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Promotion of electricity from renewable energy in Europe post 2020 - the economic benefits of cooperation

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Abstract

In Europe, the availability of renewable energies, especially from sun and wind, differs significantly across regions. Consequently, cooperation in the deployment of renewable energy among European countries potentially yields substantial efficiency gains. However, in order to achieve the 2020 renewable energy targets for electricity, Member States of the European Union almost purely rely on domestic production. For the period after 2020, a European renewable energy target has not yet been defined, but decarbonization pathways outlined in the Roadmap of the European Commission include renewable energy shares of electricity generation to be 50-60% by 2030. Therefore, we analyze the benefits of cooperation compared to continuing with national renewable energy support after 2020. We use a large-scale dynamic investment and dispatch model of the European electricity system and find that compared to a 2030 CO_2 -only target (-40% compared to 1990 emission levels), electricity system costs increase by 5 to 7% when a European-wide renewable energy target for electricity generation (of around 55%) is additionally implemented. However, these additional costs are lower by 41 to 45% compared to the additional electricity system costs which would arise if the renewable energy target was reached through national support systems (without cooperation). Furthermore, we find that the cooperation gains (i.e., the cost reduction achieved by cooperation) are quite robust: They decrease only slightly when interconnectors are not further extended (compared to today) and depend only slightly on assumptions about investment cost developments of renewable energy technologies. With regard to the practical implementation of cooperation, however, unclear administrative issues and questions concerning the fair sharing of costs and benefits between the Member States represent major obstacles that need to be tackled in order to reach renewable energy targets at the lowest costs possible.

Keywords: Renewable energy, Cooperation mechanisms, Power System Optimization

JEL classification: Q48, Q40, C61, Q50

1. Introduction and background

For the year 2020, the European Union (EU) has agreed upon a target of 20% for the share of renewable energy sources (RES) in gross final energy consumption, comprising the electricity, heating and cooling and transportation sectors. A sectoral breakdown of the national targets was defined by each EU Member State in the National Renewable Energy Action Plans (NREAP). In addition, the Member States were asked to notify via their NREAPs, whether they plan to make use of the cooperation mechanisms defined in the European Directive 2009/28/EC. The purpose of these cooperation mechanisms is to facilitate a cost reduction in achieving national targets by promoting RES in a different Member State or in a third country in which generation costs are lower. Across different European regions, full load hours of fluctuating renewables such as wind and solar technologies vary by factors up to 100% (Fürsch et al. (2013)) such that substantial potential benefits from cross-border cooperation arise (see, e.g., EWI (2010)). Nevertheless, the national schemes for target achievement stated in the NREAPs rely almost purely on domestic RES production and hardly envisage the use of cooperation mechanisms.

Beyond 2020, a European renewable energy target has not yet been defined. However, in October 2009, the European Council agreed upon the target to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels. Within the EU Roadmap (EC (2011)), which analyzes possible decarbonization pathways to reach the 2050 target, an emission reduction of 40% by 2030 was identified as an important milestone. Furthermore, all decarbonization pathways analyzed include substantial deployments of renewable energies within the coming decades, reaching RES-E shares between 50% and 60% in 2030.

In this paper, we analyze the benefits of a larger use of cooperation mechanisms beyond 2020, compared to effects of continuing with national RES support as currently envisaged by almost all Member States for the period up to 2020. We focus on the electricity sector and use a large-scale linear optimization model of the European power system, including investment and dispatch decisions for thermal, renewable and storage technologies. This modeling approach allows us to take into account the interdependencies between regional renewable deployment and its effects on the power system. On the one hand, cooperation may possibly lead to higher RES-E integration costs because of a higher regional concentration of RES-E generation on sites with favorable meteorological conditions, which, however, are often located far from demand centers. On the other hand, in electricity systems with grid congestions between market regions, cooperation may possibly also induce cost-savings in the non-RES-E sector. In this case, cooperation in RES-

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E support enables an overall optimization of electricity generation, including renewable and non-renewable sources. Furthermore, we analyze the robustness of cooperation gains with regard to interconnector capacity extensions and RES-E investment cost developments, which, to our knowledge, has thus far been neglected in numerical analyses of cooperation gains. Interconnector extensions in Europe currently progress very slowly (EWI and energynautics (2011)). If planned interconnector extensions are not realized, gains from cooperation may be lower since electricity cannot be transported from favorable sites to demand centers. Also, cooperation gains may be sensitive to RES-E investment cost developments, especially in terms of the resulting cost-difference between RES-E technologies available in all countries (e.g., biomass, photovoltaics) and those renewable energy sources that are regionally concentrated (e.g., wind offshore).

Our main findings include that compared to a CO_2 -only target for 2030 (-40% compared to 1990 emission levels), electricity system costs increase by 5 to 7% when a European-wide renewable energy target for electricity generation (of around 55%) is additionally implemented. However, these additional costs are lower by 41 to 45% compared to the additional electricity system costs which would arise if the renewable energy target was reached through national support systems (without cooperation). Furthermore, we find that the cooperation gains (i.e., the cost reduction achieved by cooperation) are quite robust. Though the optimal regional and technological generation mix is influenced by different levels of interconnector extensions and varying investment costs for RES-E technologies, cooperation gains decrease only slightly when interconnectors are not further extended (compared to today) and depend only slightly on assumptions about investment cost developments of renewable energy technologies. With regard to the practical implementation of cooperation, however, unclear administrative issues and questions concerning the fair sharing of costs and benefits between the Member States represent major obstacles that need to be tackled in order to reach renewable energy targets at the lowest costs possible.

The remainder of the paper is structured as follows: In Section 2 we provide an overview of related literature. In Section 3 we describe the methodological approach of our analysis and present the most important assumptions underlying the scenario analysis. Section 4 covers model results and interpretations. In Section 5 we address possible obstacles to cooperation, which need to be tackled in order to increase cooperation between Member States. Conclusions are drawn in Section 6.

2. Related literature and contribution of the current work

The discussion surrounding stronger cooperation in renewable energy support in Europe has a history spanning more than a decade. Already in the context of the 2001 EU Renewables Directive (2001/77/EC), which defines (indicative) renewable targets for 2010, have many authors discussed the potential benefits of European-wide harmonized support systems (e.g., Voogt et al. (2001) and Del Río (2005)) or the suitability of different support scheme designs for a harmonized approach (e.g., Lauber (2004), Munoz et al. (2007) and Söderholm (2008)). For the target year 2020, possible gains from harmonization have been quantified, e.g., by Ragwitz et al. (2007), EWI (2010), Capros et al. (2011), Aune et al. (2012) and Jägemann et al. (2012). Although the authors use different model types, which in turn have different regional and technological coverage, all authors find that cooperation in RES may yield substantial cost savings. An overview of the models used for these analyses and the quantified cooperation gains is provided in Table 1.

Table 1: Overview of related literature

Authors	Model used	Cooperation gains are quantified in terms of:	Resulting cooperation gains
Voogt et al. (2001)	REBUS	additional costs of RES-E supply	- 15 to - 70% (depending on target distribution)
Ragwitz et al. (2007)	Green-X	support expenditures for RES-E	- 16 to - 21% or up to + 42% (depending on support design)
EWI (2010)	LORELEI & DIME	total costs of RES-E generation	-20% (cumulated 2008-2020)
Capros et al. (2011)	PRIMES	total energy system costs	-16 to -25% (depending on other policy options, e.g. implementation of CDM)
Aune et al. (2012)	LIBEMOD	additional energy system costs (due to RES target)	-70% (yearly costs)
Jägemann et al. (2012)	DIMENSION	total costs of electricity generation	- 10% (cumulated 2010-2050)

While Voogt et al. (2001) quantify the benefits of a EU-wide cooperation for the achievement of the 2010 RES-E targets, all other papers analyze cooperation gains in the context of the 2020 targets. Voogt et al. (2001) and EWI (2010) analyze cooperation gains in terms of cost savings for electricity supply from RES, either in terms of absolute costs (EWI (2010)) or in terms of additional costs with regard to electricity market prices (Voogt et al. (2001)). In contrast, Ragwitz et al. (2007) compare support expenditures for RES-E under different promotion systems. Capros et al. (2011) and Aune et al. (2012) apply multi-market models and determine cost savings in terms of energy system costs, including electricity supply costs as well as costs in other energy markets (e.g., natural gas). Jägemann et al. (2012) use a large-scale dynamic optimization model of the European electricity generation sector, which covers thermal, renewable and storage technologies. The authors determine the excess costs of technology-specific national RES-E targets for 2020, as defined in the NREAPs, compared to a technology-neutral European-wide RES-E target for 2020.

We use the same general modeling framework as Jägemann et al. (2012) to determine the benefit of European cooperation in the decade 2021 to 2030 and to analyze the robustness of cooperation gains with regard to interconnector extensions and RES-E investment costs. To our knowledge, we are the first to focus on cooperation gains in the decade 2021 to 2030, a period that is currently in the focus of the political debate. We take into account that many favorable potentials throughout Europe may already be in use in order to fulfill the NREAP targets. In addition, a higher RES-E share has to be reached by 2030 (compared to 2020). Thus, gains of cooperation may diminish because, with or without cooperation, many high-cost RES-E generation options are required in order to achieve the target.

In addition, the influence of different interconnector capacity restrictions and of different RES-E investment cost developments on possible gains from cooperation, to our knowledge, has thus far been neglected in numerical analyses of cooperation gains. However, the influence of limited interconnector extensions on coordinated RES-E supply has recently been addressed in a theoretical two-country model by Laffont and Sand-Zantman (2012). Their key finding is that the optimal level of coordination in RES-E support depends on the level of transmission capacity between the two countries. Moreover, Saguan and Meeus (2012) analyze the interaction between cooperation in renewable energy support and cooperation in transmission planning in a two-region modeling example. However, for a real-world electricity system, the influence of interconnector extensions and cost developments of RES-E on the level of cooperation gains, to our knowledge, have not yet been quantified.

3. Methodological approach and assumptions

We use a dynamic linear dispatch and investment model for Europe incorporating thermal, storage and renewable technologies. The model is an extended version of the long-term investment and dispatch model DIMENSION of the Institute of Energy Economics (University of Cologne), as presented in Richter (2011). The model in its extended version has been recently applied, e.g., by Fürsch et al. (2013) (who provide a detailed model description).[1] In the following, we briefly summarize the main model characteristics (Section 3.1) and give an overview of the input parameters chosen for the analysis presented (Section 3.2).

3.1. Model description

The model minimizes total discounted system costs of the European electricity system. These costs comprise investment, fixed operation and maintenance, variable production and ramping costs.[2] Costs are minimized subject to the conditions of meeting hourly electricity demand in each market region and of ensuring security of supply. For the latter condition, securely available generation capacities must be sufficient to cover peak demand (increased by a security margin). In addition, European-wide CO_2 emissions are limited by an emission cap. RES-E targets must be met either on a national or on a EU-wide level, depending on the scenario. Furthermore, the electricity infeed and/or the amount of construction of certain technologies is restricted due to meteorological conditions (such as wind speed, solar radiation and water inflows to hydro reservoirs), space potentials (e.g., for wind parks), fuel potentials (e.g., for biomass or lignite) or political restrictions (such as nuclear phase-out plans). Curtailment of renewable energy infeed is endogenously chosen by the model as long as this option reduces system costs (e.g., because ramping costs can be avoided). Electricity import and export streams are limited by exogenously defined net-transfer-capacity values between market regions. Within market regions, grid copper plates are assumed. Further model elements are described in Richter (2011).

Within this analysis, we model all Member States of the European Union (with the exception of Malta and Cyprus), Switzerland and Norway. Different wind and solar conditions throughout Europe are captured by modeling 47 wind onshore regions, 42 wind offshore regions and 38 photovotaic regions, which are determined according to meteorological data (EuroWind (2011)).[3] The different hourly, daily and seasonal characteristics of renewable infeed and electricity demand are captured by modeling four typical days per model year.

The model incorporates thermal, renewable and storage technologies. The existing European power plant fleet is represented by different vintage classes, which account for different technical properties such as conversion efficiencies. Thermal power plants can be equipped with combined-heat-power-technology and/or carbon-capture-and-storage (CCS) (from 2030 onwards). We assume that, before 2025, only nuclear

[1] The DIMENSION model is based on the DIME model of the Institute of Energy Economics (Bartels (2009)). DIME has been applied, e.g., by Nagl et al. (2011), Paulus and Borggrefe (2011), Grave et al. (2012) and Fürsch et al. (2012). The extended version of the DIMENSION model, as presented in Fürsch et al. (2013), includes most elements of the renewable energy investment model LORELEI (Wissen (2011)).

[2] In contrast, combined heat and power plants can earn incomes from the heat market, which are deducted from the objective value. Thus, the objective value only includes costs induced by the supply of electricity.

[3] For an overview of these regions, see EWI and energynautics (2011).

plants already under construction today can be commissioned. However, existing plants can be retrofitted to increase plant lifetime by 10 years. Endogenous storage investments are only possible for compressed-air-storage technology, as pump storage and hydro storage potentials are already largely used and further investments are often difficult due to environmental concerns. Renewable technologies covered by the model include photovoltaics (base and roof), concentrated solar power (CSP), onshore wind, offshore wind (deep and shallow water), biomass (solid and gas), hydro (run-of-river and storage) and geothermal power. In addition, different wind turbine classes, available at different points in time, are modeled to represent technological progress (see Wissen (2011) and EWI and energynautics (2011)).

3.2. Assumptions

Table 2 depicts the assumed final electricity demand development per country up to 2030. Up until 2020, the demand development is based on the 'additional energy efficiency' scenario of the NREAPs (Beurskens et al. (2011)).[4] For the development after 2030, electricity demand growth rates are based on EWI and energynautics (2011). In addition, the potential heat generation in CHP plants per country is depicted (based on EURELECTRIC (2008) and Capros et al. (2010)).

[4]For Norway and Switzerland, which do not have a NREAP, electricity demand growth rates based on EWI and energynautics (2011) have been applied.

Table 2: Final electricity demand [TWh_{el}] and potential heat generation in CHP plants [TWh_{th}]

	2010		2020		2030	
Austria	66	(40.7)	74	(41.2)	80	(41.5)
Belgium	97	(14.5)	111	(14.7)	119	(14.8)
Bulgaria	36	(6.8)	37	(6.9)	41	(7.0)
Czech Republic	70	(54.0)	84	(55.1)	95	(55.7)
Denmark	36	(54.0)	38	(54.7)	43	(55.1)
Estonia	10	(1.4)	11	(1.4)	12	(1.4)
Finland	88	(64.4)	102	(65.2)	109	(65.7)
France	533	(31.2)	546	(31.6)	585	(31.8)
Germany	604	(191.0)	562	(192.4)	562	(192.9)
Greece	59	(17.1)	68	(17.4)	79	(17.7)
Hungary	43	(13.9)	51	(14.2)	58	(14.4)
Ireland	29	(3.2)	33	(3.2)	35	(3.3)
Italy	357	(166.1)	375	(169.2)	433	(171.7)
Latvia	7	(6.4)	9	(6.5)	10	(6.6)
Lithuania	7	(4.7)	9	(4.8)	10	(4.9)
Luxembourg	6	(0.9)	7	(0.9)	7	(0.9)
Netherlands	124	(112.8)	136	(114.3)	146	(115.1)
Norway	104	(3.6)	119	(3.6)	127	(3.6)
Poland	141	(91.5)	170	(93.3)	191	(94.4)
Portugal	55	(13.6)	65	(13.9)	75	(14.1)
Romania	62	(91.5)	74	(93.3)	83	(94.4)
Slovakia	29	(16.7)	33	(17.0)	38	(17.2)
Slovenia	14	(1.2)	16	(1.2)	18	(1.2)
Spain	291	(57.9)	375	(59.0)	433	(59.9)
Sweden	152	(28.9)	155	(29.3)	166	(29.5)
Switzerland	59	(0.7)	67	(0.7)	72	(0.7)
United Kingdom	369	(67.2)	377	(68.1)	404	(68.6)

Table 3 depicts the investment cost development up to 2030. Assumptions are based on EWI and energynautics (2011) with the exception of photovoltaic investment costs, which have been adapted in order to account for recent cost degressions (BSW (2011)). Furthermore, investment costs for concentrating solar plants have been adapted according to data from IRENA (2012), Turchi et al. (2010) and Hinkley et al. (2011).

Table 3: Investment costs [€ $_{2010}/kW$]

	2020	2030		2020	2030
Nuclear	3,157	3,157	Biomass gas	2,398	2,395
Nuclear Retrofit	300	300	Biomass gas - CHP	2,597	2595
Hard Coal	1,500	1,500	Biomass solid	3,297	3,293
Hard Coal - innov.	2,250	1,875	Biomass solid - CHP	3,497	3,493
Hard Coal - CCS	-	2,000	Geothermal (hot dry rock)	10,504	9,500
Hard Coal - innov. CCS	-	2,475	Geothermal (high enthalpy)	1,050	950
Hard Coal - innov. CHP	2,650	2,275	PV ground	1,440	990
Hard Coal - innov. CHP and CCS	-	2,875	PV roof	1,600	1,100
Lignite	1,850	1,850	Concentrated solar power	3,016	2,926
Lignite - innov.	1,950	1,950	Wind onshore 6 MW	1,221	-
Lignite - innov. CCS	-	2,550	Wind onshore 8 MW	-	1,161
OCGT	700	700	Wind offshore 5 MW (shallow)	2,615	-
CCGT	1,250	1,250	Wind offshore 8 MW (shallow)	-	2,512
CCGT - CCS	-	1,550	Wind offshore 5 MW (deep)	3,105	-
CCGT - CHP	1,500	1,500	Wind offshore 8 MW (deep)	-	2956
CCGT - CHP and CCS	-	1,700			
Pump storage	-	-			
Hydro storage	-	-			
CAES	850	850			

Table 4 shows the conversion efficiencies, CO_2 emission factors, technical availability, operational and maintenance costs and the technical lifetime for conventional plants (see EWI and energynautics (2011)).

Table 4: Economic-technical parameters for conventional and storage technologies

Technologies	$\eta(gen)$ [%]	$\eta(load)$ [%]	CO_2 factor [t CO_2 /MWh_{th}]	avail [%]	FOM costs [€ $_{2010}/kW$]	Lifetime [a]
Nuclear	33.0	-	0.0	84.50	96.6	60
Hard Coal	46.0	-	0.335	83.75	36.1	45
Hard Coal - innovative	50.0	-	0.335	83.75	36.1	45
Hard Coal - CCS	42.0	-	0.034	83.75	97.0	45
Hard Coal - innovative CCS	45.0	-	0.034	83.75	97.0	45
Hard Coal - CHP	22.5	-	0.335	83.75	55.1	45
Hard Coal - CHP and CCS	18.5	-	0.034	83.75	110.0	45
Lignite	43.0	-	0.406	86.25	43.1	45
Lignite - innovative	46.5	-	0.406	86.25	43.1	45
Lignite - innovative CCS	43.0	-	0.041	86.25	103.0	45
OCGT	40.0	-	0.201	84.50	17.0	25
CCGT	60.0	-	0.201	84.50	28.2	30
CCGT - CHP	36.0	-	0.201	84.50	40.0	30
CCGT - CCS	53.0	-	0.020	84.50	88.2	30
CCGT - CHP and CCS	33.0	-	0.020	84.50	100.0	30
Pump storage	87.0	83.0	0.0	95.00	11.5	100
Hydro storage	87.0	-	0.0	90.00	11.5	100
CAES	86.0	81.0	0.0	95.00	9.2	40

Table 5 reports technological and economic characteristics for renewable energy technologies. The availabilities of fluctuating renewable energy technologies vary on an hourly level and between the different meteorological regions throughout Europe, and are thus not able to be depicted in Table 5. The secured capacity corresponds to the share of capacity that can be assumed to be securely available at peak demand (see EWI and energynautics (2011)).

Table 5: Economic-technical parameters for renewable technologies

Technologies	Efficiency [%]	Availability [%]	Secured capacity [%]	FOM costs [$€_{2010}/kW$]	Lifetime [a]
Biomass gas	40.0	85	85	120	30
Biomass gas - CHP	30.0	85	85	130	30
Biomass solid	30.0	85	85	165	30
Biomass solid - CHP	22.5	85	85	175	30
Geothermal (HDR)	22.5	85	85	300	30
Geothermal	22.5	85	85	30	30
PV ground	-	-	0	15	25
PV roof	-	-	0	17	25
Concentrated solar power	-	-	40	120	25
Wind offshore 6MW (deep)	-	-	5	152	25
Wind offshore 8MW (deep)	-	-	5	160	25
Wind offshore 6MW (shallow)	-	-	5	128	25
Wind offshore 8MW (shallow)	-	-	5	136	25
Wind onshore 6MW	-	-	5	41	25
Wind onshore 8MW	-	-	5	41	25
Run-of-river hydropower	-	-	50	11.5	100

Table 6 depicts the assumed fuel price development up to 2030. Assumptions are based on IEA (2011) and EWI and energynautics (2011). The CO_2 price is determined endogenously in the model by imposing a CO_2 emission reduction (in the power sector) of 20% (40%) compared to 1990 levels by 2020 (2030).

Table 6: Fuel costs in $€_{2010}/MWh_{th}$

	2008	2020	2030
Nuclear	3.6	3.3	3.3
Coal	17.28	12.5	12.8
Lignite	1.4	1.4	1.4
Natural gas	25.2	28.1	28.3
Biomass (solid)	15.0-27.7	15.7-34.9	16.7-35.1
Biomass (gas)	0.1-70.0	0.1-67.2	0.1-72.9

4. Scenario Analysis

4.1. Scenario definition

We compare the costs of achieving a European RES-E share of 55% by 2030 using national RES-E support to the costs of achieving the target under EU-wide cooperation.[5] The RES-E share of 55% was chosen in line with the decarbonization pathways of the EU Roadmap, including RES-E shares between 50% and 60% in 2030 (see Section 1). Both national and EU-wide coordinated RES-E support is modeled as a technology-neutral support, implying that technologies with lowest costs are chosen first - either on a national or on an EU-wide level. Moreover, in both cases, the technology-specific national NREAP targets are reached in 2020 (see Beurskens et al. (2011) for an overview), whereas possible gains from cooperation only refer to the subsequent timeframe 2021-2030. We analyze possible gains from EU-wide cooperation in RES-E support for different national target settings as well as for different assumptions regarding interconnector extensions and RES-E investment cost developments. The setting of the national targets is crucial in determining the magnitude of the cooperation gains as the distribution of the targets dictates the reference costs against which the cooperation gains are calculated. The availability of interconnector capacities restricts the use of favorable RES-E sites in regions with low electricity demand and thus presumably also influences the magnitude of the cooperation gains. Similary, the development of RES-E investment costs presumably influences the magnitude of the cooperation gains because cost differences vary between the generation options available in all countries and those that are regionally concentrated. Table 7 provides an overview of the modeled scenarios.

Table 7: Overview of modeled scenarios

		Energy economic assumptions			
		Reference	w/o TYNDP	Lower Offshore Wind Costs	Lower Phovoltaic Costs
Target setting	Equal Share	national RES-E support vs. EU-wide cooperation			
	Extrapolation				
	Flatrate Growth				

With regard to the setting of national targets, we model the following cases:

- ‘Equal share’: Each Member State must increase its RES-E share up to 55% by 2030.

[5]As the electricity systems of Switzerland and Norway are embedded in the European power system, these two countries are included in the calculation even though the countries are not part of the EU. Norway and Switzerland can therefore contribute in reaching the common RES-E target in the cooperation case. However, we assume that, regardless of the national target setting for the EU Member States, the targets for Switzerland and Norway remain close to today´s RES-E shares, which significantly exceed the EU average.

- ‘Extrapolation’: The RES-E deployment of each country, as stated by its NREAP 2020 target, is extrapolated to 2030.[6]

- ‘Flatrate growth’: Each Member State must increase its 2020 RES-E share by 20 percentage points by 2030.

The different settings of national targets cover a broad range of possible effort sharing agreements. The ‘Equal share’ target setting results in a large effort for countries that have low RES-E shares in 2020, while other countries (such as Sweden and Austria) already exceed the 55% share in 2020 and thus would not require a further increase in their share. In the ‘Extrapolation’ case, the greatest effort is demanded from those countries which also made the greatest effort in the 2010-2020 decade. However, these are mostly countries with a high GDP per capita and/or favorable RES-E potentials, as these components were used to determine the 2020 target distribution. The ‘Flatrate growth’ target setting poses the same burden on all countries as far as the percentage increase is concerned. However, also in this case, the slope of the RES-E merit order curve and the demand development in each country essentially determine the burden imposed by the national targets. An overview of the assumed national RES-E targets can be found in the Appendix.[7]

With regard to interconnector extensions and RES-E investment cost developments, we model the following reference case and sensitivity analyses:

- ‘Reference’: Interconnectors are extended according to ENTSOE´s Ten-Year-Network-Development-Plan (TYNDP, see ENTSO-E (2010)). Assumed investment costs for RES-E correspond to those depicted in Table 3.

- ‘w/o TYNDP’: Interconnectors are not extended. Net-tranfer-values (NTC) remain at today´s level. All other assumptions are identical to the ‘Reference’ case.

- ‘Lower Offshore Wind Costs’: Investment costs for offshore plants are 10% lower than depicted in Table 3. All other assumptions are identical to the ‘Reference’ case.

- ‘Lower Photovoltaic Costs’: Investment costs for photovotaic systems are 10% lower than depicted in Table 3. All other assumptions are identical to the ‘Reference’ case.

[6]Note that in order to ensure that a EU-wide target of around 55% is reached by all national target settings the ‘Extrapolation’ case includes a flatrate increase of 5 percentage points in each country in addition to the extrapolation.

[7]Note that we assume a linear pathway for achieving the 2030 targets and thus also set 2025 RES-E (and CO_2) targets. These 2025 targets are determined as a linear interpolation between the 2020 and the 2030 targets.

We model sensitivities with regard to interconnector extensions and to offshore wind and photovoltaic investment costs for two reasons: First, both network extensions and cost degressions of renewables are subject to high uncertainty - either because, e.g., opposition from the local population often leads to delays of planned network extensions or because technological progress is uncertain. Second, both aspects potentially have a high influence on the extent of cooperation gains. Lower interconnector capacities presumably lead to lower gains from cooperation because the best RES-E sites in Europe can be used to a lesser extent. In contrast, lower costs of offshore wind presumably increase the benefit from cooperation, as favorable potentials for offshore wind are regionally concentrated in Northern Europe and can be used to a larger extent in a cooperative European support system. The benefit of using these resources further increases if investment costs of offshore plants are low. Lower investment costs for photovoltaic, on the one hand, may similarly increase the benefit from cooperation due to the increased opportunity of using sites with high solar radiation in the Mediterranean region. On the other hand, potentials (however not necessarily favorable ones) for photovoltaic systems exist in all countries, such that this generation option may be used to a larger extent under a national target scheme. Thus, given lower photovoltaic costs, the achievement of national targets may be less costly.

In the following, we present results for the reference case (Section 4.2) and discuss the influence of interconnector extensions and RES-E investment cost developments on potential cooperation gains (Section 4.3 and Section 4.4, respectively).

4.2. Results - Reference case

Table 8 depicts differences between the national and the EU-wide RES-E support scenarios in 2030 in terms of European electricity generation and European generation capacities. Regardless of the national target setting (Equal Share, Extrapolation or Flatrate Growth), generation from coal plants, photovoltaic systems and biomass plants is higher when RES-E targets are achieved on a national level, while generation from nuclear plants as well as from on- and offshore wind plants is higher when RES-E support is coordinated on the European level. Capacity differences reflect varying technological and regional generation patterns under national and cooperative RES-E support. On average, photovoltaic systems and wind plants (onshore and offshore) have lower energy outputs in the national support scenarios, because sites with comparatively low solar radiation and low wind speeds are also used in achieving national targets. Thus, e.g., onshore wind capacities in the 'Equal Share' and the 'Flatrate Growth' scenarios are lower when RES-E support is coordinated, although wind onshore generation is higher. In the following differences between the generation and capacity levels under national and cooperative support are discussed in more detail.

Table 8: Differences in European electricity generation [TWh] and generation capacities [GW] between national support and cooperation in 2030 (Reference)

Generation [TWh]

	Equal Share			Extrapolation			Flatrate Growth		
	national	coop.	**diff.**	national	coop.	**diff.**	national	coop.	**diff.**
Nuclear	866	968	**-102**	978	1011	**-34**	947	1000	**-54**
Lignite	370	362	**7**	366	367	**-1**	369	366	**4**
Coal	480	399	**81**	473	427	**46**	439	413	**26**
Gas	48	56	**-8**	42	67	**-25**	63	61	**3**
Oil	0	0	**0**	0	0	**0**	0	0	**0**
Storage	78	87	**-9**	84	81	**3**	78	85	**-7**
Hydro	551	552	**0**	552	552	**0**	552	552	**0**
Biomass	208	174	**34**	178	170	**8**	186	172	**14**
Wind onshore	706	711	**-5**	689	705	**-16**	704	707	**-3**
Wind offshore	299	359	**-61**	299	335	**-37**	244	345	**-101**
PV	370	325	**45**	324	270	**54**	393	291	**102**
CSP	49	47	**1**	49	48	**0**	49	47	**1**
Geothermal	94	94	**0**	94	93	**1**	94	94	**1**
Others	56	56	**0**	56	56	**0**	56	56	**0**

Capacity [GW]

	Equal Share			Extrapolation			Flatrate Growth		
	national	coop.	**diff.**	national	coop.	**diff.**	national	coop.	**diff.**
Nuclear	141	151	**-10**	149	154	**-5**	147	153	**-6**
Lignite	57	56	**2**	56	57	**-1**	57	56	**1**
Coal	73	65	**8**	73	66	**7**	69	65	**3**
Gas	147	147	**-1**	147	147	**0**	151	147	**4**
Oil	5	5	**0**	5	5	**0**	5	5	**0**
Storage	78	82	**-3**	78	76	**2**	74	79	**-4**
Hydro	154	155	**-1**	155	155	**0**	155	155	**0**
Biomass	29	24	**5**	25	24	**1**	26	24	**2**
Wind onshore	315	311	**4**	301	308	**-6**	310	309	**2**
Wind offshore	89	91	**-2**	82	85	**-3**	69	87	**-19**
PV	311	251	**60**	273	205	**68**	330	223	**108**
CSP	11	11	**0**	11	11	**0**	11	11	**0**
Geothermal	13	13	**0**	13	13	**0**	13	13	**0**
Others	11	11	**0**	11	11	**0**	11	11	**0**

Generation from photovoltaic systems, biomass plants and coal plants is higher in the national support scenarios. The reason for higher photovoltaic generation is a higher generation at sites with low solar radiation (e.g, in Belgium, Germany and even in Sweden when a national target of 83% must be reached in the 'Flatrate Growth' scenario) which overcompensates for lower generation at sites with high solar radiation (e.g., in Spain and Portugal), which are used to a higher extent in the cooperative support scenarios. Higher biomass generation in the national support scenarios can be mainly attributed to additional generation in Finland and in the Equal Share scenario also to higher biomass generation in Hungary and Italy. Higher coal generation in the national support scenarios essentially replaces nuclear generation. Generation from nuclear plants is lower on a European level because, in the national support scenarios, RES-E generation in countries with existing nuclear plants or political plans to construct nuclear plants (FR, BG, CZ, PL, SK, RO) is usually higher than in the cooperative scenarios. Due to limited interconnector capacities - despite extensions according to the TYNDP - high nuclear in addition to high RES-E generation would exceed regional demand and export possibilites in these countries. The largest difference between nuclear and coal generation occurs when each country is required to reach a 55% RES-E share ('Equal Share'). This target distribution leads to the highest RES-E generation in France, which impedes the use of French nuclear plants. Generation from wind plants, especially from offshore wind plants, is substantially higher in the scenarios with cooperative RES-E support because wind generation at sites with high wind speeds is associated with comparatively low generation costs. Additional offshore generation in the cooperative (compared to the national) support scenarios mainly comes from Skandinavia, the Netherlands and Ireland. However, offshore generation in the national support scenarios is higher in Germany and, depending on the national target setting, in France and the United Kingdom.

In addition, total RES-E generation is higher in the national support scenarios because RES-E generation exceeds national targets in countries with favorable meteorological conditions for wind- or solar-based electricity generation and low national targets compared to their RES-E potential (e.g., in Portugal and Ireland). This additional RES-E generation contributes to a cost-efficient achievement of the CO_2 emission reduction target. In the cooperative support scenarios, RES-E generation from these favorable sites replaces RES-E generation in other regions and the CO_2 emission reduction target is achieved by a higher generation from nuclear plants.

Additional results of the cost-efficient regional RES-E deployment in the cooperative support scenarios and the respective deviations in the national support scenarios are provided in Table 9.[8] The table depicts the RES-E generation per country, depending on the different settings of national targets, both for the national and for the cooperative support scenarios. In Table 9, only about half of the countries modeled are depicted. The countries listed are those countries which yield the greatest deviation in RES-E generation from their national targets, when a European-wide cooperation is implemented.

[8]Note that we use the term 'cost efficient' in the context of a European-wide RES-E target - with a CO_2 emission reduction target only, a smaller share of RES-E would be cost-efficient. In our scenario settings, a European RES-E share of 46% is achieved in 2030 if no additional RES-E target is modeled after 2020. However, this share also includes RES-E generation from plants that were built in order to achieve the NREAP in 2020.

Table 9: RES-E generation in national and cooperative support scenarios in 2030 in selected countries [TWh]

	Equal Share			Extrapolation			Flatrate Growth		
	national	coop.	**diff.**	national	coop.	**diff.**	national	coop.	**diff.**
Group A									
Belgium	53	32	**21**	50	32	**18**	49	32	**17**
Finland	60	38	**22**	49	34	**15**	58	34	**24**
Germany	309	258	**51**	364	256	**108**	329	258	**72**
Group B									
France	322	265	**57**	254	252	**3**	275	254	**21**
Czech Rep.	52	24	**28**	25	23	**1**	33	24	**8**
Great Britain	222	210	**13**	234	199	**36**	206	205	**1**
Greece	43	46	**-2**	56	42	**14**	47	44	**3**
Poland	105	68	**37**	68	68	**0**	75	68	**7**
Sweden	105	110	**-5**	126	110	**16**	137	110	**27**
Group C									
Ireland	23	47	**-23**	27	46	**-19**	30	47	**-17**
Netherlands	80	121	**-41**	103	121	**-18**	83	121	**-38**
Norway	127	204	**-77**	127	193	**-65**	127	195	**-68**
Portugal	43	70	**-27**	55	65	**-10**	56	65	**-9**
Spain	238	297	**-59**	244	295	**-51**	260	297	**-37**
Group D									
Italy	238	198	**40**	169	180	**-11**	201	189	**12**

The countries depicted have been clustered into four groups: Countries in the ‘A’ group are characterized by higher RES-E generation in the national support scenarios compared to the cooperative support scenarios, regardless of the national target setting. Countries in the ‘B’ group are also characterized by a higher RES-E generation in the national support scenarios under most scenario settings; however, for at least one target setting, hardly a deviation from the cost-efficient generation in the cooperative support scenarios occurs. In countries, belonging to the ‘C’ group, RES-E generation in the national support scenarios is always lower than in the cooperative support scenarios. These countries are characterized by high wind speeds or high solar radiation. Italy (‘D’ group) is a special case because, depending on the target setting, RES-E generation in the national support scenarios is either significantly lower or significantly higher than in the cooperative support scenarios.

As a result of the suboptimal regional and technological RES-E generation in the national support scenarios (compared to the cooperative support scenarios), the costs of achieving a RES-E share of 55 % by 2030 are significanty higher in the national support scenarios. Table 10 shows the additional electricity system costs in the decade 2021-2030 that are induced by national and EU-wide 2030 RES-E targets as opposed to a 2030 CO_2 target only (-40% compared to 1990 levels). Moreover, the resulting gains from cooperation are shown, expressed as the difference in additional costs of the 2030 RES-E target (compared to the CO_2 target only) with national and with cooperative support. All costs are cumulated from 2021 to 2030 and discounted by 5% (to the base year 2020).

Table 10: Additional costs induced by the 2030 RES-E target and cooperation gains (2021-2030)

	Equal Share	**Extrapolation**	**Flatrate Growth**
Additional costs of 2030 RES-E target - national support (bn. €$_{2010}$)	166	125	133
Additional costs of 2030 RES-E target - cooperative support (bn. €$_{2010}$)	93	68	79
Gains from cooperation (bn. €$_{2010}$)	73	57	54
Gains from cooperation (%)	44	45	41

Additional electricity system costs induced by the 2030 RES-E target vary between 68 and 93 bn. €$_{2010}$ if the RES-E target is cost-efficiently reached by using efficient technologies and sites throughout Europe. The cost differences between the different cooperative support scenarios result from slightly different 2030 RES-E shares. The 'Extrapolation' and the 'Flatrate Growth' target distribution result in a European RES-E target of approximately 55 % (54.5% and 55.4%, respectively). The 'Equal Share' target distribution results in a higher European RES-E target (56.8%) because some countries already exceed the 55% share in their 2020 NREAP targets. However, it becomes clear that, given our assumptions, the European RES-E merit order curve is relatively steep given RES-E shares of approximately 55%: While the RES-E share in the 'Flatrate Growth' scenario is 0.9 percentage points higher than in the 'Extrapolation' scenario (corresponding to 1.6% higher RES-E generation), additional costs of achieving the 2030 RES-E target increase by 16%.[9] Comparing the additional electricity system costs of the 2030 RES-E target of the national versus the cooperative support scenarios, gains from cooperation amount to 54-73 bn. €$_{2010}$. In other words, the additional costs induced by the (national) RES-E targets can be reduced by 41 to 45 % when the best sites throughout Europe can be used. It is important to note that these cost differences refer to electricity system costs and not only to the costs of RES-E production. For example, more regionally concentrated RES-E generation in the cooperative support scenarios may increase the need for system flexibility. In the Equal Share and the Flatrate Growth target setting scenarios, it can be seen that more storage units are deployed given cooperative rather than national support. The gains from cooperation thus already include the indirect costs of RES-E support,

[9]Similarly, while the RES-E share in the 'Equal Share' scenario is 1.4 percentage points higher than in the 'Flatrate Growth' scenario (corresponding to 2.5% higher RES-E generation), additional costs of the 2030 RES-E target increase by 18%.

i.e., the costs of RES-E integration in terms of flexibility and security of supply requirements.[10] Note also that, as described above, not exactly the same RES-E quantities are reached under national and cooperative support. Some countries surpass their targets in the national support scenarios and thereby contribute to the achievement of the European CO_2 emission reduction target.[11] The gains from cooperation thus include both the cost advantage of using best sites throughout Europe to achieve the European RES-E target and the advantage of using low-cost emission reduction possibilities in the overall electricity sector to achieve the European CO_2 target.

4.3. The influence of interconnector extensions on cooperation gains

Table 11 depicts the difference in generation between national support and cooperative support scenarios in 2030, both when interconnectors are extended according to the TYNDP (left columns, see also Table 8) and when interconnectors are not extended (right columns). The overall picture is similar for the scenarios with and without interconnector extensions: In the national support scenarios, generation from photovoltaic systems and fossil-fuel power plants is higher, whereas in the cooperative support scenarios, generation from nuclear and wind plants is higher. However, the absence of interconnector extensions has two major consequences: First, lower import and export possibilities impede the use of low-cost electricity generation options throughout Europe. This includes renewable generation options (i.e., offshore wind) and non-renewable generation options (i.e., existing nuclear and lignite). Second, lower interconnector capacities limit the possibility to balance regional demands and fluctuating RES-E infeed. Thus, the requirement for flexible generation or demand on a national level increases.

[10]In contrast, costs of the electricity grid are not included in the calculation. However, Fürsch et al. (2013) show that substantial extensions of the transmission grid are beneficial in order to access favorable RES-E sites and that the induced grid extension costs are rather small compared to cost differences occurring in the generation system.

[11]RES-E generation in 2030 is around 1% higher for national compared to cooperative support. In 2025, differences amount to around 5%.

Table 11: Differences in European electricity generation [TWh] between national and cooperative support scenarios in 2030 (with and without TYNDP)

	TYNDP			w/o TYNDP		
	national	cooperative	**difference**	national	cooperative	**difference**
Equal Share						
Nuclear	866	968	**-102**	755	890	**-135**
Lignite	370	362	**7**	362	357	**5**
Coal	480	399	**81**	451	421	**30**
Gas	48	56	**-8**	171	108	**62**
Oil	0	0	**0**	0	0	**0**
Storage	78	87	**-9**	78	105	**-28**
Hydro	551	552	**0**	552	552	**0**
Biomass	208	174	**34**	208	193	**16**
Wind onshore	706	711	**-5**	699	704	**-5**
Wind offshore	299	359	**-61**	311	332	**-20**
PV	370	325	**45**	374	344	**30**
CSP	49	47	**1**	49	46	**3**
Geothermal	94	94	**0**	94	94	**0**
Others	56	56	**0**	56	56	**0**
Extrapolation						
Nuclear	978	1011	**-34**	859	913	**-54**
Lignite	366	367	**-1**	356	361	**-5**
Coal	473	427	**46**	453	429	**24**
Gas	42	67	**-25**	174	156	**18**
Oil	0	0	**0**	0	0	**0**
Storage	84	81	**3**	78	87	**-9**
Hydro	552	552	**0**	552	552	**0**
Biomass	178	170	**8**	181	189	**-8**
Wind onshore	689	705	**-16**	683	696	**-13**
Wind offshore	299	335	**-37**	303	303	**0**
PV	324	270	**54**	324	293	**31**
CSP	49	48	**0**	49	46	**3**
Geothermal	94	93	**1**	94	94	**0**
Others	56	56	**0**	56	56	**0**
Flatrate Growth						
Nuclear	947	1000	**-54**	842	906	**-64**
Lignite	369	366	**4**	362	360	**3**
Coal	439	413	**26**	431	433	**-2**
Gas	63	61	**3**	172	132	**40**
Oil	0	0	**0**	0	0	**0**
Storage	78	85	**-7**	79	96	**-17**
Hydro	552	552	**0**	552	552	**0**
Biomass	186	172	**14**	191	192	**-1**
Wind onshore	704	707	**-3**	692	699	**-7**
Wind offshore	244	345	**-101**	254	311	**-56**
PV	393	291	**102**	387	314	**73**
CSP	49	47	**1**	49	46	**3**
Geothermal	94	94	**1**	95	94	**0**
Others	56	56	**0**	56	56	**0**

We identify the following effects of interconnector capacities on the optimal generation mix in the cooperative RES-E support scenarios, compared to national support:

- The best wind availabilities across Europe are better exploited under cooperative RES-E support. This advantage is greater when interconnector capacities are larger. Thus, the difference in wind generation between cooperative and national support is larger if the TYNDP is realized.

- Photovoltaic generation is lower given cooperative support because only best solar sites are competitive with other RES-E generation options throughout Europe. When interconnector capacities are larger, more favorable RES-E generation options across Europe (i.e., wind in Northern Europe) can be used and solar generation at sites with medium solar generation in Central Europe is smaller. Thus, the difference in solar generation between cooperative and national support is larger if the TYNDP is realized.

- Nuclear generation is higher given cooperative support because the use of renewable and non-renewable generation options can be optimized on a European-wide level. With cooperative support, RES-E generation in countries with existing nuclear plants or the political will to construct nuclear plants is lower compared to national support. Thus, a larger use of nuclear generation is possible. When interconnectors are larger, this relative advantage of the cooperative RES-E support decreases. With larger interconnectors, a higher nuclear, in addition to a high RES-E generation, is possible on a national level. Thus, the difference in nuclear generation between cooperative and national support is smaller if the TYNDP is realized.

- When interconnector capacities are larger, international power flows contribute significantly to balance demand and fluctuating RES-E infeed. Thus, the need for flexibility on a national level is smaller, both under cooperative and national RES-E support. In the cooperative RES-E support scenarios, storage generation in countries with a high wind penetration is smaller when interconnector capacities are larger. In the national support scenarios, a large share of non-renewable generation is coal rather than gas based when interconnector capacities are larger. Thus, the difference in generation from storage units between cooperative and national support is smaller if the TYNDP is realized. Furthermore, a lower generation from nuclear plants under national compared to cooperative support is replaced by coal rather than by gas when interconnector capacities are larger.

Differences in regional generation patterns between national and cooperative support scenarios do not fundamentally change given an absence of interconnector extensions. Countries with favorable meteorological conditions also generate more RES-E in cooperative than in national support scenarios, however, generally to a lower extent. For example, the cost-efficient wind generation in Ireland, Norway and Denmark is lower due to limited export possibilites. In contrast, e.g., solar generation in Spain in the cooperative support scenarios is hardly reduced when the TYNDP is not realized, because the additional solar generation in the cooperative (compared to the national) support scenarios mainly replaces non-renewable based generation in Spain and is not exported to other countries.

With regard to gains from cooperation, the absence of interconnector extensions has, as expected, a decreasing effect. However, gains from cooperation remain at a significant magnitude of 47 to 62 bn €$_{2010}$ (cumulated from 2021 to 2030) which translates to a reduction of the additional costs induced by the (national) RES-E targets by 36% to 37%.

4.4. The influence of RES-E investment costs on cooperation gains

Table 12 depicts the additional costs induced by the 2030 RES-E target under national and cooperative RES-E support systems, as well as the associated cooperation gains when investment costs for photovoltaic systems or for offshore wind plants are 10% lower than in the reference case. Numbers in brackets indicate the difference compared to the reference case (either in bn. €$_{2010}$ or in percentage points).

Table 12: Effect of RES-E investment costs on additional costs induced by the 2030 RES-E target and cooperation gains (2021-2030)

Photovoltaic Costs - 10%	**Equal Share**	**Extrapolation**	**Flatrate Growth**
Additional costs of 2030 RES-E target - national support (bn. €$_{2010}$)	156 (-10)	115 (-10)	124 (-9)
Additional costs of 2030 RES-E target - cooperative support (bn. €$_{2010}$)	90 (-3)	68 (0)	76 (-3)
Gains from cooperation (bn. €$_{2010}$)	65 (-8)	47 (-10)	48 (-6)
Gains from cooperation (%)	42 (-2)	41 (-4)	39 (-2)
Offshore Wind Costs - 10%			
Additional costs of 2030 RES-E target - national support (bn. €$_{2010}$)	160 (-6)	121 (-4)	131 (-2)
Additional costs of 2030 RES-E target - cooperative support (bn. €$_{2010}$)	91 (-2)	67 (-1)	76 (-3)
Gains from cooperation (bn. €$_{2010}$)	69 (-4)	55 (-2)	54 (0)
Gains from cooperation (%)	43 (-1)	45 (0)	42 (+1)

Lower costs for photovoltaic systems (compared to the reference case) mainly lead to higher photovoltaic and to lower offshore wind-based generation under either national or cooperative RES-E support. Given national RES-E support, the switch from offshore- to photovoltaic-based generation mostly occurs in countries characterized by medium wind speeds and medium solar radiation as opposed to the best sites throughout

Europe (e.g., France and Germany). Under cooperative RES-E support, e.g., photovoltaic generation in Italy is higher than in the reference case, while offshore generation in Great Britain is lower. In contrast, generation at the best sites for offshore wind (e.g., in the Netherlands and Denmark) is not affected by lower photovoltaic costs. Also, generation from other generation options such as onshore wind, is hardly affected by lower photovoltaic costs. In contrast, the overall costs of reaching the 2030 RES-E target is reduced by lower investment costs for photovoltaic systems, both given national and cooperative RES-E support. The cost reducing effect is, however, more pronounced in the national support scenarios, in which photovoltaic capacities are largely higher, such that gains from cooperation decrease to 47 - 65 bn. €$_{2010}$ (to 39 - 42 %).

Lower investment costs for offshore wind plants also lead to generation switches between offshore wind- and photovoltaic-based generation. In addition, in the cooperative RES-E support scenarios, higher offshore wind-based generation partly replaces biomass-based generation. Contrary to the hypothesis made in Section 4.1, gains from cooperation do not increase with decreasing offshore wind costs. In absolute terms, gains from cooperation either do not change ('Flatrate Growth' scenario) or decrease slightly. In relative terms, gains from cooperation do not change, decrease or increase in a negligible order of magnitude. Although offshore wind-based *generation* is significantly higher in the cooperative support scenarios, *capacities* are only slightly higher (but deployed at sites with higher full load hours). Consequently, lower investment costs for offshore plants affect approximately the same number of offshore wind plants in the national and in the cooperative support scenarios. In terms of offshore wind generation costs, absolute reductions due to decreasing investment costs are, however, larger in the national support scenarios because full load hours are lower on average. Thus, in the 'Equal Share' and 'Extrapolation' scenarios, additional costs induced by the 2030 RES-E target decrease more when RES-E is supported on a national level. In the 'Flatrate Growth' scenarios, the highest difference in offshore wind capacity between national and cooperative support occurs (8 GW in the reference case, 18 GW when offshore wind costs are lower). In this case, cost reductions in the national and the cooperative support scenario are in the same order of magnitude: The effect of higher offshore wind capacities in the cooperative scenario balances the effect of a larger absolute reduction of generation costs in the national scenario.

5. Possible obstacles to cooperation in RES-E support

In Section 4, we have shown that stronger cooperation in RES-E support yields substantial cost savings in the period after 2020 and that these cost savings are relatively robust to different developments of the grid infrastructure and RES-E investment costs. As discussed in Section 2, several authors have already quantified cost savings from cooperation in achieving the 2020 target. However, currently hardly any Member States plan to use cooperation mechanisms in order to reach their national 2020 targets.[12] One exception is the joint support system of Sweden and Norway that was implemented in 2012. In addition, Italy and Luxembourg both intend to profit from RES sources outside their national borders in order to achieve their targets. This section addresses possible obstacles to a cooperative RES-E support that need to be tackled in order to reduce the costs of increasing the European RES-E share. In the following, we analyze the main obstacles facing the implementation of cooperation mechanisms, as stated in the individual Member States' NREAPs (see EC (2010)), and thereby provide further insights on political measures required to increase cooperation among Member States (MS).

- **Uncertainty surrounding national RES-E deployment paths**

  Future RES-E deployment is not exactly predictable, especially in countries with a price-based RES-E promotion system. MS explain within their NREAPs that they are interested in statistical transfers in the case their national target is surpassed, but would also like to be assured that their own target is met (see, e.g., NREAP Ireland and NREAP Germany).

- **Uncertainty surrounding RES-E deployment in third countries**

  Even more than RES-E deployment on national territories, the progress of joint projects between MS and third countries is difficult to foresee. For example, many MS are involved in initiatives to import RES-E from the North African countries. However, Italy is the only country that states within its NREAP that it aims to fulfill a part of its target through imports from third countries. In contrast, e.g., France explains that the current status of the project does not allow for the quantification of the amounts of RES-E that could be imported within the target period of the Directive.

- **Administrative issues**

  Another obstacle hindering the use of cooperation mechanisms are unclear administrative issues. Within the NREAPs, the MS were requested to describe national procedures for arranging statistical transfers or joint projects. Most countries declared that no procedures have yet been established and that there is no clear common understanding of how cooperation mechanisms could work in practice (see, e.g., NREAP Ireland). In addition, there is a lack of information concerning the potential for joint projects in other MS or third countries (see, e.g., NREAP Slovakia or NREAP Spain).

[12]Cooperation mechanisms defined within the European Renewables Directive include statistical transfers, joint projects and joint support systems between Member States. In addition, targets can be achieved through cooperation mechanisms with non-EU Member States under certain conditions. For more detailed information, see EC (2012).

- **Sharing of integration costs**

  Several MS state that the implementation of statistical transfers or joint projects is only eligible if integration costs of a higher RES-E share are borne by all participating Member States. These integration costs include, e.g., costs for reinforcing the national grid and interconnectors as well as balancing costs (see, e.g., NREAP Ireland and NREAP Germany). Obviously, it is not evident how, for example, grid enforcement costs induced by renewable energies can be clearly distinguished from those induced by other power plants or changes in the demand structure (Dena (2010)). To quantify the integration costs induced only by those RES quantities needed for cooperation mechanisms is even less straightforward.

- **Insufficient interconnector capacities**

  Besides the unclear cost distribution of grid investments, an important issue for the implementation of cooperation mechanisms is the actual realization of grid enhancements, especially regarding interconnectors. Thus, administrative issues or issues of public acceptance that hinder grid extensions can be an obstacle to the use of cooperation mechanisms. Spain explains in its NREAP that participation in joint projects would be 'senseless' for Spain if interconnectors between Spain and France (and the rest of the European Union) are not enforced. Furthermore, the Spanish NREAP states that the interconnectors between the European Union and the North African countries are insufficient with regard to the envisaged RES-E imports from North Africa. Portugal´s NREAP declares that it could easily go beyond its own RES target given an extension of the interconnector capacity between France and Spain.

- **Influence on the conventional power market**

  A rising RES-E share has significant effects on the conventional power system. Portugal explains that the Portuguese electricity market currently has surplus capacity and therefore does not intend to produce more RES-E than required for national target achievement. A rising amount of RES-E would lead to shrinking full load hours of thermal power plants and thus affect their profitability.

- **Other political targets**

  Finally, some governments also pursue political targets that can only be achieved by domestic RES promotion. For example, the Netherlands have set a higher target for themselves than the mandatory target of the EU directive, which, in addition, should be achieved through domestic production. Germany states in its NREAP that the benefits from cooperation mechanisms have to be balanced with the benefits from local RES production (such as local employment).

In summary, a sharing of costs and benefits between Member States is challenging, and unclear administrative procedures, a lack of information about RES-E potentials in other countries and uncertainty about the progress of RES-E projects may hinder the use of cooperation mechanisms. Potential drawbacks of cooperation have also been addressed in the literature. Del Río (2005) states that harmonization may be in conflict with national socioeconomic and environmental objectives, e.g., if a country wants to increase employment by creating green jobs. Klessmann et al. (2010) point out that a quantification of indirect costs and benefits resulting from cooperation mechanisms is hardly possible. These indirect costs include, e.g., grid integration costs or environmental costs (e.g., impact on the landscape) whereas potential benefits listed by Klessmann et al. (2010) include, e.g., local job creation and innovation. Pade et al. (2012) also identify the distribution of costs and benefits as a major challenge. In addition, the authors discuss in detail barriers that are specific to the implementation of the different cooperation mechanisms. When implementing a joint support scheme, countries have to agree on a common support system design, which can be very difficult in practice. Joint projects are more easily to implement; however, Pade et al. (2012) point out that transaction costs can be an important barrier for small size projects. Moreover, the authors explain that uncertainty surrounding the setting of RES targets in the period post 2020 is a barrier to cooperation because countries with low-cost RES potentials may not be willing to exploit their potentials given uncertainty about the development of future targets.

6. Conclusions

Generation costs of fluctuating renewables vary substantially throughout Europe due to different meteorological conditions. Thus, any RES-E support system that does not incentivize the use of best sites across Europe induces high extra costs. In this analysis, we have shown that continuing with national support systems after 2020 would increase the additional cost of a 2030 RES-E target substantially. Furthermore, we find that the economic benefit of cooperation, in terms of cost savings in the electricity system, is quite robust: The cost savings decrease only slightly when interconnectors are not further extended (compared to today) and depend only slightly on assumptions about the developments of RES-E investment costs.

In order to benefit from cooperation in practice, prevailing obstacles facing cooperation need to be tackled. Based on an analysis of the NREAP documents, we find that a sharing of costs and benefits between Member States is challenging and that unclear administrative procedures, a lack of information about RES-E potentials in other countries and uncertainty surrounding the progress of RES-E projects may hinder the use of cooperation mechanisms. However, the example of the joint support system of Norway and Sweden shows that these obstacles can be overcome.[13] Moreover, the European Commission is currently working on the development of guidelines on the implementation of cooperation mechanisms to provide information on legal conditions and on possible methodologies to share costs and benefits (EC (2012)). Moreover, hybrid support systems (as opposed to pure national or pure cooperative support systems) may yield a large part of possible cooperation gains while limiting the distributional effects. For example, Jansen (2011) proposes a bottom-up harmonization in which joint renewable quota systems can be supplemented with national support measures in order to take into account national concerns. Pade et al. (2012) also propose 'technology or geographically specific joint support schemes' (e.g., only for offshore wind) as a short- to medium-term solution. The advantage of this approach would be that these specific joint support schemes could coexist with national support schemes. Thereby, some barriers to cooperation would be removed, such as the difficulties in agreeing on a common support system or the pursuit of different objectives the Member States have with regard to RES-E support. The authors state that while full harmonization would lead to the highest efficiency gains, it is difficult to implement in the short term. In the context of European cooperation in transmission system planning, Buijs (2011) investigates how different forms of collaboration affect overall and country-wise economic welfare and discusses the impact of different compensation mechanisms. Further research in this area is clearly required in order to avoid large excess costs of achieving national targets without cooperation.

[13]Klessmann et al. (2010) explain that the idea of a joint support system between Norway and Sweden was first abolished in 2006 because 'it was very hard to find a final agreement how to share the costs and benefits in such a system'.

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Appendix

Table A.1: RES-E shares in 2010 and 2020 (according to NREAPs) and assumed RES-E targets for 2030 in the scenarios 'Equal Share', 'Extrapolation' and 'Flatrate Growth'

	2010 (NREAP)	**2020** (NREAP)	**2030** Equal Share	Extrapolation	Flatrate Growth
	[%]	[%]	[%]	[%]	[%]
Austria	73	71	71	76	91
Belgium	5	21	55	42	41
Bulgaria	11	21	55	36	41
Czech Republic	7	14	55	26	34
Denmark	34	52	55	75	72
Estonia	2	5	55	13	25
Finland	26	33	55	45	53
France	16	27	55	44	47
Germany	17	39	55	65	59
Great Britain	9	31	55	58	51
Greece	13	40	55	71	60
Hungary	7	11	55	20	31
Ireland	20	43	55	70	63
Italy	19	26	55	39	46
Latvia	45	60	60	80	80
Lithuania	8	21	55	39	41
Luxembourg	4	12	55	25	32
Netherlands	9	37	55	70	57
Poland	8	19	55	36	39
Portugal	41	55	55	74	75
Romania	27	43	55	63	63
Slovakia	19	24	55	34	44
Slovenia	32	39	55	51	59
Spain	29	40	55	56	60
Sweden	55	63	63	76	83
Switzerland*	55	n/a	57	57	57
Norway*	90	n/a	100	100	100

*2010 share according to Eurostat