15.8 | 15.6 | 18.3 | 17.0 | 17.6 | 16.6 | 23.1 | 19.2 | 19.4 | 19.4 |
| Turkey | 2021-2030 | 0.6 0.5 | 0.6 | 0.5 | 0.7 | 0.7 0.5 | 1.0 | 0.6 | 1.1 | 0.8 0.5 | 1.5 | 0.8 | 1.5 |
| | 2021-2040 | 0.3 0.3 | 0.4 | 0.3 | 0.4 | 0.4 0.3 | 0.6 | 0.3 | 0.7 | 0.5 0.3 | 1.2 | 0.5 | 1.2 |
| West Balkans | 2021-2030 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | 2021-2040 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 |
| North Africa | 2021-2030 | 0.9 | 0.5 | 0.5 | 0.6 | 0.9 | 0.5 | 0.5 | 0.5 | 0.9 | 0.5 | 0.5 | 0.6 |
| | 2021-2040 | 0.7 | 0.4 | 0.4 | 0.5 | 0.7 | 0.5 | 0.5 | 0.6 | 0.7 | 0.5 | 0.5 | 0.6 |
| **Support expenditures** [billion €] | | | | | | | | | | | | | |
| EU28 | 2021-2030 | 46.4 | 42.2 | 41.6 | 42.6 | 54.9 | 48.9 | 47.4 | 49.8 | 66.7 | 58.1 | 55.4 | 58.9 |
| | 2021-2040 | 34.1 | 25.2 | 24.5 | 28.6 | 50.2 | 38.1 | 33.4 | 41.8 | 66.1 | 52.6 | 45.6 | 56.4 |
| Turkey | 2021-2030 | 2.5 1.7 | 2.5 | 1.9 | 2.5 | 3.1 1.7 | 3.5 | 2.1 | 3.6 | 4.0 1.7 | 4.9 | 2.4 | 5.0 |
| | 2021-2040 | 1.9 1.0 | 1.7 | 1.2 | 2.3 | 3.3 1.1 | 3.8 | 1.7 | 4.5 | 5.1 1.0 | 6.3 | 2.2 | 7.0 |
| West Balkans | 2021-2030 | 0.4 | 0.4 | 0.3 | 0.4 | 0.6 | 0.5 | 0.5 | 0.6 | 1.0 | 0.8 | 0.7 | 0.8 |
| | 2021-2040 | 0.4 | 0.2 | 0.2 | 0.3 | 0.6 | 0.6 | 0.5 | 0.7 | 1.0 | 1.0 | 0.8 | 1.1 |
| North Africa | 2021-2030 | 1.6 | 1.6 | 1.5 | 1.6 | 1.6 | 1.8 | 1.7 | 1.8 | 1.6 | 2.0 | 1.9 | 2.0 |
| | 2021-2040 | 2.9 | 1.3 | 1.3 | 1.6 | 2.9 | 2.0 | 1.7 | 2.3 | 2.9 | 2.6 | 2.2 | 2.8 |

Notes:

With the exception of the reference case (EU only), all scenarios assume full RES cooperation between the EU and its neighbours

In accordance with literature external cost of 65 €/t $CO_2$ are used to express the avoidance of CO2 emissions monetarily

Virtual vs. physical trade of renewable electricity:

- For West Balkans virtual trade is assumed in all (default and) sensitivity scenarios
- For Turkey virtual trade is the default option, only in the sensitivitey case related to Turkey physical trade is presumed (since not part of the EU/EC)
- For North Africa physical trade is assumed in all (default and) sensitivity scenarios

*This report* focuses on the quantitative assessments undertaken on the extent to which RES cooperation can create mutual benefits, identifying costs and benefits for both sides but in particular with respect to RES target achievement (2020, 2030 and beyond) at EU level. Prospects for RES generation in Turkey, North Africa, the Western Balkans and the EU are calculated under various policy pathways, reflecting the uncertainty on the way forward – e.g. concerning the ambition level of future RES targets and RES developments at EU level and in the assessed neighbouring regions / countries as well as with regard to RES cooperation. Thus, this overarching integrative assessment paints a big picture scenario and provides valuable policy implications for future cooperation between the EU28 Member States and their neighbouring countries. Furthermore, co-effects are shown that could occur from the different levels of RES deployment.