Study on the Central and South Eastern Europe energy connectivity (CESEC) cooperation on electricity grid development and renewables

Final report

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List of abbreviations

Abbreviation	Definition
ACER	Agency for the Cooperation of Energy Regulators
CBA	Cost-Benefit Analysis
CBAM	Carbon border adjustment mechanism
CEF	Connecting Europe Facility
CESEC	Central and South Eastern Europe energy connectivity
CHP	Combined heat and power
CNECs	Critical network element and contingencies
CP	Contracting Party (of the Energy Community)
CWE	Central Western Europe
DG ENER	Directorate-General for Energy
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EnC	Energy Community
EnS	Energy not Supplied
ENTSO-E	European Network of Transmission System Operators for Electricity
EPMM	European Power Market Model
EU	European Union
FWC	Framework Contract
GHG	Greenhouse Gas
GIS	Geographic Information System
GSK	Generation Shift Key
MinRAM	Minimum remaining available margin
MS	Member States of the European Union
MoU	Memorandum of Understanding
NECP	National Energy and Climate Plan
NERP	National Emission Reduction Plan
NGO	Non-Governmental Organisation
NPV	Net Present Value
NRA	National Regulatory Authorities
NSI East	North-South Interconnections in central eastern and south eastern Europe
NTC	Net Transfer Capacity
PCI	Projects of Common Interest
PECI	Projects of Energy Community Interest
PMI	Projects of Mutual Interest
PPA	Power Purchase Agreement
PV	Photovoltaic
PTDF	Power Transfer Distribution Factor
QC	Quality Control
RES	Renewable Energy Sources
RES-E	Electricity generation from renewable energy sources
SEE	South Eastern European
TGM	Consentec Transmission Grid Model
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan
WB6	West-Balkan 6 countries
WBIF	Western Balkan Investment Framework

Abbreviation	**Country**
AL	Albania
AT	Austria
BA	Bosnia and Herzegovina
BG	Bulgaria

Abbreviation	Country
BY	Belarus
CY	Cyprus
CZ	Czechia
DE	Germany
FR	France
EL	Greece
HR	Croatia
HU	Hungary
IT	Italy
MK	North Macedonia
MD	Moldova
ME	Montenegro
RO	Romania
RS	Serbia
SI	Slovenia
SK	Slovakia
TR	Turkey
UA	Ukraine
UA_W	West Ukraine
XK	Kosovo

EXECUTIVE SUMMARY

Background

The Initiative for the Central and South Eastern European Energy Connectivity (CESEC) was launched in 2015 to address concerns of gas supply security in the nine EU Member States and the eight non-EU Contracting Parties. In 2017, the Initiative was extended to cover cooperation in the area of renewable energy and, in this form, it addresses three related issues: first, it aims to consolidate the security of energy supply in a region that has historically been affected by limited diversity of the energy mix and exposure to external disruptions, particularly in gas supply; second, it addresses the need for modernisation of the wider electricity system, in a region where the bulk of – mainly fossil fuels-based - power generation plants are approaching the end of their operational life; and third, it aims to support increasing power generation and trade of renewable energy, as a partial means to address the first two objectives.

Objectives

This report provides a detailed analysis of the potential for cost-effective renewable energy projects and associated infrastructure requirements in the CESEC region, in the short and long terms of 2030 and 2050, respectively. The analysis has an explicit focus on cross-border cooperation among CESEC members, as opposed to separate assessments of individual countries. This is to keep in line with the nature of the CESEC initiative, the ultimate goal of which is to build on synergies between the EU Member States to increase the resilience of the overall regional energy system. The ultimate goal of the analysis is to **identify the infrastructure, regulatory and market requirements that facilitate the integration of renewable energy sources (RES) in the CESEC region.** To this end, the content of this report is structured around answering the following questions[1]:

- What are the geographical locations of prime interest for RES development, with a cross-border dimension?[2]
- What are the connecting electricity infrastructure needs required to facilitate RES integration?[3]
- Which cross-border electricity infrastructure projects can be identified as priority projects in enabling the integration of electricity from RES, in the CESEC region?
- What are the technical, regulatory and market issues that create barriers to cross-border cooperation and hinder renewables deployment?[4]

Approach

To answer these questions, the analysis focuses on the differences in cost and technology – and corresponding policy - implications in pair-wise combinations of three sets of scenarios, regarding 1. the time horizon, 2. the RES targets and 3. the electricity interconnector infrastructure. More specifically, the two different time horizons considered in this study are the short term – 2030, and the long term – 2050. Second, the two sets of RES targets considered in this study are: a. the targets set out in the National Energy and Climate Plans (NECP), where defined - or alternative targets - which correspond to the scenario of reference contribution from RES in the electricity mix, and b. the targets underlying the Green Deal initiative, which correspond to the scenario of high contribution from RES. Finally, the three electricity infrastructure scenarios considered here are: a. the electricity infrastructure currently in place as well as reinforcements underway - whereby new capacity of RES technology is installed

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[1] This Executive Summary presents a compact version of the main results. For the more detailed answers to the four questions, see Chapter 6: Conclusions and recommendation.
[2] This question corresponds to the analysis presented in Chapter Three.
[3] Questions Two and Three correspond to the analysis presented in Chapter Four.
[4] This question corresponds to the analysis presented in Chapter Five.

domestically, b. additional electricity infrastructure projects, as reflected in the planned projects in TYNDP, PECI and CESEC priority list, and c. infrastructure projects identified in addition to these latter projects. In scenarios b. and c., new capacity of RES technology is installed in regions with higher potential for power generation from RES technologies and neighbouring countries that rely on cross-border electricity trade.

The analysis uses a mixed-method approach (Chapter Two). The first question - *What are the geographical locations of prime interest for RES development, with a cross-border dimension?* - is addressed using a combination of literature review and Geographical Information System (GIS) mapping.

Based on the results of this analysis, the study uses three well-established energy system models, with a history of application in policy analysis, to address the following two questions, namely - *What are the connecting electricity infrastructure grid needs required to facilitate RES integration? and What are possible cost-effective projects with a cross-border dimension that could be further assessed and proposed as priority projects in the CESEC framework?*

Each of these models looks at individual aspects of the energy system and together they provide a comprehensive analysis of the energy system-wide impacts of the uptake of RES. More specifically, the Green-X Model is used to determine the implications for RES deployment of different energy policy scenarios. The high level of detail of the model specifications allows for the understanding of the associated costs, expenditure and benefits corresponding to different scenarios of RES deployment. The European Power Market Model is a high-granularity model used to determine the cost-optimal combination of power generation plants and cross-border transmission capacity. Finally, the Consentec Transmission Grid Model is used to provide a detailed representation of the European transmission system. The high level of detail of the model specifications allows for determining the impacts that changes in power generation or demand have on grid expansion requirements, among others.

The last question - *What are the technical, regulatory and market issues that create barriers to cross-border cooperation and hinder renewables deployment?* - is addressed by a combination of literature review and expert interviews and surveys.

The analysis presented in this report reveals key insights that could guide the cost-effective uptake of RES projects with a cross-border dimension, in the CESEC region.

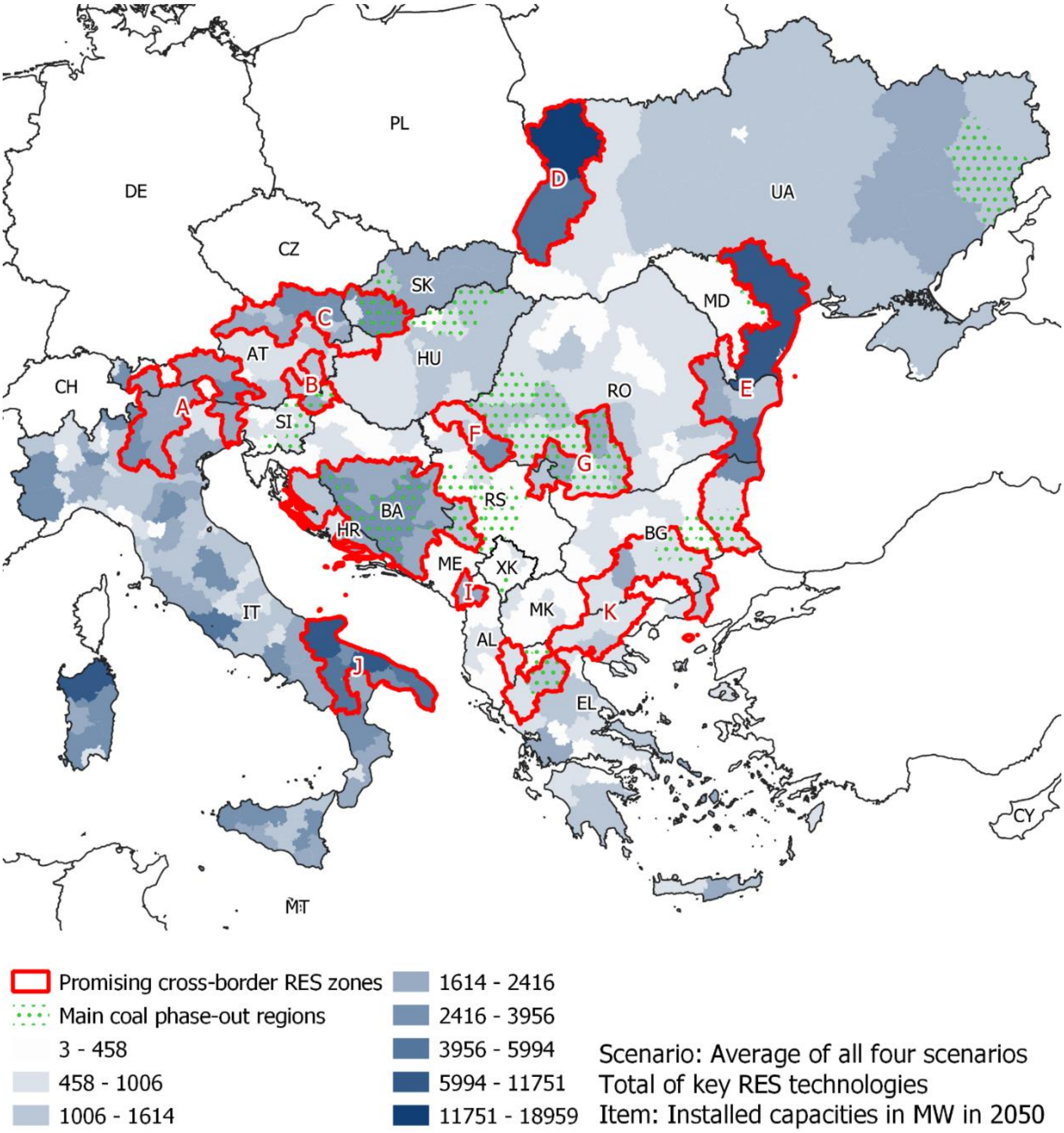
Keeping to the framework introduced by the four questions above, this report finds the following:

The CESEC region includes promising site locations for cost-effective solar PV and onshore wind close to internal borders.

Electricity from RES is expected to reach shares of either 49% or 53.1% in the CESEC electricity mix by 2030, depending on whether the reference NECP or the Green Deal targets are implemented. By 2050, the difference between the two scenarios is much more pronounced: electricity from RES is expected to reach either 75-77% or 85-87% of the regional electricity mix, in the reference of the Green Deal scenarios, respectively.

There is a systematic difference between the current deployment of RES in the EU Member States (MS) of the CESEC region, compared to the non-EU Member State counterparts: to reach the Green Deal targets, RES power generation in the EU Member States would need to slightly more than double, whereas, for the non-EU Member States, the increase should be at least four-fold. Power from photovoltaic systems – both centralised and decentralised – stands out as the largest contributors to the future energy mix. Onshore wind is a close second largest contributor. The most promising locations for offshore wind are close to some of the most promising locations for onshore wind. However, given the much more attractive economics for onshore wind and having land still available for wider deployment of onshore wind and PV, offshore wind becomes a relatively distant third most promising technology for the time being. Other RES are close to or have already reached their potential for cost-effective contribution.

Figure 0.1 <u>Mapping of identified promising cross-border RES zones</u> and overview on the mapping of the installed capacities of key RES technologies in total (incl. wind, solar, hydro) in the CESEC region by 2050, indicating averages across all scenarios (RefRES and HighRES, with and w/o cooperation).



For solar PV, promising site conditions are widely spread but specifically in the Southern parts of the CESEC region and of each respective country. Onshore wind energy offers promising site conditions in several CESEC countries. The site quality in Ukraine is remarkable, where according to the meteorological data at hand, similar conditions to onshore or even offshore developments in the North of Europe are applicable. Promising sites are also applicable in several parts of Italy, in Bosnia and Herzegovina, at the border of Austria, Hungary and Slovakia, at the North-Eastern border of Bulgaria, in Eastern parts of Romania and at several locations within Greece to name a few examples. Offshore wind offers promising site conditions in the Adriatic / Mediterranean Sea between Italy and Albania, at several locations within the Greek sea territory and in the Black sea area of Romania and Ukraine. There is however a strong competition to onshore wind which is available at comparatively similar site conditions but comes at present at significantly lower cost, specifically in the Black Sea area (within Ukraine).

Cross-border power trade and proactive cooperation in RES policy making has a large potential to contribute to the geographical smoothing of cost-effective electricity generation from RES: at the CESEC level, cost savings of 19% can be attributed to RES cooperation, facilitated by cross-border grid infrastructure. Albania, Bosnia and Herzegovina, Italy, Montenegro and Slovakia may offer promising RES potentials for export by 2030. In the long term to 2050, the picture partly changes: Bosnia and Herzegovina may again act as host country for the future RES uptake but other countries such as Greece, Moldova, Romania or Ukraine also join this group.

Currently planned projects for cross-border electricity infrastructure are critical both to prevent market congestion and to enable the integration of electricity from RES, but their impact is more clearly visible after 2030.

The currently planned infrastructure projects in the CESEC region – i.e. the projects in the TYNDP, PECI and the CESEC priority list - are critical in supporting the market integration of the identified RES projects. This is indicated by the price convergence of the CESEC power markets, where significant wholesale price reductions and even more sizeable reduction in price variance is observed. Depending on the assumed RES deployment, the projects contributing to RES integration show significant differences related to their location in the CESEC region and the target year when they become relevant.

Overall, the currently planned projects: reduce the need for curtailment of power generated by RES, support the integration of RES on the reserves market, address transmission grid bottlenecks and contribute to the reduction of CO_2. Currently planned projects are also necessary to reduce existing bottlenecks caused by reasons other than increasing RES generation. With the existing grid topology, congestions would occur at the West Balkan region, while with the realisation of the planned projects remaining congestions would be centred at the borders of Italy, Austria and Slovenia. Without the planned extensions, there are significant congestions in the system, reaching a critical level by 2050 at many borders.

The welfare analysis carried out on the planned and on the proposed new infrastructure projects shows, that the planned projects are beneficial from a socio-economic point of view. These socio-economic benefits are clearly positive in the high renewable deployment scenarios. With a lower level of RES deployment, infrastructure development costs might be higher than the economic benefits for a given period of time, between 2030 and 2050. This underlines the importance of iterative planning: infrastructure developments should follow the RES capacity developments to reach economically and socially optimal pathways. Therefore, a delay in any of these projects can result in significant market congestion or grid bottlenecks, among others.

Further electricity infrastructure projects provide only marginal benefits in terms of cost-effective RES integration.

The further expansion of the CESEC power grid, with new lines identified beyond the already planned projects, has a low effect on the wholesale electricity prices. This means that the proposed list of additional projects mainly serves RES integration objectives, as operationalised by minimising curtailment. These new projects include cross-border interconnections as well as internal lines, which underlines that import/export capabilities are not only dependent on the amount of cross-border transmission. The infrastructure projects identified to be beneficial in the considered scenarios are widely spread over the CESEC region. However, some of the countries (e.g. IT, BG, EL) are stronger affected than others.

One important caveat of the results of the modelling exercises concerning cross-border RES cooperation (cf. section 3.2) is that they are contingent on homogenous regulatory frameworks among the CESEC countries. However, the qualitative assessment of barriers to RES deployment as well as to cross-border infrastructure projects points to political and regulatory barriers as the most severe set of barriers. While the set of barriers differs per country, this observation is consistent across all CESEC countries. Financial and technical barriers are identified as somewhat less stringent, although this assessment varies per country. Overall, social and environmental barriers were ranked at the lower end of severity, although it is important to note that this also differed per country and per type of technology.

Conclusions and recommendations

The way forward towards meeting the three ambitions of increasing security of supply, enabling the modernisation of the energy system and increasing the deployment and trade of RES in the CESEC region relies on a coordinated approach to the individual challenges identified in this report. In practical terms, this translates to defining a transparent framework to prioritise RES projects with a cross-border dimension that are best positioned to achieve the highest and earliest aggregate benefits. An important overarching finding of this report is that identified projects listed in Table 4.11 are well-placed to enable the cross-border RES projects necessary to meet regional targets. The main policy implication of this finding is to ensure these projects are implemented on schedule. The recommendations included in this report (Chapter Six) address the entire set of identified barriers to the cost-effective integration of RES in the CESEC region. Across countries, political and regulatory barriers to cross-border RES are assessed as the most severe. These are followed by technical and financial barriers and, lastly, socio-economic and environmental barriers. This study provides an in-depth and comprehensive analysis of the electricity market, CO2 emissions and social welfare effects, among others, of the cost-effective integration of electricity from RES in the CESEC's regional – current and planned – electricity infrastructure. The recommendations derived from the study results aim to contribute to rigorous guidance of the process of decision making in forward-looking electricity system development within the CESEC region.

1 OBJECTIVE AND BACKGROUND

1.1 Objective of the study

The key objective of this study is to **identify the electricity infrastructure, regulatory and market needs facilitating RES integration in the CESEC region.**

The Central and South Eastern Europe energy connectivity (CESEC) cooperation can actively contribute to the European Union climate and energy targets for 2030, and to the transition toward a net-zero carbon economy by 2050[5]. To support the CESEC region, the European Commission initiated this study to:

1) **Identify the potential for the Renewable Energy Sources (RES) integration in the CESEC region**, based on the available technical and economic RES potential within the CESEC region, commercial interest, location of demand and the ability to replace existing fossil-based generation;

This resulted in a consolidated mapping, identifying the most prosperous regions to exploit renewable energy sources and current barriers to be overcome (Chapter 3);

2) **Identify the connecting infrastructure needs to ensure RES integration**, by:

Evaluating the contribution of CESEC priority electricity infrastructure projects to RES integration, assessing their implementation progress and identifying further connecting infrastructure project needs.

This resulted in a thorough analysis of infrastructural prerequisites to facilitate renewables integration in the electricity sector (Chapter 4);

3) **Identify possible renewable projects with a cross-border dimension** (e.g. wind farm and associated grid connection) that could be further assessed and proposed to be taken up in the CESEC framework in future

This resulted in a list of possible renewable cross-border projects (Chapter 3.2);

4) **Identify implementation challenges and barriers to RES deployment and cross-border cooperation**.

This resulted in the identification of challenges and barriers to RES deployment and cross border cooperation is the third pillar of this study (Chapter 5).

5) Draft **conclusions and recommendations** for policy action and regulatory changes for CESEC cooperation to foster renewable deployment in the CESEC region;

This resulted in several targeted conclusions and policy recommendations for future actions to overcome identified challenges and barriers (Chapter 6).

6) **Ensuring stakeholder engagement**, through the involvement of relevant stakeholders and experts within the region and at EU level, consolidating the results through a workshop and present results at CESEC Ministerial Conference.

This ensured that stakeholders could provide views and reactions to the draft in the stakeholder workshop and were interviewed on the challenges for implementation.

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5 The study was conducted prior to the publication of the Fit-for55- package. Assessments and developments were valued in that perspective.

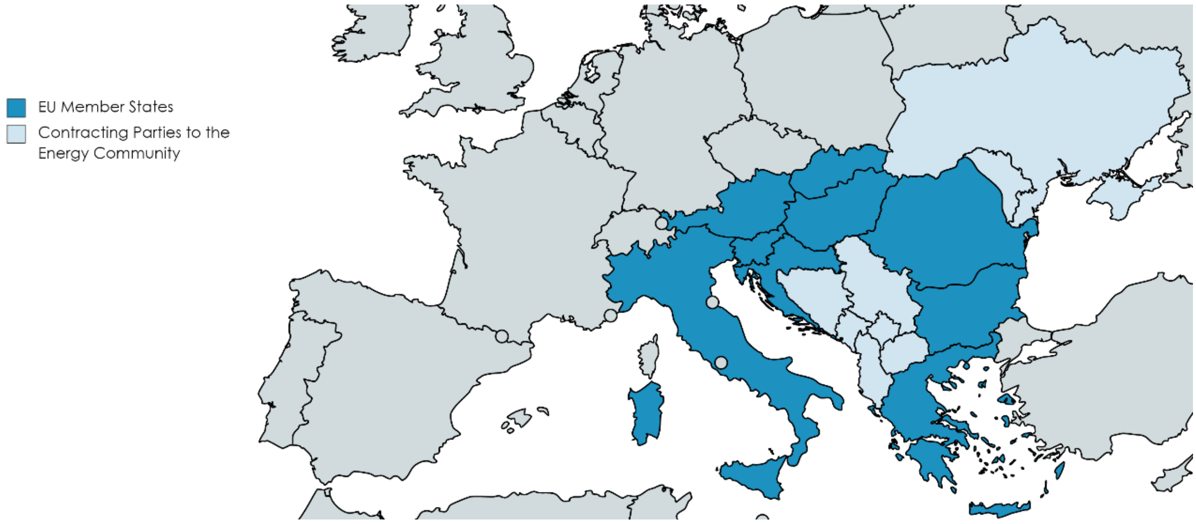
Ecorys has, together with TU Wien, REKK, Consentec, Fraunhofer and SQ Consult undertaken this study between December 2020 and October 2021, using literature review, modelling, data analysis, stakeholder involvement and interviews to come to the results in this study.

To achieve the objectives above, a thorough analysis was conducted on existing studies and data in the region and previous works of the consortium, including a cross-verification with relevant national data and various data sources. Moreover, assumptions and results were reflected and consolidated within the planned stakeholder engagement. In terms of geographical coverage, the study focuses on the CESEC countries.

1.2 Background

The region covered by the CESEC initiative is very heterogenous in terms of general economic development, as well as concerning energy supply and demand patterns, including the current use of renewable energy.

Figure 1.1 CESEC countries



Ensuring energy supply security has been a key issue of concern shared by Central and South Eastern European countries, which led to the creation of the CESEC initiative back in 2015. The region is characterised by a strong dependency on fossil fuel imports and has been exposed to cuts in gas supply in the past, indicating the potential vulnerability and impact of external disruptions. Most countries within the CESEC region have limited diversity in gas supply since long-term gas supply contracts from a single supplier had been of predominance. There is also a general lack of alternative gas supply sources, partly driven by the missing or inefficient use of interconnections within the region, and legacy transit regimes with legal and technical characteristics potentially resulting in market foreclosure (CESEC Countries, 2015).

Apart from fossil fuel import dependence, another pressing issue for various CESEC members is the need for modernisation of the energy sector since a large fraction of the existing fossil fuel-fired power plants have reached or are close to reaching the end of their operational lives. Again, also here the situation is diverse across the CESEC region: while for some CESEC members a reduction of fossil-fuelled production has been initiated, for other members these generation assets still represent the bulk of their generation capacity, increasing the challenge imposed. The need for modernisation goes well hand in hand with the need for decarbonisation. All these elements require the establishment of a sound transformation process of the energy sector over the next decade.

While mostly not explicitly part of the energy policy debate, the health impact of the energy sector is also a key challenge for the region. The combustion of fossil fuels causes poor air quality which is a real threat to the health of citizens in several CESEC countries. In this context, the European Environment Agency estimates that about 400,000 people die prematurely in Europe each year due to air pollution (EEA, 2019). South-Eastern European countries are amongst those with the highest levels of air pollution in cities and associated mortality rates in Europe (IQAir, 2020).

The socio-economic conditions of some CESEC members, with substantially lower levels of income per capita than the average of the European Union (IRENA, 2019) as well as higher levels of perceived investment risk, present barriers that need to be overcome to address the above-mentioned challenges while ensuring energy affordability for citizens and improving the countries' economic competitiveness.

Policy context

Several important elements prescribe the policy context-specific for the CESEC region and concerning the focal points of this project. A summary of these elements is provided below:

The CESEC Initiative – focusing on supply security and cooperation (on renewables) among its members

In September 2015, the Commission launched the Initiative on CESEC, initially focusing on gas policies, driven by concerns in supply security as discussed above (CESEC Countries, 2015). In 2017, a Memorandum of Understanding has been signed by CESEC members, which extends the cooperation to other areas, including renewable energy.

Integrated National Energy and Climate Plans – a key element for more strategic policy planning

In November 2015, the European Commission adopted its first Communication on the State of the Energy Union (EC, 2015), stating that integrated national energy and climate plans (NECPs), addressing all key dimensions of the Energy Union, are crucial tools for the implementation of the Energy Union Strategy and the development of more strategic energy and climate policy planning.

As part of this Communication, the European Commission published a Guidance to the EU Member States on integrated NECPs, which provided the basis for the EU Member States to initiate the preparation of national plans for the period 2021 to 2030. This document has also served to set out the main pillars of the corresponding governance process.

Similar to the European Union, the **Contracting Parties of the Energy Community** have committed themselves to launch monitoring and reporting in the areas of renewables, energy efficiency and greenhouse gas emissions as well as other climate-relevant information. Additionally, the Paris Agreement established an enhanced transparency framework for action and support with respect to climate change which as such defines the climate change-related reporting obligations for the period after 2020.

In this context, the Energy Community adopted a **Recommendation on preparing for the development of NECPs** addressing all key dimensions of the Energy Union by the Contracting Parties of the Energy Community (EnC, 2018). The Recommendation aims at building the analytical, institutional and regulatory preconditions for the development of integrated NECPs. This recommendation is not legally binding and therefore, it does not impose obligations on Contracting Parties, nor does it establish any formal deadline. However, as indicated in Article 5, the preparation of national plans should be an iterative and dynamic process launched in 2018. According to planning, draft NECPs should be submitted during the first quarter and finalised by the end of the year 2020. In reality, some further delays in that process are appearing for some Contracting Parties (CPs). The NECP process established at the EU level has already shown that it appears challenging for countries to complete their NECP on time, specifically if the process of public consultation is taken up seriously. Valuable lessons learned can then be gained from the review and consistency check within and across draft NECPs. The feedback provided by the European Commission (EC) has also helped the EU Member States in identifying options to increase their ambitions and improve the quality of their NECPs.

So far, Northern Macedonia has prepared an NECP and also other CPs, e.g. Serbia, started drafting an NECP (Balkan Green Energy News, 2021). Some of the contracting Parties have issued a National Emission Reduction Plan (NERP), which is required under the Large Combustion Plant Directive. Bosnia and Herzegovina, Ukraine, North Macedonia and Kosovo have issued such NERP. Other relevant policy initiatives are for example the Economic and Investment Plan for the Western Balkan that started in December 2020. This covers also the Green Agenda for the Western Balkans (EC, 2020b). In this Investment plan for example the Fierza hydropower plant in Albania will be rehabilitated through the Western Balkan Investment Framework (WBIF) and technical assistance will be provided to renewable energy sources in Bosnia and Herzegovina.

RES potentials in the CESEC region

In general terms, CESEC countries possess excellent resource conditions for increasing the use of renewables in the electricity sector. According to the recently published CESEC REmap study (IRENA, 2020) and as confirmed by other studies done at a subregional or national level (cf. section 3.1), the region has vast untapped potentials of *solar photovoltaics and onshore wind* – two key technologies for the transformation of the electricity sector. Previous IRENA analysis (IRENA et al., 2017) in the region had already estimated the current cost-competitive potential for renewable electricity generation in South-East Europe at about 130 GW. Moreover, the cost-competitive potential for renewable generation is expected to grow substantially towards 2030, driven by further reductions in technology costs and expected increases in carbon prices. A conservative estimate of the technical potential in the broader CESEC region amounts to about 800 GW and about 400 GW for onshore wind and solar PV respectively[6] (IRENA, 2020). Within the course of this project, a cross-check and verification of these figures was undertaken, based on literature and complementary model-based analyses. That aims for deriving a consolidated basis concerning the resource availability within the CESEC region. While only a fraction of that technical potential can be tapped cost-effectively within the forthcoming decade, these figures indicate that resource availability is not a limiting factor for accelerating the deployment of these renewable technologies within the region.

Apart from wind and solar, electricity generation from *biomass and biogas* can also be substantially increased within the region. IRENA estimates the long-term sustainable potential of bioenergy-based electricity supply at about 32 GW across the CESEC region. Moreover, bioenergy-based electricity supply serves here as an important asset for energy security since it can provide firm generation capacity in systems with high shares of variable renewables, similar to what is provided today by the use of fossil fuels. Furthermore, bioenergy can act as an enabler for tackling synergies between the power and the heat supply sector through the use of combined heat and power (CHP) systems to feed district heating networks, which are common in several parts of the region.

Hydropower is a mature renewable technology, already accounting for about a fifth of total electricity generation in the CESEC region. Most of the existing capacity was however installed decades ago. A substantial pipeline of additional hydro developments exists in several CESEC countries (Neubarth, 2018; KPMG, 2010; WBIF, 2019). Hydropower plants can serve as a key asset to the electricity system thanks to their commercial viability and since they may act as an enabler for cost-effective integration of (other) variable renewables like wind and solar photovoltaics. Hydropower may offer a large untapped technical potential within the region but the consideration of environmental constraints and social acceptance limits the realistic uptake within the

[6] For comparison, the cumulative installed capacity of all generation technologies in the CESEC region was about 274 GW in 2015.

forthcoming decade significantly. Refurbishment or upgrading of existing generation assets are therefore no-regrets options, complemented by new plants that comply well with European environmental protection regulations.

Infrastructure needs in the CESEC region

To provide solutions for all previously listed challenges in the CESEC region and, specifically, to foster renewable integration, significant infrastructure development is required in the coming decade both amongst the EU and non-EU countries. This demand for improved connectivity is well indicated by the number of projects proposed for the PCI, PECI (Projects of Energy Community Interest) and PMI (Projects of Mutual Interest) processes, as the NSI East electricity and gas region contains close to 30 project clusters in electricity and gas in the PMI list (C(2019) 7772 final, Annex). Energy Community countries proposed more than 25 projects for the PECI and PMI selection this year (ECS, 2021). These were cross-checked with other sources like the Energy Community Network development plan, and the relevant projects were included in the modelling (PCI grid). The wholesale price differences within the region are also among the highest in Europe, indicating significant bottlenecks in the cross-border electricity flows in the region mainly due to infrastructure constraints: For example, according to the latest ACER Market Monitoring Report (ACER-CEER, 2020), in 2019 the average of absolute price differentials was 8.8 €/MWh on the Slovakian-Hungarian border, in spite the coupled day-ahead markets, while AT-IT (11.4 €/MWh) and AT-HU (11.3 €/MWh) borders were in the top ten borders with the highest average day-ahead price differentials across Europe in 2019. Not only do the physical network constraints present bottlenecks for further market integration, but further improvements in capacity calculation methodologies for cross-border trade can also be achieved in the CESEC region. As the overall deployment level of variable renewable electricity sources (RES-E) is well below its potential and below the EU average in most countries, these constraints would become more severe if the targeted more ambitious RES-E deployment levels are achieved.

European policy initiatives may assist

At the European level, several policy initiatives may facilitate the uptake and integration of renewable energy within the CESEC region. Key pillars among these are:

The **Trans-European Networks for Energy (TEN-E) Regulation (No 347/2013)** aims to support a well-interconnected EU energy infrastructure, including links between Member States' electricity grids. This shall serve as an enabler for the integration of more renewable electricity, improve competition, market integration and supply security. The large number of electricity PCIs (C(2019) 7772 final, Annex) in the CESEC region highlights the need for additional infrastructure to address bottlenecks and integrate electricity from renewable energy. Furthermore, the Energy Community also identified several priority projects in the lists of PECI and of PMI (Decision D12018111/MG-EnC).

The **Connecting Europe Facility (CEF)** for the period 2021-2027 includes, as a new element, the support for cross-border cooperation in the field of renewable energy in addition to the support for projects of common interest under the TEN-E Regulation (C(2019) 7772 final; European Parliament, 2015). This could support renewable generation projects in the broader sense – i.e. including grid integration, storage and conversion facilities, involving joint projects with third countries as well as cooperation agreements between the EU Member States.

The **Western Balkan Investment Framework (WBIF)**. The WBIF provides financing and technical assistance to strategic investments in the energy, environment, social, transport, and digital infrastructure sectors. It also supports private sector development initiatives. It is a joint initiative of the EU, financial institutions, bilateral donors and the governments of the Western Balkans. Within energy, the WBIF has so far supported 52 projects in the fields of Energy Efficiency, Transmission & Distribution and Sustainable Hydropower (WBIF, 2021).

1.3 Structure of this report

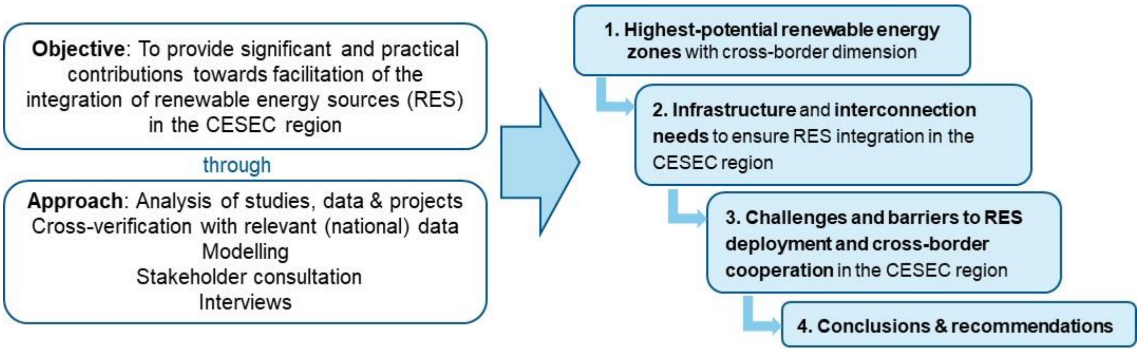
This final report summarises the work undertaken in the underlying study. In terms of structure, this first chapter explains the objectives and context. Subsequently, chapter 2 contains the methodology used. Chapter 3 comprises the outcomes of the assessment of RES potentials in the CESEC region) and subsequently the mapping of cross-border RES projects. In chapter 4 connecting infrastructure needs are identified to ensure RES integration. The results are presented from the modelling work concerning the RES uptake in CESEC and the related mapping exercise for identifying promising Cross-Border RES projects and the grid-related analysis. Chapter 5 presents the barriers and challenges for implementation based on research and interviews. Lastly, in Chapter 6 conclusions and recommendations can be found.

The annexes contain a list of key literature used (Annex 1), details on approach and assumptions used for a GIS-based analysis of wind and solar potentials (Annex 2), a recap on 2030 RES targets (Annex 3), a detailed list of identified promising cross-border RES zones (Annex 4), details on assumptions used in power sector modelling (Annex 5), and detailed modelling results of the power sector modelling (Annex 6).

2 METHODOLOGY

2.1 *Overall approach*

Figure 2.1 The overview of the study



For meeting the objectives, four complementary tasks (c.f. Figure 2.1) were conducted:

1. Identifying highest-potential RES zones with a cross-border dimension;
2. Identifying infrastructure and interconnection needs to ensure RES integration;
3. Identifying challenges and barriers to RES deployment and cross-border cooperation;
4. Deriving conclusions and recommendations, building on the analyses performed and complementary stakeholder consultation.

The underlying approach of each of these tasks is described in further detail within this chapter, cf. section 2.3 to 2.6. Apart from desk research, involving a literature survey and data gathering/processing, and a proactive stakeholder engagement, several key activities in this project required **key expertise in the area of modelling**. A brief recap of the correspondingly applied approach and the applied modelling suite is provided below, cf. section 2.2. Further details on the models used within the activities performed are provided in subsequence to that within the detailed task description. Moreover, please note that assumptions on key input parameters taken in power sector modelling are listed in Annex 5 to this report.

2.2 *Overview on modelling: activities and applied modelling suite*

Modelling activities for the identification of cross-border renewable energy projects and the identification of connecting infrastructure needs to ensure RES integration:

- An important prerequisite for the identification of cross-border renewable energy projects was to undertake a prospective analysis of future RES deployment by technology and country for the CESEC region;
- Complementary to that, the identification of connecting infrastructure needs to ensure RES integration was required. This implied identifying possible grid constraints that come along with the uptake of renewables under the current grid topology and by consideration of planned grid extensions. Based on the above, options for and benefits of further grid enhancements for a cost-effective RES integration were analysed.

These requirements could best be met by using specialised models that incorporate the specifics of the CESEC region. Models used needed to be ready for incorporating data inputs (as derived within this project) as well as for performing the modelling works collaboratively in a quick but sound manner (in order to perform the comprehensive list of activities well in time).

Overview of the applied modelling suite:

In accordance with the above, **the consortium made use of the consortiums' modelling capabilities** – more precisely, the consortiums' methodology centred around the use of three well-established models:

- TU Wien's **Green-X model**, a powerful model for assessing future RES deployment under different policy frameworks within Europe;
- REKK's **European Power Market Model (EPMM)**, a well-established tool for conducting power system analysis under the given geographical scope; and
- **Consentec's Transmission Grid Model (TGM)**, a toolbox that allows for detailed modelling of the transmission systems (and selected distribution systems) in the region of the European Network of Transmission System Operators for Electricity (ENTSO-E).

The models and their interplay are described below.

Characterisation of the Green-X model

Green-X is an energy system model, developed by TU Wien, that offers a detailed representation of the potentials and the related technologies of various RES in Europe and neighbouring countries, including all EU Member States and all Contracting Parties of the Energy Community. It aims at indicating the consequences of RES policy choices in a real-world energy policy context. The model simulates technology-specific RES deployment by country on a yearly basis, up to 2050, taking into account the impact of dedicated support schemes as well as economic and non-economic framework conditions (e.g. regulatory and societal constraints). Moreover, the model allows for an appropriate representation of financing conditions and the related impact on investor's risk. This, in turn, allows 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.

The Green-X model can build on a long track record of applications in studies conducted at the national, regional and European level. First uses at the EU level date back to 2004, e.g. the study "Analysis of the Renewable Energy Sources' evolution up to 2020 (FORRES 2020)" (Ragwitz et al., 2005), and since then the model has been applied in various European studies on renewable energies with distinct topical focusses, for example on assessing financing aspects (cf. "Financing Renewable Energy in the European Energy Market" (De Jager, 2011)) or on analysing future RES prospects by 2020, 2030 and beyond (c.f. "Dialogue on a RES policy framework for 2030 (Towards2030-Dialogue)" (Doukas et al., 2017) and "Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation (SET-Nav)" (Crespo et al., 2019)). Apart from research and consultation projects, model results have been documented in various scientific papers.[7]

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[7] Selected references of the Green-X model are:
Held Anne, Mario Ragwitz, Frank Sensfuß, Gustav Resch, Luis Olmos, Andrés Ramos, Michel Rivier (2018): "How can the renewables targets be reached cost-effectively? Policy options for the development of renewables and the transmission grid", Energy Policy 116 (2018) 112–126, https://doi.org/10.1016/j.enpol.2018.01.025.
Pablo del Río, Gustav Resch, Andre Ortner, Lukas Liebmann, Sebastian Busch, Christian Panzer: "A techno-economic analysis of EU renewable electricity policy pathways in 2030", Energy Policy 104 (2017), p. 484–493, http://dx.doi.org/10.1016/j.enpol.2017.01.028.
Resch Gustav, Gephart Malte, Steinhilber Simone, Klessmann Corinna, Del Rio Pablo, Ragwitz Mario

Characterisation of the European Power Market Model (EPMM)

The **European Power Market Model (EPMM**) is a unit commitment and economic dispatch model, which during the optimisation process satisfies the electricity consumption needs in the modelled countries at minimum system cost considering the different types of costs and capacity constraints of the available power plants and cross-border transmission capacities. The model minimises the production cost of power plants to satisfy demand. These costs include start-up and shut-down costs of the power plants, the costs of production (mainly fuel and CO_2 costs) and the costs which occur to RES producers in the form of curtailment. The model simultaneously optimises all 168 hours of a modelled week, and as a result, determines the hours of the week in which power plants operate and at what production level. The model is executed for each week of the given year, where all 8760 hours could be modelled. EPMM endogenously models 41 electricity markets in 38 countries across the ENTSO-E network. The model runs yield the optimal generation mixes and required number of power plant start-ups for the region.

Potentially missing production and the available upward and downward capacities for reserve services are also important outputs of the model. In the EPMM, each country represents one node, and network constraints inside the countries are not considered. Cross-border transmission capacities are represented by net transfer capacities (NTCs) values, which put an upper limit to cross-border electricity trading. In the EPMM perfect allocation of NTC capacities is assumed, taking into account historical NTC levels, which implicitly includes the information regarding former market couplings. This assumption is close to the allocation method in case of market coupling. Imports and exports take place to minimise system cost and maximise the security of supply. The model outputs include the Energy not Supplied (EnS) values, curtailment levels (both RES and nuclear) as well as reserve availability and its resulting costs levels and can be used to derive these results under various weather pattern scenarios.

The model and its predecessor (EEMM) was used in many studies, e.g. in the SEERMAP project (in combination with TU Wien's Green-X model) (Szabó et al., 2019), in the assessment of the EC project on the integration of Ukraine and Moldova to the European grid (Szabó et al., 2020), and also for the assessment of the TEN-E regulation (Support to the evaluation of Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure (DG ENER, 2021)).

Characterisation of the Consentec Transmission Grid Model (TGM)

The Consentec Transmission Grid Model (TGM) is a toolbox that allows for detailed modelling of the transmission systems (and selected distribution systems) in the ENTSO-E region. The transmission system model contains a detailed representation of the European transmission system (CESEC regions covered as far as belonging to synchronous area Continental Europe) on a nodal basis. TGM can be used to investigate impacts of changes in energy production and demand (as increased levels of RES deployment) in detail, regarding, for instance, line loading, grid expansion demand (optimising investment decisions) and related costs. Another important application of the TGM model is the calculation of network representations that can be used in electricity system models like EPMM. Due to computational constraints, a nodal network representation is not possible for such system optimisation tools. Instead, they have to rely on regionally differentiated models for capacity representation like the NTC or flow-based approach. Nevertheless, if input data for system optimisation tools are built in an intelligent manner from a high-resolution model which allows for a consideration of transit and loop flows and the dependency of grid expansion costs on operation points, a sufficiently high accuracy can be reached. TGM in this context has proven to be capable to provide highly accurate models for system optimization tools which among others include the dependence of distribution network costs on RES technologies and RES penetration, or the dependency of costs for transmission grid expansion on the topology

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(2013): "Coordination or harmonisation? Feasible pathways for a European RES strategy beyond 2020", in: Energy & Environment (Volume 24 No. 1 & 2 2013).

of the existing grids, non-linear dependency on operating points and exchanges between neighbouring systems. TGM was successfully applied together with various electricity-system models for that purpose and back testing with high-resolution network calculation methods (such as nodal load-flows) has proven the feasibility and accuracy of the modelling approach.

The model is currently used in several studies, e.g. "Scenarios for the transformation of the German energy systems" commissioned by a German ministry, "Risk of bidding-zone splits as a consequence of the EU's Clean Energy Package" commissioned by a European utility and investigations on the impact of new interconnections between France and Great Britain on the continental European transmission grid carried out for international investors.

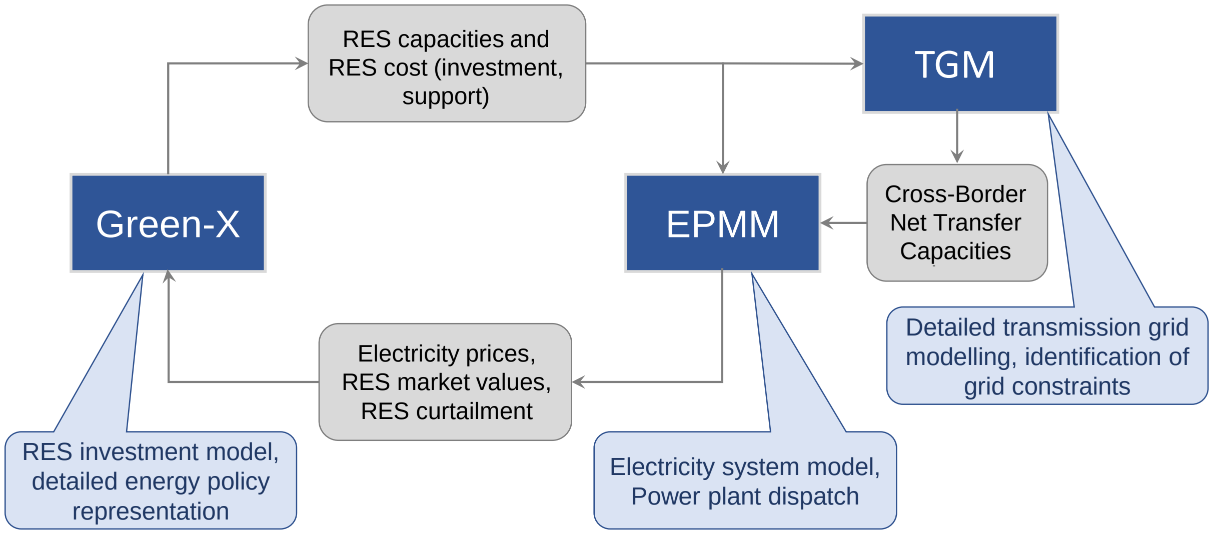
The combination of the three models

The combination of these models offers unique advantages while bearing negligible risks:

- Each of these models has been developed and is operated by members of the consortium and has been extensively used in similar studies, among others for the Energy Community Secretariat, the European Commission (DG ENER), the European Climate Foundation (ECF) and at the national level for various clients, including ministries, NGO's and the industry;
- All models have been tested and verified by various stakeholders within a broad set of past activities as briefly described above;
- The models have a sound geographical coverage of the whole CESEC region and they have been applied within various studies under a comparatively similar geographical scope;
- The models complement each other well thanks to their distinct topical scope, and they can be easily operated in conjunction. For example, the linkage between Green-X and EPMM has been proven within various projects, specifically within a geographical focus on South Eastern Europe.

Figure 2.2 illustrates the model coupling – i.e. the interplay between Green-X, EPMM and TGM. For assessing the interplay between the renewables uptake, the electricity market and the corresponding grid infrastructure, Green-X is complemented by its power-system companions – i.e. EPMM and TGM to shed further light on the interplay between supply, demand, storage and grid constraints in the electricity sector thanks to a higher intertemporal resolution than in the renewable energy investment model Green-X. TGM complements the detailed power sector analysis done by EPMM with a transmission grid analysis, providing grid typology specific endogenously calculated cross-border net transfer capacities. And results from the EPMM and TGM models are fed back to Green-X to update the Green-X model assumptions on electricity costs and prices as well as on RES curtailment at country level.

Figure 2.2 Model coupling between Green-X, EPMM a TGM for an assessment of RES developments in the electricity sector under distinct grid topologies



2.3 Methodology for identifying highest-potential RES zones with a cross-border dimension

The identification of the highest potential RES zones with a focus on projects that offer a cross-border dimension served as the starting element within this project, providing the basis for the further assessment undertaken within this study.

Approach for identifying highest-potential RES zones and cross-border RES projects

To identify the potential for RES integration in the CESEC region, a twofold approach was used:

- A detailed **analysis of applicable RES potentials in each of the CESEC countries was undertaken**, serving as input for subsequent energy modelling in the course of this study. The analysis of future RES potentials also serves as the basis for a mapping exercise dedicated to identifying the CESEC region areas with the highest and most cost-effective potential for renewable energy deployment. The available RE resources are acknowledged, as well as the commercial viability[8];
- Based on the above, future RES deployment was assessed up to 2030 and beyond (2050) using scenarios. This served to **identify possible "cross-border renewable energy projects**", comprising a combination of generation assets and associated grid connection with a cross-border impact.

Subsequently, the underlying approach of each of these two steps is explained in further detail.

8 The commercial viability was addressed in this study in a two-fold manner – i.e. on the one hand, by acknowledging land use constraints that reflect conflicts of commercial interest in the GIS-based analysis done for solar and wind, and, on the other hand, by modelling future RES deployment in accordance with country/region-specific policy needs.

Identification of the highest-potential renewable energy zones in the CESEC region per technology

Objective and approach

The aim was to **identify for the CESEC region the areas with the highest and most cost-effective potential for the development of renewable energy** ("renewable energy zones"), building on an assessment of energy resources and related costs and acknowledging the probability of development (including commercial interest).

To achieve this, a mapping exercise was launched for identifying the CESEC region areas with the highest and most cost-effective potential for renewable energy deployment, acknowledging the available RE resources as well as the commercial viability.

The RES-related analysis includes the following renewable electricity generation technologies:

- wind energy (on- and offshore);
- solar (rooftop and industrial scale);
- bioenergy;
- geothermal; and
- hydropower (run-of-river and storage).

All these technologies are relevant for the CESEC region under the given timeline (up to 2050), whereby large differences among the technologies in their availability across individual countries are indispensable as confirmed during this study.

Activities

To identify for the CESEC region the areas with the highest and most cost-effective potential for the development of renewable energy ("renewable energy zones"), the following activities were undertaken:

1. **Update/collection of information on future potentials of RES, including biomass feedstocks**
   The following key datasets served as the basis for the assessment of the resource base for investigated RES technologies:
   - TU Wien's **Green-X database**, containing verified assumptions on technology-specific RES potentials and related costs by CESEC countries, including financing cost, served as a starting point and solid basis for this assessment;
   - The **IRENA database**, specifically concerning solar and wind potentials (IRENA et al., 2017), building on GIS-based assessments for both key supply options, and for biomass where the recently published IRENA study "Renewable Energy Prospects for CESEC" (IRENA, 2020) contains data on sustainable biomass options for the CESEC region;
   - The **ENSPRESSO database of JRC**: an open data for the whole EU-27 and the Energy Community (EnC), comprising a comprehensive transparent and coherent database of wind, solar, biomass and hydropower energy potentials (Ruiz et al., 2019);
   - The **LOCATE - Territories and Low-Carbon Economy**: One objective of this project was the provision of an overview on the regional (NUTS-3) potential for generating and distributing renewable energy across Europe, broken down into wind power, photovoltaics, hydroelectric power, tidal power, geothermal energy, biomass and the renewable part of waste (Schremmer et al., 2018).

First, a comparison and cross-check of the available datasets was conducted to clarify the data used for further processing, specifically the mapping exercise that needs to be performed subsequently. Building on the datasets listed above as well as on other studies in that topical context, a comprehensive literature review on identified future potentials was undertaken, specifically for hydropower, geothermal energy and biomass (with emphasis on acknowledging environmental constraints). Then, a consolidated dataset on feasible RES potentials in the CESEC region was derived serving as a basis for subsequent modelling (cf. section 3.2).

2. **A mapping exercise to identify promising "renewable energy zones"**
   A mapping exercise has been conducted at a detailed geographical distribution (NUTS-3) to identify for the CESEC region "renewable energy zones", i.e. areas with the highest and most cost-effective potential for the development of renewable energy:
   - In practical terms, this implied undertaking a **GIS-based analysis for the processing of weather data,** specifically of relevance **for wind and solar**;
   - A comprehensive meteorological dataset on time-series of wind, solar irradiation, temperature etc. under a detailed geographical resolution was processed for past weather years, serving as a basis for identifying unconstrained resources potentials across the whole CESEC region, including adjacent marine areas;
   - As the next step within the GIS-based assessment, *spatial constraints* were incorporated that stem from competing land use, such as nature protection (e.g. by excluding Natura 2000 protected areas), urban, agriculture, military use or other purposes that limit the suitability for renewable power production and related grid deployment. Offshore wind is according to past experience less relevant for the CESEC region but recently gaining key policy attention at the European level[9]. Specifically, for offshore wind, competing uses of the sea (e.g. main shipping routes, nature protection areas and specifically tourism) were taken into consideration (i.e. by excluding related areas from the applicable resource base as a simplification[10]);
   - Other RES technologies like geothermal energy, biomass and hydropower were added to the mapping exercise, including in a more bottom-up manner site-specific information derived from the literature and stock-taking exercise conducted;
   - Complementary to the renewable resources, the GIS-based analysis also included a mapping of (transmission) grid infrastructure as well as of current and expected future demand centres, done in a more simplified and stylised way by processing population data and information on industry zones available at sub-regional level (NUTS-3). This allowed for the *identification of spatial opportunities* for "renewable energy zones", notably the availability of grid connection and local consumption opportunities;
   - Throughout the whole analysis, special attention was paid to RES potentials in coal regions thanks to possible benefits concerning available infrastructure, land, skills and industrial heritage already in place;
   - The results were presented to the CESEC working group, thus allowing them to provide feedback on the draft results.

3. **Mapping of existing RES generation facilities**
   As a first step, existing RES generation facilities were incorporated in the GIS-based mapping exercise.

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9 To ensure that offshore renewable energy can help reach the EU's ambitious energy and climate targets, the Commission published a dedicated EU strategy on offshore renewable energy COM(2020)741 on 19 November 2020 that assesses its potential contribution and proposes ways forward to support the long-term sustainable development of this sector.

10 The exclusion of such areas represents a simplification done within this study. Coexistence with other sea uses than energy is in reality possible as proven by past offshore wind developments in the North of Europe.

- For doing so, an up-to-date commercial data set was acquired (European wind farms database as of The Wind Power (2021)) on existing wind installations covering the whole European continent;
- Complementary to that, information derived from the database inventory undertaken (originally targeted towards future RES potentials) served as a basis for the mapping of the existing power plant stock for other generation assets[11], complemented by bottom-up desk research.

Methodology for the identification of potential cross-border RES projects

Objective and approach

The core objective was to **identify possible cost-effective "cross-border renewable energy projects" with a cross-border dimension** that could be further assessed and taken up in the CESEC framework.

Based on the outcomes of the mapping exercise concerning RES potentials in the CESEC region, a model-based assessment was undertaken of future RES deployment up to 2030 and beyond (2050). This was conducted based on scenarios for all countries and technologies that are included in this study. This model assessment served to identify possible "cross-border renewable energy projects", comprising a combination of generation assets and associated grid connection with a cross-border impact. For the identification of those projects, the principle was followed that each of those possible projects should in principle affect more than one country in the region and hence require a coordinated approach for implementation.

Activities

To identify the potential cross-border RES projects, the following steps were taken:

1. **(Model-based) Outlook of future RES deployment by 2030 and beyond (2050):**
   An important prerequisite for the identification of cross-border renewable energy projects was to undertake a prospective analysis of future RES deployment by technology and country for the CESEC region. The modelling capabilities of the well-established Green-X model were applied, a powerful model for assessing future RES deployment under different policy frameworks within Europe (cf. section 2.2), to derive distinct scenarios of future RES deployment in accordance with market prospects and policy needs. The scenario definition applied in this context and a recap on 2030 RES targets are both described below.

2. **Identification of cost-effective "cross-border renewable energy projects":**
   As a final step, possible cost-effective "cross-border renewable energy projects" were identified that possess a cross-border dimension to be further assessed and taken up in the CESEC framework. This was based on a quantification of the potential capacity for renewable integration in the region, and the contribution of each RES capacity identified to the 2030 energy (i.e. RES) and climate (i.e. greenhouse gas (GHG)) targets. In practical terms, the outcomes of the above-described modelling of future RES deployment were then transferred back into the mapping exercise of RES potentials.

[11] Specifically the ENSPRESSO database of JRC (Ruiz et al., 2019) provides useful information on the existing RES power plant stock within Europe.

Renewable Scenario definition

For the model-based assessment of 2030 and 2050 RES deployment in the electricity sector, the following scenario definition was used: in total, two pairs of RES deployment scenarios were quantified. One pair of scenarios with a moderate level concerning the future RES uptake in accordance with national planning), and another pair assuming a strong RES uptake in accordance with EU Green Deal needs. Furthermore, light was shed on the impact arising from cross-border RES cooperation. Details on the conception of the scenarios are provided below.

The first pair covers the Reference RES scenarios, where RES deployment follows national projections derived from (draft) NECPs or alternative energy and climate strategies[12] of the CESEC countries. These Reference RES scenarios have two sub-cases:

1. **Reference RES – no cross-border RES cooperation (RefRES–NoCoop):** in this scenario 2030 RES deployment is based on domestic fulfilments of targeted RES efforts. This means that in this scenario every country is assumed to aim for achieving its targeted RES share for 2030 (and beyond) primarily by generation capacities located in the country's territory;
2. **Reference RES – cross-border RES cooperation (RefRES-Coop):** The other scenario follows a region-wide, least-cost approach for meeting targeted RES shares within the CESEC region. Consequently, cross-border RES cooperation is assumed to be enhanced when this is economically beneficial.

The Reference RES scenarios indicate the feasibility of meeting the countries own targets for future RES deployment. More precisely, that scenario definition aims to align 2030 RES targets on National Energy and Climate Plans (NECPs) prepared by the EU Member States as well as corresponding documents (Draft NECPs) available for CPs of the Energy Community.[13] Details on the assumptions taken are provided in Table 2.1 below.

A comparison of the two sub-cases alone provided a quantified assessment of the cost savings stemming from cross-border cooperation in achieving targeted RES efforts. Moreover, higher constraints in cross-border grid infrastructure and probably higher RES integration impacts (curtailments, reserve requirements) was also considered within the analysis.

The second pair of scenarios assessed a higher level of RES deployment in the region, subsequently named as *High RES* scenarios. The targeted future RES efforts are based on the 2030 RES shares to be achieved if the EU climate ambition is strengthened ("EU Green Deal perspective"). Subsequently, a fair effort sharing across the Member States was calculated, expressing national contributions for the EU RES target in accordance with an approach for doing so as described in the EU Governance Directive[14] (Regulation 2018/1999). For the Contracting Parties of the Energy Community a similar approach

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[12] For all EU Member States of the CESEC region draft and final NECPs are available and formed the basis for targeted 2030 and 2040 RES deployment. Within the Energy Community a similar exercise has been launched but so far only for a limited set of Contracting Parties draft NECPs are available and, moreover, the overall process of establishing 2030 energy and climate targets is less advanced. In the absence of (draft) NECPs other documents or projections were used, reflecting national strategies or planning. Complementary to that also the National Renewable Energy Action Plans of the Contracting Parties of the Energy Community were used.

[13] As a consequence of non-availability of draft NECP data for CPs (with the exception of Northern Macedonia), reference trends derived in the "study on overall 2030 energy and climate targets for the Energy Community", conducted by TU Wien and REKK on behalf of the Energy Community Secretariat have served as alternative data source.

[14] The question arose how to distribute the increased overall RES effort at EU level across individual Member States. Annex II of the EU Governance Directive introduces for that purpose a methodology for establishing benchmarks concerning the national contributions for the RES share in gross final energy consumption in the 2030 context at EU level. This approach follows an integrated concept that takes into account the differences in economic development, the potential for cost-effective RES deployment and the interconnection level in the European Network of Transmission System Operators for Electricity (ENTSO-E) across the EU and its Member States, respectively.

was followed, building on the outcomes of TU Wien's recently (2019) completed "study on overall 2030 energy and climate targets for the Energy Community" done on behalf of the Energy Community Secretariat. A comparison was also undertaken to the recently published IRENA study "Renewable Energy Prospects for CESEC". Again, here two sub-cases were differentiated:

1. The first scenario assumes domestic fulfilment of targets (**HighRES–NoCoop**);
2. The second scenario assumes increased cross-border RES cooperation (**HighRES-Coop**), implying expectably higher RES deployment in the identified RES zones compared to the previous case.

Similar to the reference situation, the cost savings of more efficient RES deployment were quantified. This included elements such as lower costs of RES support, potential savings due to the more concentrated nature of grid access, and higher costs of RES integration in the RES zones, as a result of more concentrated development of electricity production from hydro, wind and PV.

An illustrative schematic overview of the applied scenario definition is provided by Figure 2.3 below whereas details on the country-specific assumptions taken for defining the targeted RES volumes in 2030 are given in Table 2.1 . Complementary information on 2030 RES targets, including a comparison of planned RES targets (in accordance with NECPs where applicable) with EU Green Deal needs, is provided in Annex 3 of this report.

Figure 2.3 Applied scenario definition (schematic)

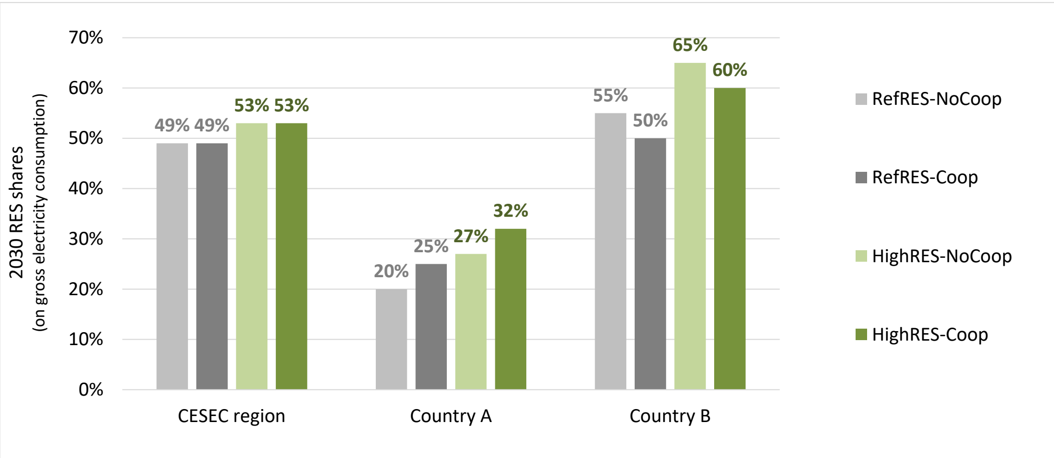


Table 2.1 Overview on 2030 targets for RES (as defined in NECPs) and for RES-E (NECP ambition and assumptions taken in modelling)

Overview on 2030 targets for RES and RES-E	RES share[1]	RES-E share[2]			
	NECP Target 2030	Ambition indicated in NECP	Ambition assumed in modelling		Status Quo 2019
Country			RefRES scenarios (National Planing)	HighRES scenarios (EU Green Deal Needs)	
Albania			99%	101%	88%
Austria	46%	92%	92%	97%	75%
Bosnia and Herzegovina			58%	62%	45%
Bulgaria	27%	30%	37%	39%	24%
Croatia	36%	64%	69%	73%	50%
Greece	35%	61%	71%	79%	31%
Hungary	21%	21%	24%	28%	10%
Italy	30%	55%	58%	62%	35%
Kosovo*			18%	21%	5%
Moldova			19%	19%	3%
Montenegro			62%	65%	53%
North Macedonia	38%	66%	32%	35%	24%
Romania	31%	49%	58%	61%	42%
Serbia			40%	43%	30%
Slovakia	19%	27%	29%	30%	22%
Slovenia	27%	43%	46%	49%	33%
Ukraine			16%	19%	2%
CESEC			ca. 49%	ca. 53%	32%

Note: 1 ... Share of renewable energies in gross final energy demand,
2 ... Share of electricity generation from renewables in gross electricity demand

2.4 *Methodology for identifying connecting infrastructure needs to ensure RES integration*

Objective and approach

The general approach was a quantitative, model-based assessment, where various power sector scenarios with varying levels of RES deployment are analysed under different grid topologies. It comprised a complex activity where the interplay of the three models used in this study was established and applied. These models were used in a coordinated manner as described in the methodology section (section 2.2).

The two pairs of RES deployment scenarios were further analysed under three grid topologies:

1. In step 1, the RES integration costs were assessed under a reference grid infrastructure setup, applying the Consentec transmission grid model (TGM) (cf. Section 2.2) only to the existing power network of the CESEC region, i.e. considering the grid topology of 2020 and reinforcement projects already under construction. TGM identifies the network constraints under these conditions. For that purpose, NTC values are quantified for the situations with the considered RES deployment, using 'smart' NTC calculations. These NTC values are then utilised in the EPMM market model (cf. section 2.2) to quantify further system-wide impacts (e.g. RES curtailment, changes in economic welfare, trade between countries, identifying constrained or heavily utilised cross-border lines and GHG emissions etc.);
2. In step 2, the grid topology was enhanced to the level of the present CESEC ambitions, including the planned cross-border infrastructure development projects in the region and quantifying the economic impacts of these developments similarly to step 1;

3. In the third step, a more sophisticated grid modelling takes place where, through a more iterative way, still missing cross-border infrastructure elements are identified with the grid model, exploring where missing cross-border elements can help to maximise the RES integration potential.

In total, this implied the analysis of 12 scenarios (i.e. 4 RES scenarios under 3 different grid topologies), which allowed for the modelling teams to map those infrastructure bottlenecks that could improve the conditions for further RES integration most cost-effectively.

TGM is in this study mainly used to prepare input data for transmission capacities between the market zones modelled by EPMM. As EPMM relies on the NTC approach for modelling cross-border capacities, NTC figures for EPMM are the main output of the TGM. In EPMM cross-border capacities are allocated to traders in an efficient and competitive way.

The calculation of NTCs is based on a flow-based capacity calculation according to the requirements of the electricity regulation (EU) 2019/943. This includes application of Power Transfer Distribution Factor (PTDF)-based thresholds for the selection of critical network elements and contingencies, application of the so-called "MinRAM" approach (ensuring minimum trading capacities) and consideration of dynamic Generation Shift Keys (GSKs) to model the impact of net position changes on the considered network elements. The capacity calculation delivers a flow-based domain based on a detailed representation of the transmission system in the region taking into account cross-border and internal critical network elements. As only some of the CESEC countries are part of the Core flow-based capacity calculation region, the calculated NTCs might differ from actual trading capacities in Core and non-Core countries. According to the characteristics of the 'smart' NTC approach (in particular that calculated NTCs are simultaneously feasible in the market), it is ensured that the NTCs for the non-Core countries are not overestimated while the trading capacities in the Core region are slightly reduced by that approach mainly in the distant target years compared to the flow-based capacities. For the considered time horizon until 2050, a uniform modelling for Core and non-Core countries was decided to be appropriate.

Within the calculation of the capacity model, specific GSKs are applied for high-RES situations reflecting the additional RES generation. This ensures that the capacity model used in the market modelling most accurately reflects grid loading with high levels of RES generation and, thus, can reveal regions within the grid that are most likely to become congested (differentiated between internal and cross-border elements) due to additional RES generation within the region.

In order to prepare a reasonable operation point, the results of the market model are transferred to the grid model with a resolution on connection point level applying the following approaches for the different types of results:

1. EPMM delivers the dispatch of conventional generation at the power plant level. Based on the information on the geographical location of the units (merged database of REKK and Consentec), the generation infeed for each power plant is assigned to the closest transmission grid node;
2. RES infeed is treated as a country-wise value in the EPMM. In order to derive grid node related RES generation infeed per country, the information on the gathered RES potential differentiated between RES technologies (regional resolution on NUTS-3 level) and the mapping of grid nodes to the respective NUTS-3 region are evaluated and transferred into relative distribution factors constituting the share of each node in the total RES infeed. By applying these factors, RES infeed per technology and node is calculated for each considered time stamp;
3. EPMM processes the demand on a country-/system-wide level. Yearly demand is an exogenous input for the EPMM and it reflects the latest available information based on data received during the PECI assessment process, data from final NECPs and local partners. The load curve is built up based on historical hourly

data for each country, and modified in the modelling as a result of demand-side management (DSM) and (pumped-)storage. To break down these aggregated demand figures into grid nodes, static distribution factors are used. The basis for such distribution is taken from initial work based on TYNDP data during the parametrisation of the transmission grid model and therefore represents a typical load scenario.

As mentioned before, the calculation of NTCs to be considered in EPMM are derived from the flow-based capacity domain based on the detailed representation of the European transmission grid. The initial run of the EPMM using approximated NTCs delivered the input to calculate the flow-based parameters for the selected representative time stamps.

This includes the following calculation steps:

1. The selection of relevant combinations of critical network elements and contingencies (CNECs) serves to determine the branches and the respective outage situations whose loadings are significantly affected by trade within the CESEC region. To find the relevant CNECs, a contingency analysis has been performed to determine the five most critical outages for each line in the CESEC region grid. Those CNECs that have at least one PTDF above 5% are specified as relevant and are included in the flow-based domain;
2. PTDF figures describing the flow impact on all relevant CNECs due to a change of the net position for each bidding zone of the CESEC region are highly independent of the load/generation situation but are almost exclusively driven by the grid topology. Thus, these figures are calculated using a grid use case out of the representative time stamps. To ensure that the PTDFs reflect realistic flow impacts for a reasonable range of net position changes, the underlying generation shift keys (GSKs) per bidding zone are calculated under consideration of the set point in each representative hour and an assumption of the range of net position changes to be covered. The set point is used to identify the current position of the dispatched generation in the merit order of the respective national generation system and the given range of net position changes specifies which generation units would be included in the assumed generation shift around the set point. Depending on the size of the bidding zones and the evaluation of the respective generation portfolios ranges of net position changes to be covered by the GSKs between 150 MW and 2,000 MW have been assumed;
3. To calculate transmission capacities on the CNECs to be offered to the market (remaining available margin, RAM), the flow shares on the CNECs caused by the trade within the CESEC region according to the results of the initial EPMM run have to be determined. This has been done by multiplying the net position share caused by the trade with the calculated PTDFs and deducting the determined trade flow from the total flow for each considered CNEC resulting in the so-called base flow. The impact of trade between CESEC and non-CESEC bidding zones is reflected as a contribution to the base flow and is therefore covered in the RAM figures. According to Regulation (EU) 2019/943 a so-called MinRAM of 70% has been modelled. This means that the RAM per CNEC is set to 70% of the technical transmission capacity in case that the calculated RAM figure is below this threshold. The value of 70% has been applied to cross-border lines. As quantitative grid analyses such as redispatch simulations are not in the scope of this study and aiming at a higher RES share without overestimating infrastructure needs, it is assumed that the existing redispatch potential is sufficient to ensure 70% MinRAM in the interconnectors.

The flow-based parameters have been calculated separately for each of the representative time stamps to cover seasonal and intraday fluctuations in the resulting NTCs applied in the exact EPMM runs.

All calculation steps for the determination of the flow-based parameters are based on a DC (direct current) load flow methodology, such that the impact of losses is not contained in the RAM figures. The DC approach is in line with the capacity calculation methodologies applied in the Core and CWE (Central Western Europe) capacity calculation regions. Furthermore, losses in the transmission grid constitute around 1-2 % of total generation. In comparison with the effects of other model assumptions, the impact of losses seems negligible.

The EPMM requires NTCs per border and direction as a description of grid constraints so that the calculated flow-based domain cannot be immediately applied. Thus, the flow-based parameters constitute the basis to derive NTCs that are included within the flow-based domain and are simultaneously feasible.

As that there is not one unique, but many sets of NTCs which are feasible with a given transmission system configuration described by the flow-based domain, the following approach to determine reasonable NTC sets have been applied:

The NTCs applied in the initial EPMM run take into account the expected changes due to the assumed realisation of grid reinforcement projects in the different target years. Not all combinations of these border and direction-specific NTCs are simultaneously feasible as usually only a subset of NTCs, in particular only on one direction per border, is used by the market in the considered scenarios (e.g. high demand combined with high RES infeed). Based on these considerations, the full usage only of those NTCs in the preferred market direction according to the results of the initial EPMM run has been simulated. A comparison of the resulting flows on the CNECs with their respective RAM allows for a validation whether the set of NTCs is inside the flow-based domain or causes overloading on internal or cross-border lines or both.

Taking into account which borders/directions are most valuable from a market perspective and to which extent the NTC usage affects the loading on the CNECs, the considered NTCs are scaled up or down using individual scaling factors until the loading on at least one CNEC reaches 100% RAM. For all further NTCs, the approximated values of the initial EPMM run remain unchanged (assuming that the NTCs opposite to the preferred market direction are not used in the exact EPMM runs). By that approach, the physical flexibility in the grid is adequately represented although the capacity model itself is only NTC-based and the final transfer capacities constitute a pattern of grid capabilities to increase transport of RES generation to demand centres of the CESEC region.

2.5 Methodology for the identification challenges and barriers to RES deployment and cross-border cooperation

Objective and approach

The objective was to identify and assess the multiple issues that create barriers to cross-border RES cooperation and hinder further deployment of renewables in the CESEC countries.

The overall methodology consisted of a combination of qualitative and quantitative approaches to systematise barriers, evaluating their severity and drawing action-oriented conclusions. First, an inventory of challenges and barriers that might obstruct the implementation of cross-border cooperation and infrastructure projects in the CESEC area was developed based on extensive literature review and stakeholder consultation. The proposed inventory covers a wide spectrum of challenges spanning different geographic scales. Next, a short online survey based on the inventory was drawn up, and sent to relevant stakeholders. In addition, selected stakeholders were contacted for video interviews to add further insights and elaborate on barriers. Based on the results collected via the survey and interviews, conclusions were derived, serving as inputs for the formulation of recommendations.

Activities

To identify and assess the implementation challenges and barriers to cross-border RES cooperation, the following activities were undertaken:

1. **Inventory of challenges**
   This activity aimed at providing a comprehensive overview of the challenges cross-border RES projects are faced with. A systematic form for the inventory was set up, which classifies challenges based on their type (regulatory, financial, technical, political, socio-economic and environmental). This step was based on extensive literature review and desk research, looking both into challenges to RES projects in general and cross-border (infrastructure) projects specifically. The systematic inventory of challenges can also be used to evaluate specific projects and get a sense of the particular challenges that they are faced with.
2. **Survey**
   The survey was designed using the inventory of challenges as main input and completed with a few general questions on assessment of the benefits of cross-border RES cooperation. The survey was then tested during a stakeholder workshop using an interactive, live format. Following this, the questions were refined. Respondents also had the opportunity to add additional barriers via open questions. The final survey was then distributed to relevant stakeholders from the region, including national experts/authorities, Transmission System Operators (TSOs), National Regulatory Authorities (NRAs), project promoters, NGOs and representatives of the Energy Community Secretariat. In the survey, participants were asked to assess the severity of barriers and also had the opportunity to add further relevant barriers and comments via open text fields.
3. **Complementary stakeholder interviews**
   To complement and validate the survey results, ten different stakeholders from six countries and one international organisation active in the wider region were interviewed to provide additional insights into barriers of cross-border RES cooperation and infrastructure projects. The selected countries represent an overlap of the countries with the highest potential areas for RES deployment and those countries where most future cross-border infrastructure projects were identified, according to the modelling. While the interviews do not aim at presenting a representative picture, they do provide relevant additional insights and help to validate and put the survey results into perspective.
4. The interviews were divided into two parts. In the first part, interviewees had the opportunity to elaborate on their perception of the identified connecting infrastructure projects and needs from the perspective of their country. In the second part, interviewees assessed the severity of barriers that cross-border cooperation is faced with. Interviewees were also asked to elaborate on their ranking of barriers, draw comparisons between barriers and add additional barriers that they are experiencing. This part essentially mirrored the structure of the survey but provided ample room for participants to elaborate on their evaluations This allowed for a comparison between different barriers and challenges facing projects. Since the interviews were mainly used to complement the survey results and add additional qualitative insights to the survey, the interview sample is not representative, which should be kept in mind when interpreting the results.

2.6 Methodology for stakeholder engagement

Objective and approach

The objective was to ensure the stakeholder's engagement and a positive impact of the study.

Stakeholder engagement is important to ensure that the results of the study are checked, verified, accepted and also being used. Corresponding activities were to collect information (interviews), to verify and check information (contact during the data collection and a stakeholder workshop) and to disseminate the results (stakeholder workshop and a presentation to the high-level CESEC).

This was done by having the inputs data and results checked and verified by relevant stakeholders in the region.

Stakeholders that were involved are national experts/authorities, TSOs, NRAs, ACER, project promoters, NGOs, and the Energy Community Secretariat. When engaging with stakeholders, the consortium complied with GDPR.

Table 2.2 Overview of stakeholder engagement

Type of stakeholder	Type of stakeholder engagement (interviews, data collection, data validation, exchange of data)
Energy Community Secretariat, Electricity market and renewables expert	Data validation, interviews
IRENA, ACER	Data exchange and validation.
National experts (ministries, regulators, etc.)	Data exchange, validation, interviews.
NGOs	Data exchange
TSOs and NRAs	Interviews with selected experts to understand bottlenecks and barriers for RES integration as well as RES developers about their experiences concerning grid access.
Project promoters of priority projects	Cross-checking results coincide with earlier projects.
TSOs/NRAs in the region	Interviews with selected experts to understand bottlenecks and barriers for RES integration.

Activities

The stakeholder engagement consisted of three main activities:

1. **Data exchange and collection**: continuous stakeholder engagement throughout the project to collect data and information;
2. **Verify**: the stakeholder workshop to verify and disseminate the preliminary findings; and
3. **Disseminate**: a stakeholder presentation to share the final results of the study.

The activities are described below.

1. Data exchange and data collection

The consortium liaised with the stakeholders (e.g. the European Commission and the Energy Community) to ensure that the latest available data was used in the models, literature review and analysis. This was done throughout the study.

Data was also collected during the stakeholder workshop through a survey (see the section on barriers and challenges).

Data was also collected during the interviews on the implementation barriers and challenges to be able to understand better the barriers and challenges and how to overcome them in cross-border cooperation in RES integration. The table above provides an overview of the stakeholders interviewed.

2. Verification of results

To ensure that the stakeholders were able to provide feedback on the preliminary results a stakeholder workshop was organised on 15 June 2021, from 9.30 until 12.30. 70 participants from CESEC participated. As the workshop was online, it enabled a larger group to participate than the initially foreseen 30 people.

During this workshop, the preliminary results of the study on electricity grid development and renewables were presented. Participants were able to provide feedback.
The following elements were presented:

- Highest-potential renewable energy zones per technology and possible cross-border renewable energy projects in the CESEC region;
- Potential grid bottlenecks, CESEC infrastructure priority projects and infrastructure and interconnection needs to ensure RES integration in the CESEC region;
- Challenges and barriers to RES deployment and cross-border cooperation in the CESEC region.

As a result of the workshop, the report has been adjusted in the following way:

- The reasoning for the needed infrastructure projects is better explained;
- The role of offshore wind energy is analysed in further detail;
- Potential storage for hydrogen/batteries is addressed as far as possible;
- Coal regions are more clearly addressed in the report (cf. the comparison of coal regions and identified cross-border RES zones in section 0);
- The results of the polling and feedback given were used for the challenges and barriers part of the study.

3. Awareness of study and dissemination of results

The consortium was involved in the following awareness and dissemination activities:

1. Presentation of the approach at the CESEC Electricity and Renewable Energy Plenary and Working Group of 11 February 2021. There were about 90 participants;
2. Presentation at the above-mentioned Stakeholder Workshop of 15 June 2021 where the members of the CESEC Electricity and Renewable Energy Plenary and Working Group were invited. 70 people participated;
3. Presentation at the 2022 CESEC Ministerial conference planned.

3 RES integration potential in the CESEC region

3.1 Results from the literature review of RES potentials in CESEC countries

This section is dedicated to informing on results of the literature review of RES potentials in CESEC countries, presented in technological order. Since several studies analysed reports on the potential only in energy terms, i.e. indicating the amount of electricity that can be generated annually, the subsequent overview on assessed future potentials follows that principle except for hydropower. For hydropower, the literature review also includes the potential electricity generation capacities. Subsections 0 to 0 present the results of the conducted literature review, whereas subsection 0 presents the results of the complementary GIS-based assessment for wind and PV, i.e. two key RES technologies for power generation within the CESEC region as well as at European and global scale.

The terminology used for expressing RES potentials is introduced in this paragraph. For each technology, two tables and one depiction are included. The first table shows country-specific potentials according to the respective study and, for comparison, existing installations in 2015 in the first column. The year 2015 was chosen due to the availability of verified statistical data for all assessed countries and technologies. The detailed literature overview on potentials distinguishes between economic- and technical potentials (as far as applicable from the corresponding study). Thereby, the economic potential is in general a subset of the technical potential where the cost required to generate electricity is less than the revenue available. Details on all cited reports can be found in the annex of this report. The second table respective to the discussed technology provides an overview of assessed RES potentials and their exploitation in the REMap study. It includes two scenario results of the REMap study (IRENA, 2020) for the year 2030 in the first two columns. This is followed by the minimum and maximum economic potential and the maximum technical potential of the respective studies shown in the first table (respective for each technology). In the third part, the second table includes the exploitation rate per technology of the REMap 2030 scenario in the year 2030. It shows the exploitation rate of the minimum and maximum economic potential and of the maximum technical potential. This puts the IRENA (2020) REMap scenario assumptions regarding available RES potential per technology and country into perspective, using different literature sources.

How the identified RES potentials of the literature review are used in the modelling is discussed in detail at the end of this chapter.

Hydropower

Hydropower is generally classified as a mature RE technology, already accounting for about one-fifth of the CESEC region's power generation (IRENA, 2020). The vast majority of existing generation assets was installed decades ago, however, several studies indicate a pipeline of additional hydropower projects under planning or consideration (e.g. Macdonald, 2017; Neubarth, 2018). In general, hydropower plants can be a key asset to the electricity system by providing cost-competitive power. Storage or pump-storage units may provide - additional benefits, acting as a flexibility provider to the power system and facilitating a cost-effective integration of variable renewables.

The literature survey confirms that the untapped technical potential for the technology within the CESEC region remains large. As indicated by IRENA (2020), the realistic potential for capacity expansion by 2030 can however be classified as much more limited once environmental and social acceptance constraints are considered. Several studies (Neubarth, 2018; IRENA et al., 2017, 2020) indicate that there is within certain countries room for further expansion while complying with strict sustainability standards and with European environmental protection regulations in place. This contradicts the outcomes of an assessment performed by NGO's EuroNatur/RiverWatch for South-East European (SEE) countries, applying an ecological feasibility assessment of the hydropower projects, based on a set of own criteria, and classifying 92% of these projects in exclusion zones.

According to Neubarth (2018), this implies that the further development of hydropower in the SEE region would de facto be limited to the refurbishment and upgrade of existing hydropower plants while hardly any new hydropower project would be realised. This perspective is as well confirmed by RiverWatch (2021). The respective database of planned hydropower plants outside protected areas in the SEE region adds up to just 711 MW as shown in .

Table 3.2 . Table 3.1 and .

Table 3.2 provide the country-specific hydropower potentials (in GWh and MW) according to the respective study, including the status quo (as of 2015[15]). Since none of the studies has covered the whole CESEC region, an overall figure at CESEC level could not be provided therein.

Table 3.1 Country-specific hydropower potentials and existing installations in 2015 (in GWh) according to the respective study

Indicator in GWh	Existing installations 2015	Economic potential				Technical potential				
Source	IRENA (2020)	DLR (2006)	HPD (2012)	IRENA et al. (2017)	Neubarth (2018)	DLR (2006)	HPD (2012)	IRENA et al. (2017)	Schremmer et al. (2018)	Neubarth (2018)
Albania	5,895	n.a.	11,700	12,929	13,200	n.a.	16,000	15,572	n.a.	15,600
Austria	37,057	56,000	53,200	n.a.	n.a.	56,000	56,000	n.a.	6,154	n.a.
Bosnia and Herzegovina	5,551	19,000	19,000	14,951	14,600	24,000	24,000	24,498	n.a.	24,500
Bulgaria	5,660	12,000	n.a.	10,411	8,600	15,000	14,800	13,353	5,880	13,400
Croatia	6,391	8,000	10,500	8,919	n.a.	9,000	12,000	8,500	6,351	n.a.
Greece	6,098	12,000	15,000	n.a.	12,000	15,000	20,000	n.a.	9,663	15,000
Hungary	234	4,000	n.a.	n.a.	n.a.	5,000	4,590	n.a.	7,192	n.a.
Italy	45,538	65,000	50,000	n.a.	n.a.	105,000	60,000	n.a.	15,998	n.a.
Kosovo*	140	n.a.	n.a.	781	n.a.	n.a.	n.a.	1,348	n.a.	n.a.
Moldova	50	n.a.	n.a.	50	n.a.	n.a.	n.a.	3,361	n.a.	n.a.
Montenegro	1,491	n.a.	n.a.	4,349	4,500	n.a.	n.a.	5,022	n.a.	6,600
North Macedonia	1,865	4,000	n.a.	4,311	3,700	6,000	5,500	4,006	n.a.	5,500
Romania	16,632	18,000	30,000	19,924	n.a.	36,000	40,000	38,000	16,721	n.a.
Serbia	10,081	27,000	15,000	14,537	14,500	27,000	17,600	18,000	n.a.	18,000
Slovakia	3,866	6,000	6,000	n.a.	n.a.	7,000	6,607	n.a.	3,221	n.a.
Slovenia	3,808	8,000	6,125	5,148	n.a.	9,000	8,800	16,261	2,068	n.a.
Ukraine	5,397	n.a.	16,500	19,511	n.a.	n.a.	21,500	21,500	n.a.	n.a.
CESEC	**155,754**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

Source: DLR, 2006; HPD, 2012; IRENA et al., 2017; IRENA, 2020; Neubarth, 2018; Schremmer et al., 2018.

Table 3.2 Country-specific hydropower potentials and existing installations in 2015 (in MW) according to the respective study or database

Indicator in MW	Existing installations in 2015	Existing installations 2020	Economic potential			Technical potential		Additional potential: planned outside protected areas (March 2021)
Source	IRENA (2020)	JRC (2020)	ECN (2004)	IRENA et al. (2017)	Neubarth (2018)	IRENA et al. (2017)	Neubarth (2018)	RiverWatch (2021)
Albania	1,798	2,039	1,437	3,967	3,900	6,611	4,800	63
Austria	13,351	13,558	11,300	n.a.	n.a.	n.a.	n.a.	n.a.
Bosnia and Herzegovina	2,055	2,000	1,219	4,565	4,200	6,110	6,100	n.a.
Bulgaria	2,206	2,921	1,401	3,867	4,000	9,022	9,000	105
Croatia	1,915	2,125	2,042	2,904	n.a.	3,035	n.a.	75
Greece	2,693	3,395	2,523	3,500	6,200	8,000	8,000	53
Hungary	57	48	48	n.a.	n.a.	n.a.	n.a.	n.a.
Italy	14,628	19,393	14,927	n.a.	n.a.	n.a.	n.a.	n.a.
Kosovo*	43	65	n.a.	180	n.a.	495	n.a.	n.a.
Moldova	16	n.a.	n.a.	16	n.a.	840	n.a.	n.a.
Montenegro	651	675	n.a.	1,947	2,000	2,040	2,700	5
North Macedonia	658	575	880	1,303	1,300	1,636	2,300	110
Romania	6,359	6,174	5,765	7,893	n.a.	15,385	n.a.	n.a.
Serbia	2,408	2,800	3,813	3,560	3,600	4,736	4,700	187
Slovakia	1,606	2,455	2,400	n.a.	n.a.	n.a.	n.a.	n.a.
Slovenia	1,115	1,239	847	1,568	n.a.	3,804	n.a.	115
Ukraine	4,697	n.a.	n.a.	10,276	n.a.	13,647	n.a.	n.a.
CESEC	**56,256**	**59,460**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

[15] 2015 has been chosen as base year of comparison due to the availability of verified statistical data for all assessed countries and technologies.

Source: ECN, 2004; IRENA et al., 2017; IRENA, 2020; JRC, 2020; Neubarth, 2018; RiverWatch, 2021.

Table 3.3 present the overview of the literature review conducted (in GWh and MW), indicating, the exploitation by 2030 according to analysed REMap scenarios (IRENA, 2020), and the range of indicated economic and technical potentials in accordance with the literature. A graphical illustration of the economic and technical potential for hydropower is shown in Figure 3.1 in energy terms, indicating the electricity generation potential by country in GWh, and in

Figure 3.2 , illustrating the corresponding capacity potentials in MW.

The REMap study (IRENA, 2020) indicates an increase of hydropower generation from 156 TWh (2015) to 179-187 TWh by 2030 or from 56,256 MW in 2015 to 65,128-67,156 MW by 2030. In summary, it can be concluded that at CESEC level these assessed REMap scenarios show deployment of hydropower plants in accordance with the economic (231-295 TWh or 60.8-77.4 GW) and technical potentials (385 TWh or 105.4 MW). Generally, the technical potential has been considered as the upper boundary for the hydropower uptake in modelling. In modelling that has however been further restricted via consideration of environmental constraints where such information was applicable (c.f. .

Table 3.2 , Additional potential: planned outside of protected areas (RiverWatch, 2021)).

Table 3.3 Overview of assessed hydropower potentials and exploitation in the REMap study (in GWh)

Indicator in GWh	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	8,235	8,214	11,700	13,200	16,000	62%	70%	51%
Austria	43,201	42,638	53,200	56,000	56,000	80%	76%	76%
Bosnia and Herzegovina	6,397	6,382	14,600	19,000	24,500	34%	44%	26%
Bulgaria	4,201	5,055	8,600	12,000	15,000	59%	42%	34%
Croatia	6,339	9,087	8,000	10,500	12,000	114%	87%	76%
Greece	5,559	6,911	12,000	15,000	20,000	58%	46%	35%
Hungary	227	240	4,000	4,000	7,192	6%	6%	3%
Italy	49,300	48,028	50,000	65,000	105,000	96%	74%	46%
Kosovo*	830	657	781	781	1,348	84%	84%	49%
Moldova	66	65	50	50	3,361	130%	130%	2%
Montenegro	2,217	2,314	4,349	4,500	6,600	53%	51%	35%
North Macedonia	2,500	2,473	3,700	4,311	6,000	67%	57%	41%
Romania	16,545	17,822	18,000	30,000	40,000	99%	59%	45%
Serbia	12,337	12,326	14,500	27,000	27,000	85%	46%	46%
Slovakia	4,822	4,736	6,000	6,000	7,000	79%	79%	68%
Slovenia	4,690	4,848	5,148	8,000	16,261	94%	61%	30%
Ukraine	11,500	15,028	16,500	19,511	21,500	91%	77%	70%
CESEC	**178,966**	**186,824**	**231,128**	**294,853**	**384,762**	**81%**	**63%**	**49%**

Source: IRENA, 2020; Own calculations.

Table 3.4 Overview of assessed hydropower potentials and exploitation in the REMap study (in MW)

Indicator in MW	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	2,150	2,150	1,437	3,967	6,611	54%	150%	33%
Austria	13,741	13,741	11,300	11,300	11,300	122%	122%	122%
Bosnia and Herzegovina	2,454	2,454	1,219	4,565	6,110	54%	201%	40%
Bulgaria	2,338	2,754	1,401	4,000	9,022	197%	69%	31%
Croatia	2,190	2,495	2,042	2,904	3,035	122%	86%	82%
Greece	3,579	3,579	2,523	6,200	8,000	142%	58%	45%
Hungary	57	60	48	48	48	125%	125%	125%
Italy	19,200	19,200	14,927	14,927	14,927	129%	129%	129%
Kosovo*	234	234	180	180	495	130%	130%	47%
Moldova	19	19	16	16	840	119%	119%	2%
Montenegro	781	823	1,947	2,000	2,700	42%	41%	30%
North Macedonia	824	824	880	1,303	2,300	94%	63%	36%
Romania	6,645	6,907	5,765	7,893	15,385	120%	88%	45%
Serbia	2,941	2,941	3,560	3,813	4,736	83%	77%	62%
Slovakia	1,755	1,755	2,400	2,400	2,400	73%	73%	73%
Slovenia	1,220	1,220	847	1,568	3,804	144%	78%	32%
Ukraine	5,000	6,000	10,276	10,276	13,647	58%	58%	44%
CESEC	**65,128**	**67,156**	**60,768**	**77,360**	**105,360**	**111%**	**87%**	**64%**

Source: IRENA, 2020; Own calculations.

Figure 3.1 Overview of assessed hydropower potentials in GWh

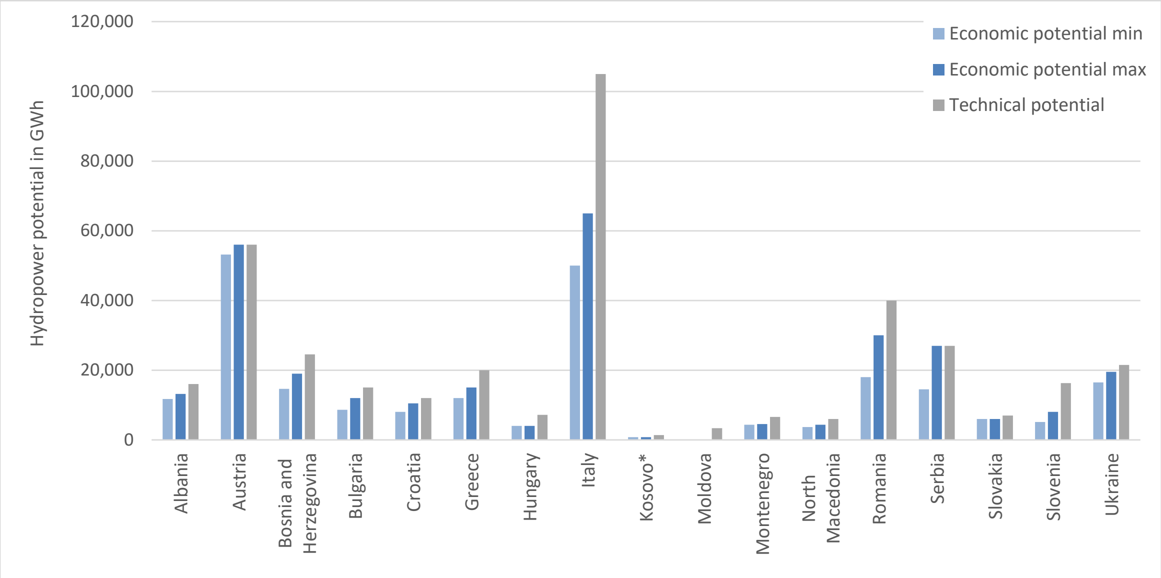
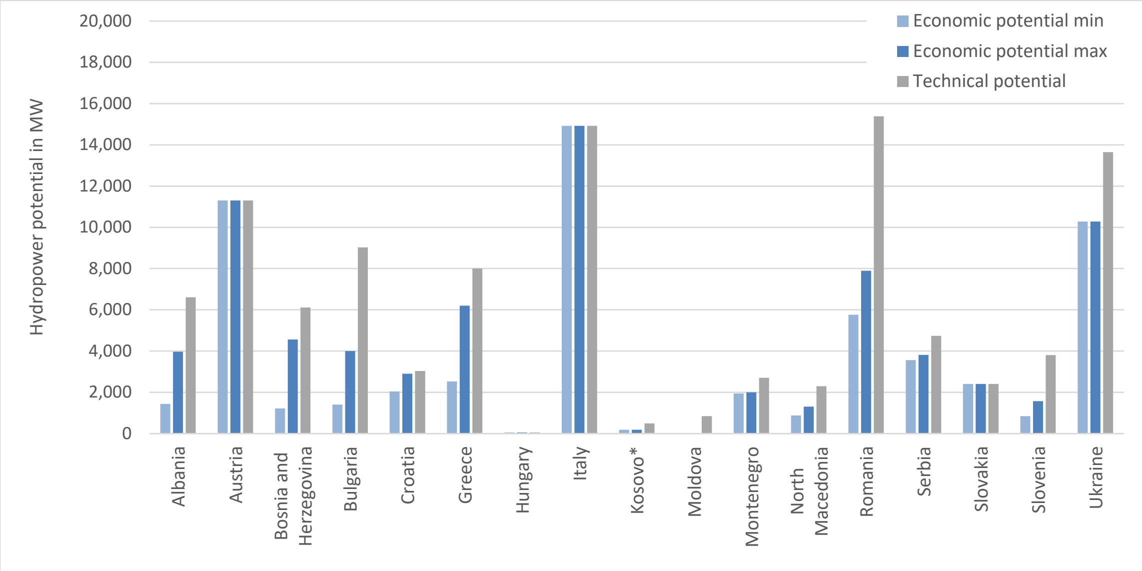


Figure 3.2 Overview of assessed hydropower potentials in MW



Bioenergy (incl. liquid and solid biomass, biogas, biowaste)

Bioenergy comprises a broad variety of feedstocks, including liquid and solid biomass as well as biogas and biowaste. It can be used as a fuel in thermal power plants for electricity generation or combined heat and power (CHP) production. Within the energy sector, bioenergy is however of dominance in heating & cooling, serving as fuel in classical stoves or modern biomass heating systems as well as for district heating. In the industry sector, it acts as a commonly applied fuel for example in pulp and paper production or for the wood processing industry. Liquid biofuels serve as fuel in transport especially when blending obligations requiring adding these to their fossil pendants (diesel and gasoline). The emphasis on using bioenergy in the electricity sector has declined in many countries across Europe, mainly driven by the strong cost decline of other renewable sources like photovoltaics (PV) and wind but also due to environmental considerations – due to the limits in resource availability and the growing competition between material uses and the use for energy purposes. For achieving carbon neutrality across the whole European economy many studies and experts claim that it may appear wise to use bioenergy there where mostly needed – i.e. in transport and industry (cf. SET-Nav study (Crespo et al., 2019)).

Within this potential assessment, both bioenergy feedstock and bioenergy electricity generation potentials within the CESEC region have been analysed. The technical potential has been considered for the modelling:

Bioenergy feedstock potentials: For the feedstock part verification of the assumptions on bioenergy feedstock potentials underlying the scenarios of the REMap study (IRENA, 2020) with the corresponding ENSPRESSO database of Ruiz et al. (2019) has been performed. The approach taken by IRENA for assessing bioenergy feedstock potentials appears solid and reflects well current practices to acknowledge sustainability concerns. A detailed description of that is provided in Annex D of the REMap CESEC study (IRENA, 2020). As applicable from Table 3.5 and Figure 3.3 in overall terms both datasets on bioenergy feedstock potentials match comparatively well – significant differences are however applicable for some South East-European countries like Ukraine, Moldova or Romania. Here the IRENA dataset appears however more reliable since JRC stated that for the Western Balkans (and most likely also other non-EU countries) the derived ENSPRESSO dataset has not yet been tested.

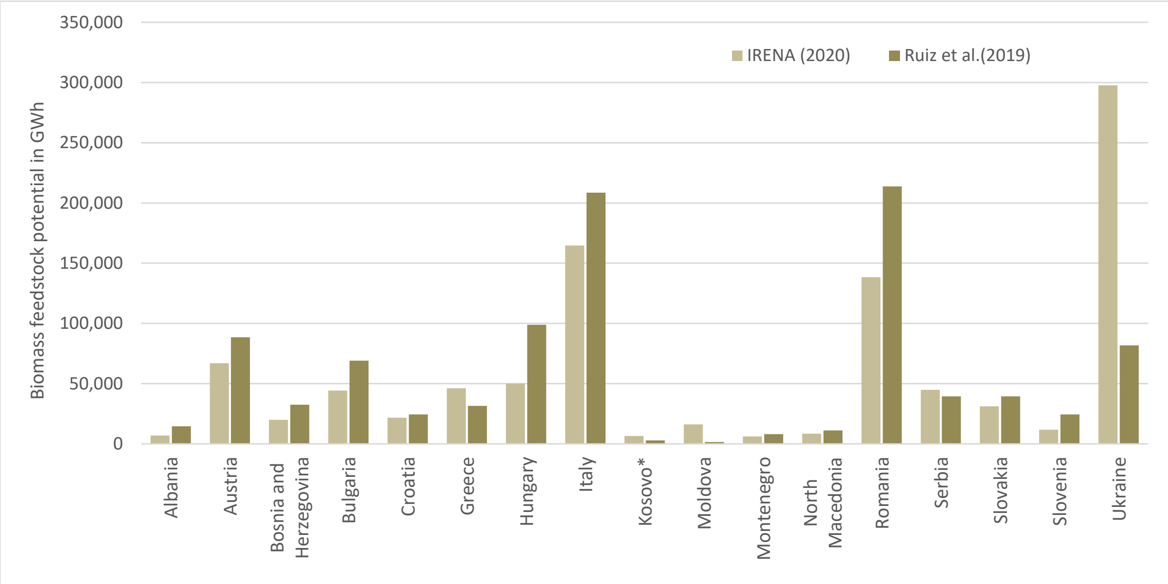
A brief recap on the approach used by IRENA: IRENA has conducted a bottom-up analysis of bioenergy potential in CESEC members based on the methodology originally established in IRENA for global bioenergy assessments (IRENA, 2014) and subsequently improved and applied to regional bioenergy potential assessments. The bioenergy potential for CESEC members was evaluated into three final bioenergy carriers: solid biomass, liquid biofuels and biogas, as listed in Table 3.5 .

Table 3.5 Overview of assessed bioenergy feedstock potential (in GWh)

Indicator in GWh	Liquid biofuels	Solid biomass	Biogas	Total	Total as of LOCATE Database	Total as of ENSPRESSO Database in 2020 Ref
Source	IRENA (2020)	IRENA (2020)	IRENA (2020)	IRENA (2020)	Schremmer et al. (2018)	Ruiz et al. (2019)
Albania	12	278	3,333	6,944	n.a.	14,490
Austria	6	60,000	5,278	66,944	91,275	88,532
Bosnia and Herzegovina	20	12,222	2,222	20,000	n.a.	32,509
Bulgaria	56	23,889	4,722	44,167	77,959	69,022
Croatia	22	13,333	2,222	21,667	27,458	24,353
Greece	104	10,278	6,944	46,111	67,818	31,545
Hungary	87	19,444	6,389	50,000	106,695	98,864
Italy	158	91,389	29,444	164,722	281,706	208,533
Kosovo*	9	1,944	1,944	6,389	n.a.	2,734
Moldova	38	3,889	1,667	16,111	n.a.	1,451
Montenegro	2	5,000	556	6,111	n.a.	8,049
North Macedonia	16	2,778	1,111	8,333	n.a.	11,046
Romania	186	71,667	15,000	138,333	280,303	213,728
Serbia	74	18,889	5,278	44,722	n.a.	39,346
Slovakia	34	19,444	2,222	31,111	28,206	39,429
Slovenia	2	10,000	1,111	11,667	23,118	24,409
Ukraine	603	100,278	30,000	297,778	n.a.	81,686
CESEC	**1,429**	**464,722**	**119,444**	**981,111**	**n.a.**	**989,725**

Source: IRENA, 2020; Ruiz et al., 2019; Schremmer et al., 2018.

Figure 3.3 Overview of assessed bioenergy feedstock potentials in GWh



- **Bioenergy electricity generation potentials:** Complementary to feedstock potentials also the electricity generation has been analysed in various studies, as listed in subsequence;
-
- Table 3.6 provides an overview of the assessment conducted, indicating the status quo (as of 2015[16]) a country-specific bioenergy electricity generation potential (in GWh). The exploitation by 2030 according to analysed REMap scenarios (IRENA, 2020), and the range of indicated economic and technical

[16] 2015 has been chosen as base year of comparison due to the availability of verified statistical data for all assessed countries and technologies.

potentials in accordance with literature are shown in Table 3.7 . Figure 3.4 complements the table with a graphical depiction of the economic and technical potential for electricity from bioenergy.

Table 3.6 Country-specific bioenergy electricity generation potentials and existing installations in 2015 (in GWh) according to the respective study

Indicator in GWh	Existing installations 2015	Economic potential				Technical potential
Source	IRENA (2020)	DLR (2006)	Heaps et al. (2009)	IRENA et al. (2017) Min	IRENA et al. (2017) Max	IRENA et al. (2017)
Albania	0	n.a.	n.a.	504	4,989	11,195
Austria	4,410	30,600	20,240	n.a.	n.a.	n.a.
Bosnia and Herzegovina	0	9,500	n.a.	180	5,470	6,220
Bulgaria	273	7,700	n.a.	400	6,000	6,290
Croatia	266	8,900	n.a.	340	3,721	5,743
Greece	230	7,200	8,840	n.a.	n.a.	n.a.
Hungary	2,161	11,300	13,020	n.a.	n.a.	n.a.
Italy	19,399	46,100	57,680	n.a.	n.a.	n.a.
Kosovo*	0	n.a.	n.a.	84	240	715
Moldova	15	n.a.	n.a.	161	4,825	5,388
Montenegro	0	n.a.	n.a.	50	425	686
North Macedonia	20	2,600	n.a.	24	166	310
Romania	525	40,900	n.a.	1,520	12,629	14,629
Serbia	24	14,300	n.a.	842	7,498	10,446
Slovakia	1,663	10,700	8,380	n.a.	n.a.	n.a.
Slovenia	266	6,300	4,180	84	1,320	1,420
Ukraine	145	n.a.	n.a.	10,277	10,278	78,389
CESEC	**29,397**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

Source: DLR, 2006; Heaps et al., 2009; IRENA et al., 2017; IRENA, 2020.

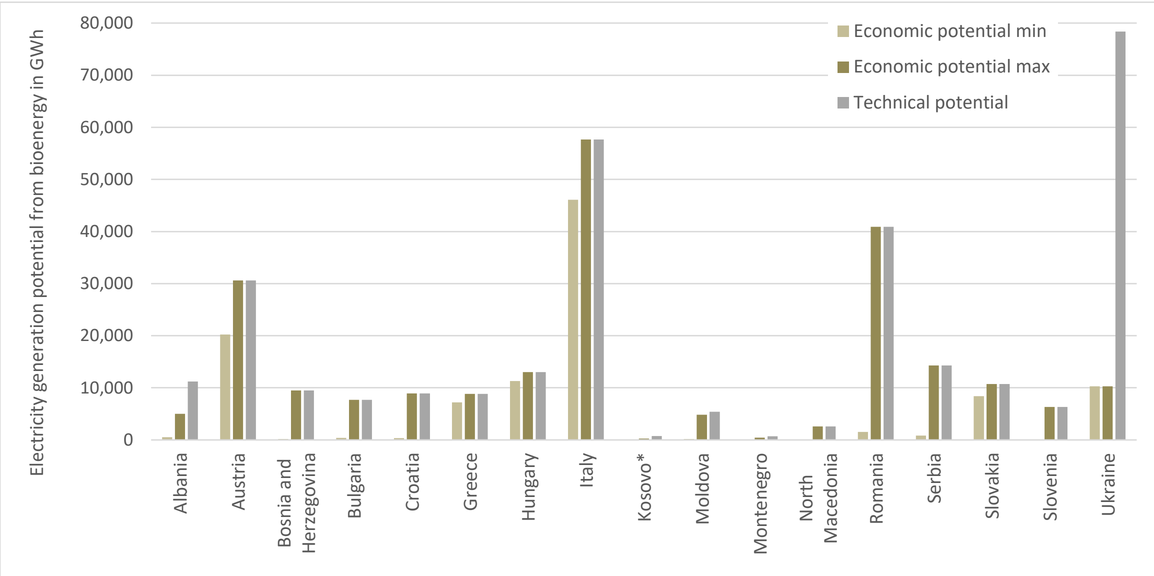
IRENA shows in their 2030 REMap prospects a broad range for the future evolution of electricity generation from bioenergy. While in the reference scenario a negligible increase from 29 TWh (2015) to 32 TWh by 2030 is indicated, 116 TWh are achieved at CESEC level in the so-called REMap scenario at the same point in time (cf. Table 3.7). The upper bandwidth is at CESEC level and for a limited number of countries above that what certain other studies (cf.Table 3.7) claim as being economic (i.e. the economic potential ranges from 108 to 232 TWh) but well below the reported technical potential (307 TWh, cf. Table 3.7). In general, the technical potential has been considered as the upper boundary for the feasible uptake of electricity generation from bioenergy for the modelling. As applicable from the modelling results (cf. section 3.2), the projected uptake of bioelectricity is modest and stays well below those limits.

Table 3.7 Overview of assessed bioenergy electricity generation potentials and exploitation in the REMap study (in GWh)

Indicator in GWh	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	299	495	504	4,989	11,195	10%	98%	4%
Austria	3,722	19,637	20,240	30,600	30,600	97%	64%	64%
Bosnia and Herzegovina	230	1,910	180	9,500	9,500	20%	1061%	20%
Bulgaria	503	5,614	400	7,700	7,700	1404%	73%	73%
Croatia	134	2,200	340	8,900	8,900	647%	25%	25%
Greece	652	5,088	7,200	8,840	8,840	71%	58%	58%
Hungary	1,665	6,943	11,300	13,020	13,020	61%	53%	53%
Italy	15,700	33,497	46,100	57,680	57,680	73%	58%	58%
Kosovo*	45	1,328	84	240	715	1581%	553%	186%
Moldova	129	1,656	161	4,825	5,388	1029%	34%	31%
Montenegro	500	542	50	425	686	1084%	128%	79%
North Macedonia	57	1,312	24	2,600	2,600	5467%	50%	50%
Romania	1,017	6,164	1,520	40,900	40,900	406%	15%	15%
Serbia	366	4,720	842	14,300	14,300	561%	33%	33%
Slovakia	2,660	2,659	8,380	10,700	10,700	32%	25%	25%
Slovenia	403	2,462	84	6,300	6,300	2931%	39%	39%
Ukraine	4,500	19,724	10,277	10,278	78,389	192%	192%	25%
CESEC	**32,582**	**115,951**	**107,686**	**231,797**	**307,413**	**108%**	**50%**	**38%**

Source: IRENA, 2020; Own calculations.

Figure 3.4 Overview of assessed bioenergy electricity generation potentials in GWh



Geothermal

The geothermal energy potential of the region is primarily characterised by a relatively low-enthalpy resource base, which is more appropriate for non-power applications. Only binary geothermal power plants[17], which allow cooler geothermal reservoirs to be used for electricity generation, are considered feasible options for generating electricity. Geothermal power plants could be deployed mainly in Bulgaria, Romania and to a lesser extent in Croatia and Slovenia, while in the rest of the CESEC region, the geothermal electricity potential is often marginal and uncertain.

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[17] A binary geothermal power plants does not allow a steam phase to separate, so carbon dioxide and the other gases remain in solution and are re-injected into the reservoir, without discharging to the atmosphere.

Table 3.8 provides an overview of the literature review conducted, indicating the status quo (as of 2015[18]) and the country-specific geothermal electricity generation potentials (in GWh). Table 3.9 adds the exploitation by 2030 according to analysed REMap scenarios (IRENA, 2020), and the range of indicated economic and technical potentials for geothermal electricity in accordance with the literature. Figure 3.5 complements the table with a graphical depiction of the economic and technical potential for geothermal electricity.

The comparison shows that 2030 prospects for geothermal electricity as derived reported in IRENA (2020) are conservative: At CESEC level only a comparatively small increase from 6 TWh (2015) to 8 TWh by 2030 is shown in the REMap scenarios (IRENA, 2020). This is below identified economic (32.0-97.9 TWh) and well below the reported technical potentials (98.2 TWh). The technical potential has been considered as the upper limit for future geothermal electricity generation in the modelling – but similar to bioenergy that potential will hardly be exploited under the proclaimed least-cost uptake of renewables (cf. section 3.2).

Table 3.8 Country-specific geothermal electricity generation potentials and existing installations in 2015 (in GWh) according to the respective study

Indicator in GWh	Existing installations 2015	Economic potential			Technical potential
Source	IRENA (2020)	DLR (2006)	IRENA et al. (2017) Min	IRENA et al. (2017) Max	IRENA et al. (2017)
Albania	0	n.a.	0	10	10
Austria	0	4,100	n.a.	n.a.	n.a.
Bosnia and Herzegovina	0	n.a.	0	50	50
Bulgaria	0	800	0	1,400	1,400
Croatia	0	1,100	0	450	450
Greece	0	9,400	n.a.	n.a.	n.a.
Hungary	0	51,900	1,392	51,900	n.a.
Italy	6,185	19,600	14,034	19,600	n.a.
Kosovo*	0	n.a.	0	0	n.a.
Moldova	0	n.a.	0	0	n.a.
Montenegro	0	n.a.	0	10	10
North Macedonia	0	n.a.	0	70	70
Romania	0	1,000	0	2,500	2,800
Serbia	0	4,100	0	70	70
Slovakia	0	3,100	n.a.	n.a.	n.a.
Slovenia	0	400	0	540	540
Ukraine	0	n.a.	0	0	n.a.
CESEC	**6,185**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

Source: DLR, 2006; IRENA et al., 2017; IRENA, 2020.

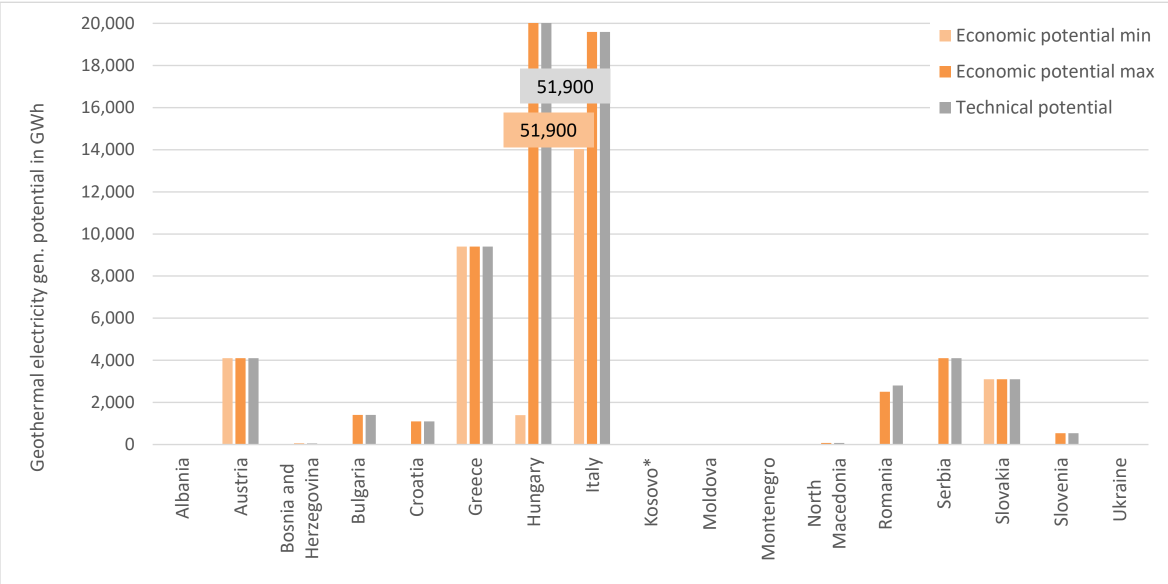
[18] 2015 has been chosen as base year of comparison due to the availability of verified statistical data for all assessed countries and technologies.

Table 3.9 Overview of assessed geothermal electricity potentials and exploitation in the REMap study (in GWh)

Indicator in GWh	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	0	0	0	10	10	0%	0%	0%
Austria	11	11	4,100	4,100	4,100	0%	0%	0%
Bosnia and Herzegovina	0	0	0	50	50	0%	0%	0%
Bulgaria	0	0	0	1,400	1,400	0%	0%	0%
Croatia	0	0	0	1,100	1,100	0%	0%	0%
Greece	0	0	9,400	9,400	9,400	0%	0%	0%
Hungary	65	65	1,392	51,900	51,900	5%	0%	0%
Italy	7,100	7,100	14,034	19,600	19,600	51%	36%	36%
Kosovo*	0	0	0	0	0	0%	0%	0%
Moldova	0	0	0	0	0	0%	0%	0%
Montenegro	0	0	0	10	10	0%	0%	0%
North Macedonia	19	19	0	70	70	0%	27%	27%
Romania	0	0	0	2,500	2,800	0%	0%	0%
Serbia	35	35	0	4,100	4,100	0%	1%	1%
Slovakia	30	30	3,100	3,100	3,100	1%	1%	1%
Slovenia	0	0	0	540	540	0%	0%	0%
Ukraine	700	700	0	0	0	0%	0%	0%
CESEC	**7,960**	**7,960**	**32,026**	**97,880**	**98,180**	**25%**	**8%**	**8%**

Source: IRENA, 2020; Own calculations.

Figure 3.5 Overview on assessed geothermal electricity potentials in GWh



Photovoltaics (PV)

According to several studies analysed, the CESEC region offers a significant potential for photovoltaics which may act as a key enabler for the transformation of the power sector. IRENA's assessment of potentials for the SEE region (IRENA et al., 2017) has estimated the current cost-competitive potential for renewable power in South-East Europe at about 130 GW. According to their latest study on the CESEC region (IRENA, 2020), the cost-competitive potential for renewable generation is supposed to grow substantially towards 2030, driven by further reductions in technology costs.

Table 3.10 offers an overview of the assessment on electricity generation potentials for PV, indicating the status quo (as of 2015[19]) and the country-specific PV electricity generation potentials (in GWh). Table 3.11 provides the exploitation by 2030 according to analysed REMap scenarios (IRENA, 2020), and the range of indicated economic and

[19] 2015 has been chosen as base year of comparison due to the availability of verified statistical data for all assessed countries and technologies.

technical potentials for PV electricity according to literature. Figure 3.6 complements the table with a graphical depiction of the economic and technical potential for PV electricity.

The comparison shows that 2030 prospects for PV electricity as derived reported in IRENA (2020) are within the range of classified being economic. At CESEC level a substantial increase from 33 TWh (2015) to 105-167 TWh by 2030 is indicated by the REMap scenarios (IRENA, 2020). The low figure is below and the high figure is within the range of identified economic (102-185 TWh) and well below the reported technical potentials (457 TWh) according to literature. PV appears of key relevance for the decarbonisation of the electricity sector within the CESEC region. For that purpose, complementary to the literature survey, an own GIS-based analysis of the technical potential for decentral and large-scale central PV systems has been conducted in the course of this study. The outcomes of that analysis have served as the basis for the subsequent modelling and are compared to the literature survey (as well as the modelled 2050 RES deployment) in subsequence, cf. section 0.

Table 3.10 Country-specific PV electricity generation potentials and existing installations in 2015 (in GWh) according to the respective study

Indicator in GWh	Existing installations 2015	Economic potential			Technical potential	
Source	IRENA (2020)	DLR (2006)	IRENA et al. (2017) Min	IRENA et al. (2017) Max	IRENA et al. (2017)	Schremmer et al. (2018)
Albania	0	n.a.	3,696	3,706	3,706	n.a.
Austria	937	2,900	n.a.	n.a.	n.a.	15,022
Bosnia and Herzegovina	0	600	4,135	4,135	4,135	n.a.
Bulgaria	1,383	2,000	10,130	10,130	10,130	19,399
Croatia	57	800	4,355	4,356	4,356	21,863
Greece	3,900	3,900	n.a.	n.a.	n.a.	21,219
Hungary	122	2,000	n.a.	n.a.	n.a.	31,447
Italy	22,943	17,600	n.a.	n.a.	n.a.	153,327
Kosovo*	0	n.a.	835	835	835	n.a.
Moldova	1	n.a.	6,044	6,044	6,044	n.a.
Montenegro	0	n.a.	1,076	1,076	1,076	331
North Macedonia	22	600	2,226	2,226	2,226	n.a.
Romania	1,982	2,000	24,743	25,806	25,806	71,539
Serbia	10	1,000	8,536	9,308	9,308	n.a.
Slovakia	506	2,000	n.a.	n.a.	n.a.	4,897
Slovenia	274	1,000	447	448	448	2,160
Ukraine	477	n.a.	54,948	88,340	88,340	n.a.
CESEC	**32,614**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

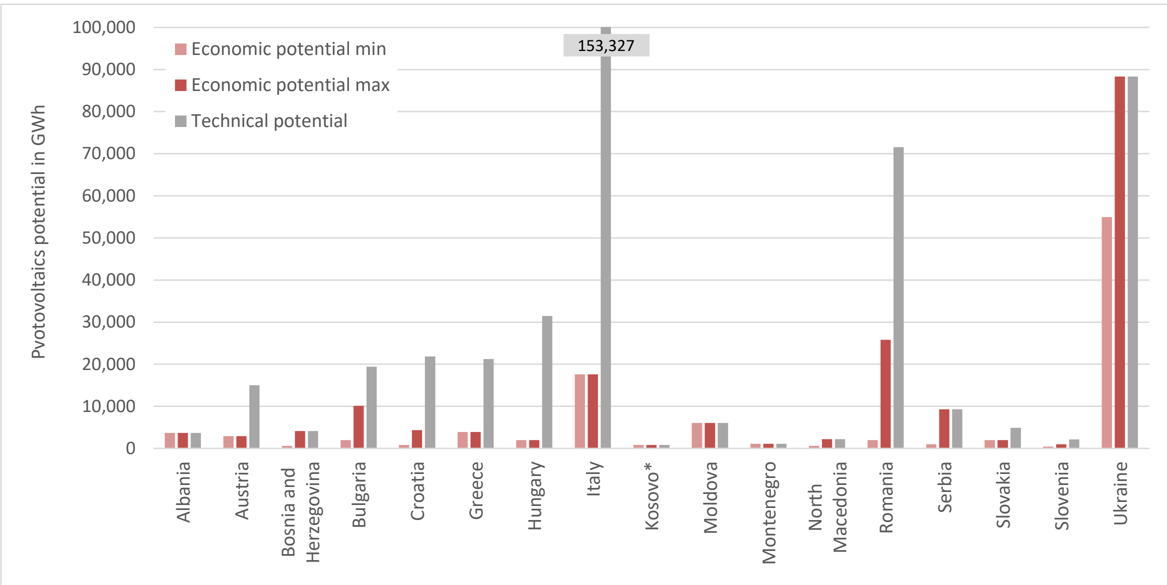
Source: DLR, 2006; IRENA et al., 2017; IRENA, 2020; Schremmer et al., 2018.

Table 3.11 Overview of assessed PV electricity potentials and exploitation in the REMap study (in GWh)

Indicator in GWh	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	192	1,697	3,696	3,706	3,706	46%	46%	46%
Austria	3,245	12,711	2,900	2,900	15,022	438%	438%	85%
Bosnia and Herzegovina	20	1,811	600	4,135	4,135	44%	302%	44%
Bulgaria	2,802	7,110	2,000	10,130	19,399	356%	70%	37%
Croatia	517	2,851	800	4,356	21,863	356%	65%	13%
Greece	9,396	14,188	3,900	3,900	21,219	364%	364%	67%
Hungary	92	5,932	2,000	2,000	31,447	297%	297%	19%
Italy	71,948	79,665	17,600	17,600	153,327	453%	453%	52%
Kosovo*	62	1,102	835	835	835	132%	132%	132%
Moldova	57	1,098	6,044	6,044	6,044	18%	18%	18%
Montenegro	52	447	1,076	1,076	1,076	42%	42%	42%
North Macedonia	144	1,646	600	2,226	2,226	274%	74%	74%
Romania	2,767	9,602	2,000	25,806	71,539	480%	37%	13%
Serbia	256	4,778	1,000	9,308	9,308	478%	51%	51%
Slovakia	750	2,588	2,000	2,000	4,897	129%	129%	53%
Slovenia	762	1,459	447	1,000	2,160	326%	146%	68%
Ukraine	11,800	18,258	54,948	88,340	88,340	33%	21%	21%
CESEC	**104,862**	**166,943**	**102,446**	**185,362**	**456,543**	**163%**	**90%**	**37%**

Source: IRENA, 2020; Own calculations.

Figure 3.6 Overview of assessed PV electricity potentials in GWh



Wind energy (onshore)

According to IRENA (2020), the region possesses a vast untapped potential for both solar PV and onshore wind, two key technologies for decarbonising the electricity sector. This perception is confirmed by the literature survey on corresponding potentials.

Table 3.12 offers country-specific wind onshore electricity generation potentials and indicating the status quo (as of 2015[20]). When comparing the two older literature sources (DLR, 2006; ECN, 2010) to the newer one (IRENA et al., 2017), an increase in the wind potential becomes obvious for Bulgaria, Romania and Slovenia. These are the only three countries covered by all literature sources. The reason for this increase in wind potential is caused by technical learning effects. Nowadays, taller and more powerful wind turbines can utilize a greater part of the theoretical wind power potential. Table 3.13 provides the exploitation by 2030 according to analysed REMap scenarios (IRENA, 2020), and the

[20] 2015 has been chosen as base year of comparison due to the availability of verified statistical data for all assessed countries and technologies.

range of indicated economic and technical potentials for onshore wind in accordance with the literature. Complementary to above, Figure 3.7 shows the economic and technical potential for wind onshore.

The comparison shows that 2030 prospects for onshore wind as reported in IRENA (2020) are within the range of classified being economic. At CESEC level a substantial increase from 36 TWh (2015) to 105-142 TWh by 2030 is indicated by the REMap scenarios (IRENA, 2020). Both figures are within the range of identified economic (52-1,336 TWh) and well below the reported technical potentials (1,703 TWh) according to literature.

As applicable from the literature survey, wind energy offers promising potentials and appears of key relevance for the decarbonisation of the electricity sector within the CESEC region. For that purpose, complementary to the literature survey, an own GIS-based analysis of the technical potential for onshore wind as well as offshore wind has been conducted in the course of this study. The outcomes of that analysis have served as a basis for the subsequent modelling and are compared with literature (as well as the modelled 2050 RES deployment) in subsequence, cf. section 0.

Table 3.12 Country-specific wind onshore electricity generation potentials and existing installations in 2015 (in GWh) according to the respective study

Indicator in GWh	Existing installations 2015	Economic potential				Technical potential	
Source	IRENA (2020)	DLR (2006)	ECN (2010)	IRENA et al. (2017) Min	IRENA et al. (2017) Max	IRENA et al. (2017)	Schremmer et al. (2018)
Albania	0	n.a.	n.a.	9,569	13,605	13,654	n.a.
Austria	4,840	3,000	4,243	n.a.	n.a.	n.a.	31,078
Bosnia and Herzegovina	0	1,000	n.a.	19,374	26,308	26,336	n.a.
Bulgaria	1,451	8,900	10,996	36,622	52,757	52,851	8,583
Croatia	795	2,600	n.a.	24,937	29,153	29,153	27,561
Greece	4,621	49,000	19,436	n.a.	n.a.	n.a.	32,142
Hungary	693	1,300	2,584	n.a.	n.a.	n.a.	16,151
Italy	14,845	79,000	53,435	n.a.	n.a.	n.a.	101,122
Kosovo*	0	n.a.	n.a.	2,273	3,850	3,850	n.a.
Moldova	2	n.a.	n.a.	50,236	50,236	50,236	n.a.
Montenegro	0	n.a.	n.a.	5,648	6,475	6,481	n.a.
North Macedonia	121	100	n.a.	2,201	7,639	7,655	n.a.
Romania	7,064	7,900	25,651	103,225	153,920	154,034	2,975
Serbia	0	300	n.a.	37,674	52,360	52,386	n.a.
Slovakia	6	700	224	n.a.	n.a.	n.a.	15,304
Slovenia	6	300	1,043	849	2,273	2,296	707
Ukraine	1,084	n.a.	n.a.	855,125	858,452	858,452	n.a.
CESEC	**35,528**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**

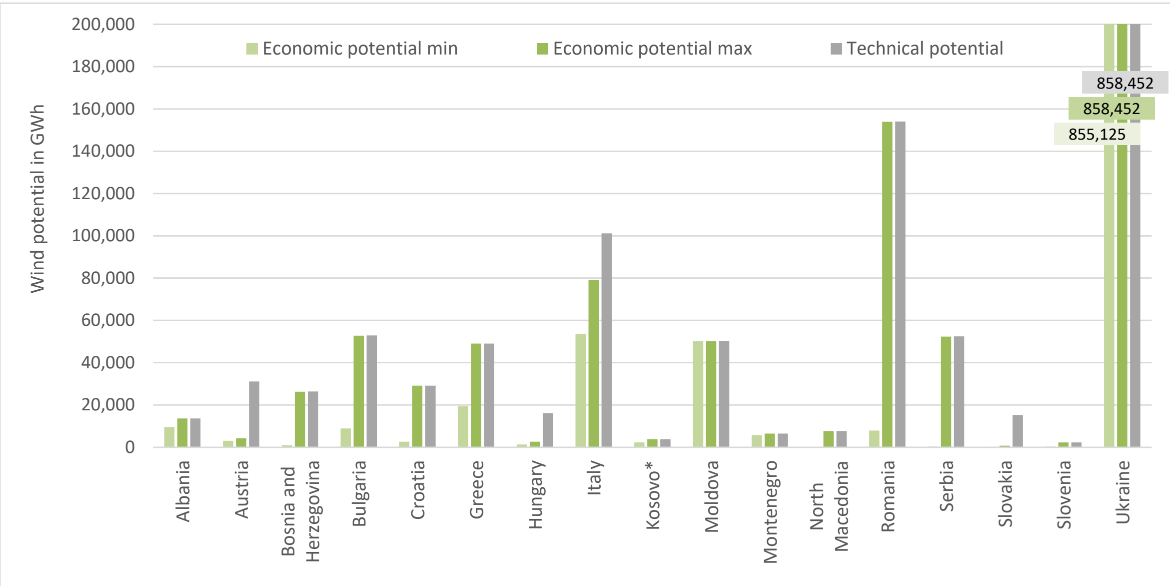
Source: DLR, 2006; ECN, 2010; IRENA et al., 2017; IRENA, 2020; Schremmer et al., 2018.

Table 3.13 Overview on assessed wind onshore electricity potentials and on exploitation in the REMap study (in GWh)

Indicator in GWh	REMap Reference Case 2030	REmap 2030	Economic potential min	Economic potential max	Technical potential	Exploitation of economic potential min	Exploitation of economic potential max	Exploitation of technical potential
Albania	168	1,794	9,569	13,605	13,654	13%	19%	13%
Austria	9,549	19,301	3,000	4,243	31,078	643%	455%	62%
Bosnia and Herzegovina	1,392	2,952	1,000	26,308	26,336	11%	295%	11%
Bulgaria	5,455	5,435	8,900	52,757	52,851	61%	10%	10%
Croatia	1,366	2,556	2,600	29,153	29,153	98%	9%	9%
Greece	15,262	14,581	19,436	49,000	49,000	75%	30%	30%
Hungary	872	5,248	1,300	2,584	16,151	404%	203%	32%
Italy	40,100	42,576	53,435	79,000	101,122	80%	54%	42%
Kosovo*	0	948	2,273	3,850	3,850	42%	25%	25%
Moldova	356	1,003	50,236	50,236	50,236	2%	2%	2%
Montenegro	436	473	5,648	6,475	6,481	8%	7%	7%
North Macedonia	380	1,756	100	7,639	7,655	1756%	23%	23%
Romania	12,571	12,689	7,900	153,920	154,034	161%	8%	8%
Serbia	2,409	3,727	300	52,360	52,386	1242%	7%	7%
Slovakia	560	1,587	224	700	15,304	708%	227%	10%
Slovenia	266	1,688	300	2,273	2,296	563%	74%	74%
Ukraine	13,400	22,910	855,125	858,452	858,452	3%	3%	3%
CESEC	**104,542**	**141,224**	**1,021,346**	**1,392,555**	**1,470,039**	**14%**	**10%**	**10%**

Source: IRENA, 2020; Own calculations.

Figure 3.7 Overview on assessed wind onshore electricity potentials in GWh



Complementary GIS-based analysis for wind and PV

Complementary to the literature survey, in the course of this study a GIS-based analysis has been conducted for both wind (on- and offshore) and solar PV since these technologies, according to literature, offer promising potentials and appear of key relevance for the decarbonisation of the electricity sector in the CESEC region as well as at European and global scale. This section informs in brief on the approach taken and presents the outcomes of the GIS-based analysis, serving as a basis for the subsequent power system modelling and the mapping exercise accompanied to that.

A summary of the approach taken is provided below whereas details concerning assumptions etc. can be found in Annex 2 of this report.

Approach taken in the GIS-based analysis of potentials for wind (on- and offshore) and PV:

The approach taken comprised the following steps:

- As a starting point, **GIS-based processing of weather data** was conducted.
- Comprehensive meteorological datasets on time-series of wind, solar irradiation, temperature etc. for past weather years were processed by use of the open-source GIS software QGIS[21] under a detailed geographical resolution (100m times 100m), serving as a basis for identifying unconstrained resource potentials across the whole CESEC region;
- As the next step within the GIS-based assessment, spatial constraints were incorporated that stem from competing land use, such as nature protection (e.g. by excluding Natura 2000 protected areas), urban, agriculture, military use or other purposes that limit the suitability for renewable power production and related grid deployment. Data sources for the land use were the CORINE land cover database as of 2021 and, in the case CORINE data was not applicable the GlobeLand database[22] as of 2021;
- **For calculating the potentials** in terms of installed capacities and electricity generation **state-of-the-art technology was considered**, involving a 5 MW class turbine for onshore wind, an 8 MW class turbine in the case of offshore wind, and for PV systems a typical module and system configuration (15% efficiency, 85% performance ratio).

Results of the GIS-based analysis of potentials for wind (on- and offshore) and PV:

This section is dedicated to inform on the outcomes of the GIS-based potential assessment, presenting the results by technology.

Photovoltaics

As applicable from the literature review, PV offers promising potentials in the CESEC region. Due to the Southern location within the European continent, many CESEC countries have comparatively high solar radiation. This is confirmed by the GIS-based analysis undertaken in the course of this study.

In this context, Figure 3.8 provides the solar radiation map of the CESEC region, indicating site conditions, i.e. global irradiance at the inclined surface, for solar PV. The applied colour code, following the rainbow pattern, informs on the site conditions for PV. Here yearly average global irradiation up to 130 W/m^2 (pale blue colour) can be classified as low. Moderate sites fall in the range from 130 to 170 W/m^2 (blue and green colour), and the best sites with good / excellent solar inflow are above 170 W/m^2 (orange, red and violet colour).

A closer look at the solar radiation map (Figure 3.8) indicates promising site conditions widely spread but specifically in the Southern parts of the CESEC region and of each respective country. Thanks to significant technological progress achieved throughout past decades, this generation asset became however economically viable even under less promising resource conditions as actual market developments have proven across the whole continent and worldwide. Thus, it can be expected that solar PV will become an important generation asset at the local and central level in future years.

21 Accessible at https://www.qgis.org/de/site/.
22 Accessible at https://observer.globe.gov/do-globe-observer/land-cover/science.

Figure 3.8 Solar radiation map of CESEC region, indicating site conditions (global irradiance on an optimally inclined surface) for solar PV

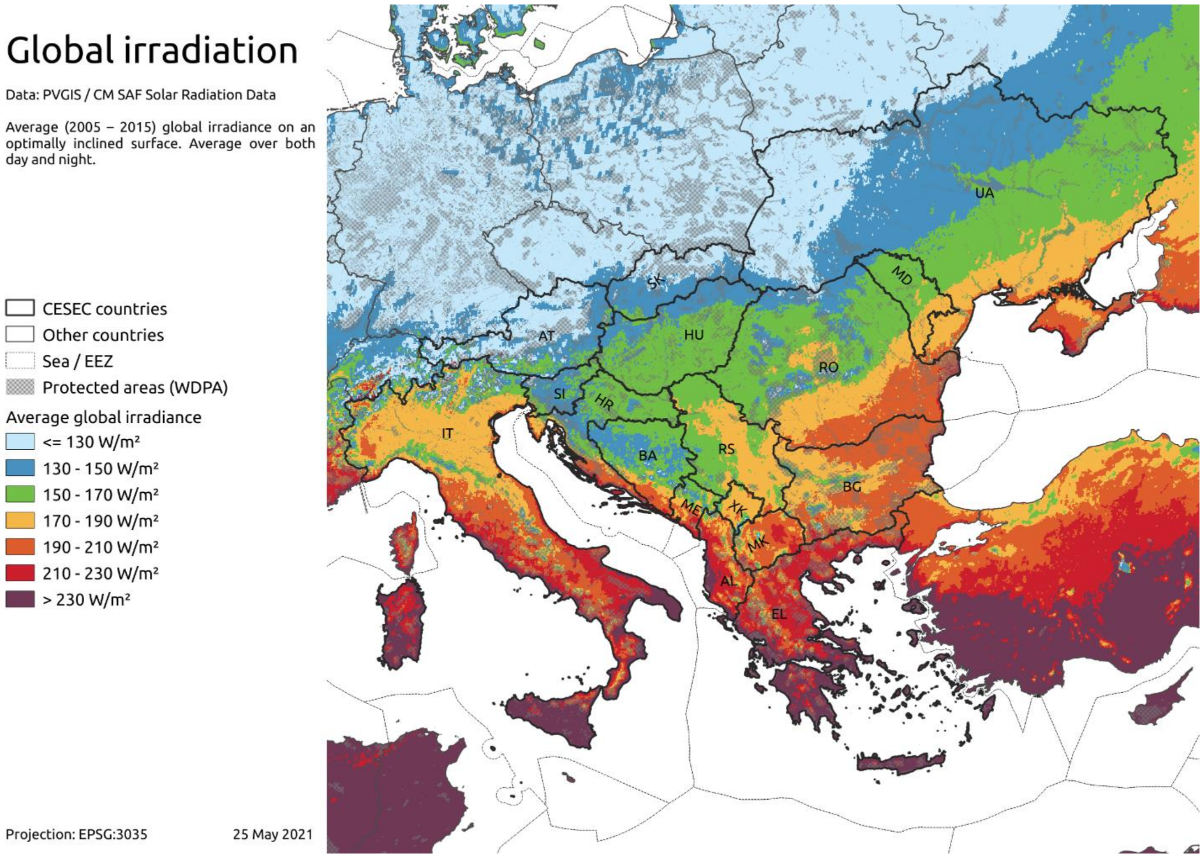


Table 3.14 Technical potentials for decentral and central PV systems in the CESEC region

GIS-based analysis of potentials for photovoltaics	Technical potential (with land use constraints)					
	Decentral PV systems		Central PV systems		Total PV systems	
	Capacitiy potential MW	Electricity generation potential GWh	Capacitiy potential MW	Electricity generation potential GWh	Capacitiy potential MW	Electricity generation potential GWh
Albania	3,041	4,576	5,129	7,601	8,171	12,177
Austria	18,372	19,587	18,187	19,227	36,559	38,813
Bosnia and Herzegovina	5,277	6,334	14,059	16,843	19,336	23,177
Bulgaria	22,742	30,984	32,701	44,686	55,442	75,669
Croatia	9,088	11,323	13,762	16,834	22,850	28,157
Greece	20,476	32,691	31,439	49,518	51,915	82,209
Hungary	31,179	36,522	43,059	50,634	74,238	87,157
Italy	90,273	126,175	110,518	158,509	200,791	284,684
Kosovo*	1,857	2,425	3,409	4,452	5,267	6,877
Moldova	7,511	9,212	19,585	24,109	27,095	33,320
Montenegro	1,160	1,613	1,628	2,105	2,789	3,717
North Macedonia	2,603	3,595	6,571	9,185	9,174	12,780
Romania	70,125	88,138	94,233	119,719	164,358	207,857
Serbia	15,557	19,610	32,921	41,371	48,478	60,981
Slovakia	13,753	14,722	15,143	16,290	28,895	31,012
Slovenia	3,631	4,148	4,123	4,717	7,754	8,865
Ukraine	110,042	127,621	305,751	357,352	415,793	484,973
CESEC	426,687	539,275	752,219	943,151	1,178,905	1,482,426

Based on solar radiation data and by application of land use constraints, limiting for example deployment of central (free-field) PV systems to less than 1% of current cropland and 0.25% of artificial areas, technical potentials for central and decentral PV systems have been calculated. The outcomes of that process are summarised in Table 3.14, listing the country-specific technical potentials for decentral and central PV systems in the CESEC region. Complementary to the above,

Table 3.15 compares the identified GIS-based technical potentials for PV systems (left) with literature (middle) and with modelled 2050 PV deployment[23] (right). As applicable from this table, the identified PV potentials are significant in magnitude and more than two times higher than the ones taken from the literature. A surprisingly good correlation can however be found between technical potentials according to literature with the identified potentials for decentral PV systems. The outcomes of the GIS-based analysis served as input for the power system modelling (as presented in the subsequent section 3.2), specifically as the upper boundary for the possible uptake and mapping PV installations to regions (NUTS-3 level). A comparison of identified potentials with modelling results (cf.

Table 3.15 right) shows that on average across the CESEC region less than one-third of that potentials is expected to be used until 2050. Due to ambitious policy targets, a significantly higher exploitation rate is however expected for Austria and Italy, and for Slovenia the limited availability of alternative technology options drives the PV uptake to similar heights.

Table 3.15 Comparison of the identified GIS-based technical potentials for PV systems (left) with literature (middle) and with modelled 2050 deployment (right)

GIS-based analysis of potentials for photovoltaics	Technical potential (with land use constraints) Total PV systems		Technical potential according to literature survey		Maximum of installed capacity by 2050 according to modelling	
	Capacitiy potential MW	Electricity generation potential GWh	GWh	% of GIS-based technical potential	MW	% of GIS-based technical potential
Albania	8,171	12,177	3,706	30%	3,154	39%
Austria	36,559	38,813	15,022	39%	28,908	79%
Bosnia and Herzegovina	19,336	23,177	4,135	18%	2,448	13%
Bulgaria	55,442	75,669	19,399	26%	14,517	26%
Croatia	22,850	28,157	21,863	78%	8,698	38%
Greece	51,915	82,209	21,219	26%	29,602	57%
Hungary	74,238	87,157	31,447	36%	24,254	33%
Italy	200,791	284,684	153,327	54%	144,535	72%
Kosovo*	5,267	6,877	835	12%	2,006	38%
Moldova	27,095	33,320	6,044	18%	1,349	5%
Montenegro	2,789	3,717	1,076	29%	1,018	37%
North Macedonia	9,174	12,780	2,226	17%	2,228	24%
Romania	164,358	207,857	71,539	34%	25,354	15%
Serbia	48,478	60,981	9,308	15%	5,601	12%
Slovakia	28,895	31,012	4,897	16%	16,836	58%
Slovenia	7,754	8,865	2,160	24%	5,640	73%
Ukraine	415,793	484,973	88,340	18%	34,392	8%
CESEC	1,178,905	1,482,426	456,543	31%	350,538	30%

Wind onshore

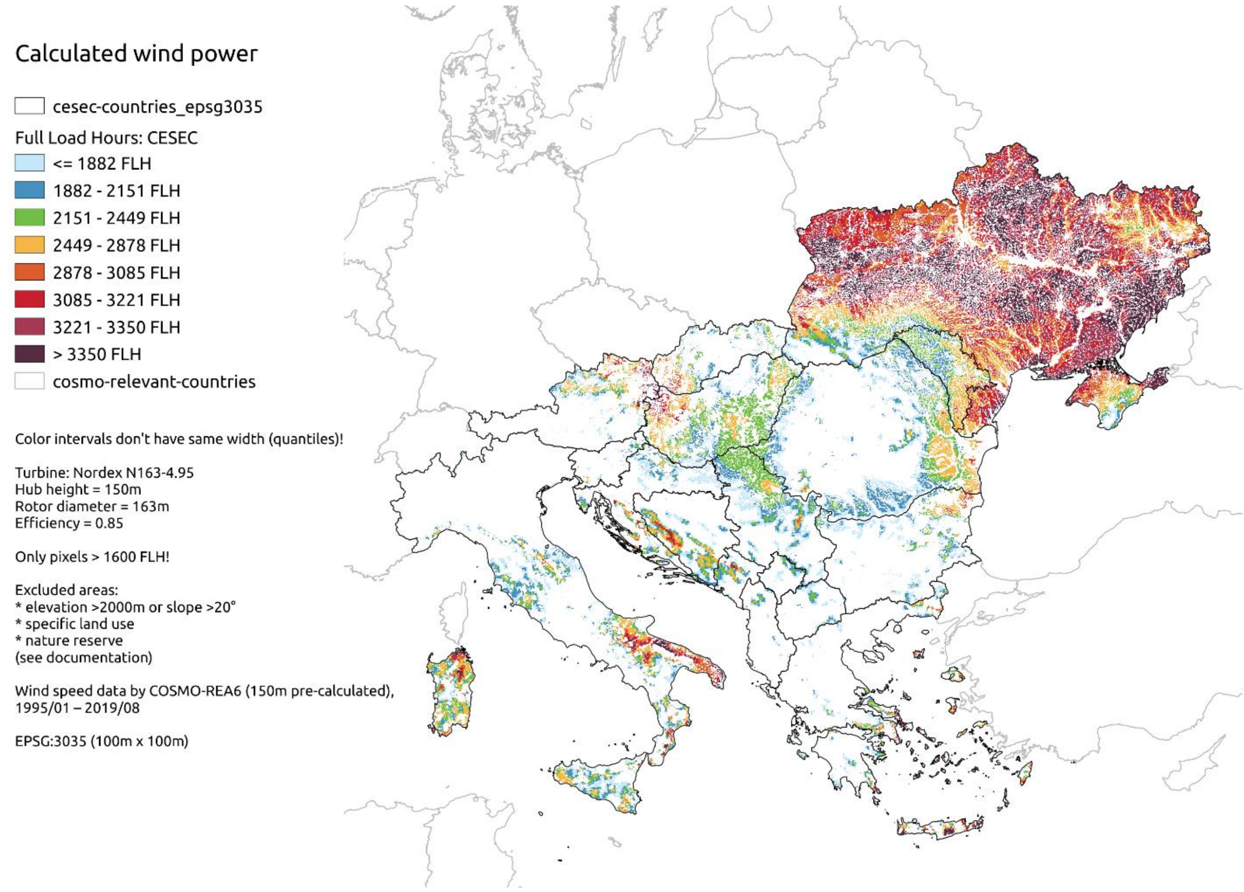
Similar to PV, according to literature the CESEC region may offer promising potentials for the uptake of wind energy in future years. As verification of that, the outcomes of the GIS-based analysis undertaken in the course of this study are presented in subsequence.

[23] Modelled 2050 deployment refers to the scenarios on the future RES uptake derived within this study as discussed in the subsequent section 3.2. More precisely, for that purpose maximum values of cumulative installed capacities of PV systems at country level are taken from the different scenarios derived.

As a starting point, Figure 3.9 shows the wind map of the CESEC region, indicating site conditions, i.e. applicable maximum full load hours (under optimal conditions concerning shading), and incorporating land-use constraints for wind onshore. The applied colour code, following the rainbow pattern, informs on the site conditions for wind onshore. Here full load hours, derived by dividing yearly electricity generation by the rated power of a wind power plant, up to 1882 h/a (pale blue colour) can be classified as low. Moderate sites fall in the range from 1882 to 2449 h/a (blue and green colour), and the best sites with good / excellent wind speed are above 2449 h/a (orange, red and violet colour).

Onshore wind energy offers promising site conditions in several CESEC countries, cf. Figure 3.9 . Remarkably is the site quality in the Ukraine where according to the meteorological data at hand similar conditions to offshore developments in the North of Europe are applicable. Promising sites are also applicable in several parts of Italy, in Bosnia and Herzegovina, at the border of Austria, Hungary and Slovakia, at the North-Eastern border of Bulgaria, in Eastern parts of Romania and at several locations within Greece to name a few examples. In general, wind onshore has become a major generation asset within Europe and globally thanks to achieved technological progress and the related economic viability.

Figure 3.9 Wind map of CESEC region, indicating site conditions (full load hours) for wind onshore



Building on wind speed data and via the application of land use constraints, technical potentials for wind onshore have been calculated. Identified country-specific technical potentials as graphically illustrated by Figure 3.9 are listed in

Table 3.16 (left). Additionally, that table offers also a comparison with literature (middle) and with modelled 2050 wind onshore deployment[24] (right). The comparison shows that identified wind onshore potentials are significant in magnitude and on average more than 30% higher than the ones taken from literature. The outcomes of the GIS-based analysis were used as input to the power system modelling (cf. section 3.2), serving as an upper boundary for the possible uptake and mapping wind onshore installations to regions (NUTS-3 level). A comparison of identified potentials with modelling results (cf.

Table 3.16 right) shows that on average across the CESEC region less than one-fifth of that potentials is expected to be used by 2050. An exception to this general trend is applicable for Austria and Slovenia, i.e. for both countries significantly stronger exploitation of the technical potential for PV is expected by 2050 according to modelling. This is a consequence of ambitious policy targets that have been set for renewables, specifically for PV.

Table 3.16 Comparison of the identified GIS-based technical potentials for wind onshore (left) with literature (middle) and with modelled 2050 deployment (right)

GIS-based analysis of potentials for onshore wind energy	Technical potential (with land use constraints)		Technical potential according to literature survey		Maximum of installed capacity by 2050 according to modelling	
	Capacitiy potential	Electricity gener-ation potential		% of GIS-based technical potential		% of GIS-based technical potential
	MW	GWh	GWh		MW	
Albania	3,826	6,563	13,654	208%	328	9%
Austria	26,961	60,494	31,078	51%	15,870	59%
Bosnia and Herzegovina	29,444	60,137	26,336	44%	4,461	15%
Bulgaria	41,184	76,473	52,851	69%	4,489	11%
Croatia	27,040	49,353	29,153	59%	3,233	12%
Greece	42,379	94,533	49,000	52%	11,946	28%
Hungary	92,647	194,781	16,151	8%	374	0%
Italy	181,618	381,812	101,122	26%	54,833	30%
Kosovo*	4,625	8,065	3,850	48%	619	13%
Moldova	11,486	24,224	50,236	207%	1,713	15%
Montenegro	14,505	28,355	6,481	23%	1,148	8%
North Macedonia	6,973	11,783	7,655	65%	1,896	27%
Romania	164,417	314,387	154,034	49%	15,078	9%
Serbia	84,305	158,545	52,386	33%	9,080	11%
Slovakia	18,850	39,699	15,304	39%	1,927	10%
Slovenia	5,135	9,248	2,296	25%	4,378	85%
Ukraine	133,734	347,343	858,452	247%	34,369	26%
CESEC	889,130	1,936,187	1,470,039	76%	165,741	19%

Wind offshore

Offshore wind is according to past experience less relevant for the CESEC region but recently gaining key policy attention at European level[25]. Literature offering a comprehensive analysis of the potential within the CESEC region was not applicable but a GIS-based analysis has been conducted within this study to inform on the possible role this technology can take in forthcoming years. Details on the underlying approach and key assumptions can be found in Annex 2 whereas the outcomes of that analysis are presented below.

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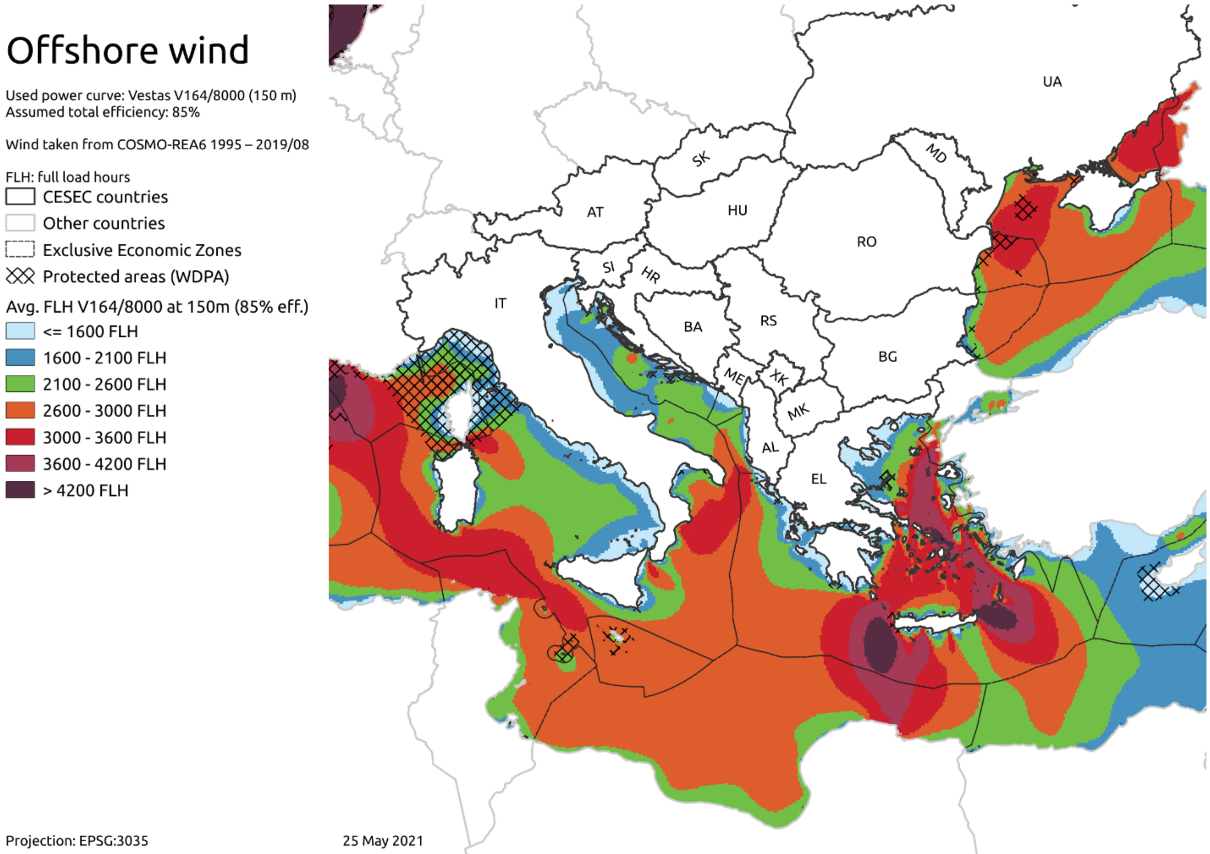
[24] Modelled 2050 deployment refers to the scenarios on the future RES uptake derived within this study as discussed in the subsequent section 3.2. More precisely, for that purpose at country level maximum values of cumulative installed capacities of onshore wind by 2050 are taken from the distinct scenarios.

[25] On 19 November 2020 the Commission published a dedicated EU strategy on offshore renewable energy COM(2020)741 that assesses the potential contribution of offshore renewables and proposes ways forward to support the long-term sustainable development of this sector.

As a starting point, Figure 3.10 shows the wind map of the CESEC region, indicating site conditions, i.e. applicable maximum full load hours (under optimal conditions concerning shading) as well as certain land-use constraints (i.e. environmentally protected areas) for marine areas. The applied colour code, following the rainbow pattern, informs on the site conditions for wind offshore. Here full load hours, derived by dividing yearly electricity generation by the rated power of a wind power plant, up to 1600 h/a (pale blue colour) can be classified as low. Moderate sites fall in the range from 1600 to 3000 h/a (blue, green and orange colour), and the best sites with good / excellent wind speed are above 3000 h/a (red and violet colour).

As applicable from this graph, offshore wind offers promising site conditions in the Adriatic / Mediterranean Sea between Italy and Albania, at several locations within the Greek sea territory and in the Black sea area of Romania and Ukraine. There is however a strong competition to the onshore wind which is available at comparatively similar site conditions but comes at present at significantly lower cost, specifically in the Black Sea area (within Ukraine, cf. Figure 3.10).

Figure 3.10 Wind map of CESEC region, indicating site conditions (full load hours) for offshore wind



Based on wind speed data and by incorporation of sea use constraints[26], technical potentials for offshore wind have been calculated. For the analysis, apart from wind speed, differences in site characteristics (i.e. water depth, distance to shore) that may play a role for the specific technology selection (i.e. floating or ground-mounted turbines) and with respect to the accompanying grid connection cost (i.e. distance to shore) have been acknowledged. The outcomes of that process are summarised in Table 3.17 , listing the country-specific technical potentials for offshore wind in the CESEC region by site category. As applicable from that table, the remaining area available for offshore wind development was however huge, leading to technical potentials far above that what could be integrated into the power system. Thus, for estimating realisable technical potentials

[26] For offshore wind military zones, nature protection areas and major shipping routes were excluded, and distances to tourism areas were respected (5 km to the shore).

only the best sites were considered by country, i.e. generally that limited deployment to approx. 1% of technically available sites. Complementary to the above, Table 3.18 compares the identified GIS-based technical potentials (left) as well as approximated realisable potentials in the 2050 timeframe (middle) with modelled 2050 offshore deployment[27] (right).

The outcomes of the GIS-based analysis served as input for the power system modelling (as presented in the subsequent section 3.2), specifically as the upper boundary for the possible uptake of offshore wind installations. A comparison of identified potentials with modelling results (cf. Table 3.18 right) shows that on average across the CESEC region however only a negligible fraction of the potential is expected to be used by 2050 (i.e. ca. 1% of the reduced realisable technical potential in the 2050 timeframe). In this context, Italy[28], Bulgaria, Greece and Romania are expected to act as the first movers within the CESEC region – but offshore deployment is far below what has been seen for its pendant onshore wind. Generally, it is the economic disadvantage compared to onshore wind that limits the use under the proclaimed least-cost deployment of renewables in forthcoming years. Technology-wise offshore wind is however ready to take a more prominent role in electricity supply within the CESEC region, for example if barriers for other RES technologies like onshore wind prevail in certain countries.

[27] Modelled 2050 deployment refers to the scenarios on the future RES uptake derived within this study as discussed in the subsequent section 3.2. More precisely, for that purpose maximum values of cumulative installed capacities of wind offshore at country level are taken from the different scenarios derived.

[28] A comparison with the planned offshore wind deployment according to Italy's NECP – i.e. 0.9 GW by 2030 – shows that modelled offshore wind use – i.e. 0.3 GW by 2050 – stays well below the politically planned one. This indicates the strong policy emphasis for this generation asset within Italy which, if future deployment follows planning, may become a role model also for neighboring countries, boosting offshore deployment well above the derived outcomes of this study.

Table 3.17 Detailed results of GIS-based analysis of technical potentials for offshore wind by country

GIS-based analysis of potentials for offshore wind energy

Water depth (z, in m)	Distance to shore (d, in nautic miles)	Albania Area potential (km2)	Albania Capacity potential (MW)	Albania Full load hours (h/a)	Bosnia and Herzegovina Area potential (km2)	Bosnia and Herzegovina Capacity potential (MW)	Bosnia and Herzegovina Full load hours (h/a)	Bulgaria Area potential (km2)	Bulgaria Capacity potential (MW)	Bulgaria Full load hours (h/a)	Croatia Area potential (km2)	Croatia Capacity potential (MW)	Croatia Full load hours (h/a)	Greece Area potential (km2)	Greece Capacity potential (MW)	Greece Full load hours (h/a)
-40 ≤ z	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	1,331	19,553	1,364	3	37	1,573	1,717	25,216	2,075	2,028	29,784	1,414	5,353	78,626	1,549
	24 ≤ d	0	0		0	0		258	3,797	2,557	1,660	24,383	1,521	3	43	3,662
-80 ≤ z < -40	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	1,139	16,730	1,555	0	0		1,131	16,612	2,445	7,053	103,604	1,668	10,802	158,663	1,748
	24 ≤ d	0	0		0	0		1,925	28,274	2,639	6,210	91,214	1,874	223	3,280	2,152
-120 ≤ z < -80	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	1,197	17,584	1,913	0	0		116	1,707	2,539	4,441	65,232	1,982	12,705	186,624	2,300
	24 ≤ d	1,046	15,370	2,295	0	0		2,174	31,938	2,662	2,342	34,405	2,150	587	8,624	2,295
z < -120	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	1,858	27,295	2,218	0	0		9	135	2,414	7,356	108,045	2,164	83,650	1,228,688	2,741
	24 ≤ d	4,770	70,068	2,666	0	0		4,654	68,367	2,772	9,050	132,932	2,323	27,044	397,232	3,101
TOTAL Area		12,121			13			34,709			55,297			482,397		
USABLE Area		11,342	166,601	2,215	3	37	1,573	11,985	176,046	2,593	40,140	589,600	1,982	140,367	2,061,782	2,646

Water depth (z, in m)	Distance to shore (d, in nautic miles)	Italy Area potential (km2)	Italy Capacity potential (MW)	Italy Full load hours (h/a)	Montenegro Area potential (km2)	Montenegro Capacity potential (MW)	Montenegro Full load hours (h/a)	Romania Area potential (km2)	Romania Capacity potential (MW)	Romania Full load hours (h/a)	Slovenia Area potential (km2)	Slovenia Capacity potential (MW)	Slovenia Full load hours (h/a)	Ukraine Area potential (km2)	Ukraine Capacity potential (MW)	Ukraine Full load hours (h/a)
-40 ≤ z	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	17,775	261,091	1,572	235	3,445	1,118	530	7,781	2,497	96	1,406	1,364	24,524	360,225	2,889
	24 ≤ d	3,857	56,656	1,605	0	0		399	5,859	2,720	0	0		19,142	281,174	3,103
-80 ≤ z < -40	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	10,328	151,708	1,882	857	12,584	1,309	427	6,278	2,799	0	0		3,853	56,598	2,509
	24 ≤ d	7,778	114,241	2,066	0	0		9,489	139,378	2,931	0	0		8,759	128,661	3,046
-120 ≤ z < -80	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	12,147	178,415	2,103	905	13,294	1,406	0	0		0	0		1,755	25,772	2,323
	24 ≤ d	7,773	114,167	2,285	580	8,521	1,951	3,811	55,983	3,031	0	0		2,580	37,900	2,844
z < -120	d < 12	0	0		0	0		0	0		0	0		0	0	
	12 ≤ d < 24	36,892	541,884	2,066	236	3,463	1,281	0	0		0	0		1,661	24,398	2,026
	24 ≤ d	62,667	920,479	2,674	2,393	35,145	2,099	4,521	66,408	2,982	0	0		8,529	125,272	2,891
TOTAL Area		536,272			6,373			29,587			208			134,966		
USABLE Area		159,216	2,338,641	2,241	5,205	76,451	1,750	19,177	281,687	2,944	96	1,406	1,364	70,804	1,040,001	2,910

Wind turbine specification:
VESTAS V164/8000

Generator size	8	MW	
Rotor diameter	164	m	
Area for one turbine	0.54	km2	Remark: 4.5 times rotor diameter in square
MW per km2	14.7	MW/km2	

Table 3.18 Comparison of the identified GIS-based technical potentials (with (middle) and without (left) realisation constraints) for wind offshore with modelled 2050 deployment (right)

GIS-based analysis of potentials for offshore wind energy	Technical potential (with marine use constraints) Capacitiy potential MW	Technical potential (with marine use constraints) Electricity generation potential GWh	Approximation of realisable technical potential by 2050 Capacitiy potential MW	Approximation of realisable technical potential by 2050 Electricity generation potential GWh	Maximum of installed capacity by 2050 according to modelling MW	% of GIS-based technical potential	% of GIS-based realisable technical potential by 2050
Albania	166,601	368,947	1,666	4,058	1	0.001%	0%
Austria	0	0	0	0	0	n.a.	n.a.
Bosnia and Herzegovina	37	58	0	0	0	0%	n.a.
Bulgaria	176,046	456,445	1,760	5,021	115	0.065%	7%
Croatia	589,600	1,168,769	5,896	12,856	0	0%	0%
Greece	2,061,782	5,455,749	20,618	60,013	92	0.004%	0%
Hungary	0	0	0	0	0	n.a.	n.a.
Italy	2,338,641	5,239,991	23,386	57,640	257	0.01%	1%
Kosovo*	0	0	0	0	0	n.a.	n.a.
Moldova	0	0	0	0	0	n.a.	n.a.
Montenegro	76,451	133,823	765	1,472	0	0%	0%
North Macedonia	0	0	0	0	0	n.a.	n.a.
Romania	281,687	829,161	2,817	9,121	28	0.010%	1%
Serbia	0	0	0	0	0	n.a.	n.a.
Slovakia	0	0	0	0	0	n.a.	n.a.
Slovenia	1,406	1,917	70	105	0	0%	0%
Ukraine	1,040,001	3,026,690	5,200	16,647	0	0%	0%
CESEC	6,732,252	16,681,551	62,178	166,934	492	0.007%	1%

3.2 *(Results on) future RES deployment in the CESEC region*

This section is dedicated to present the draft final results of the modelling activities related to Task 1, indicating future RES deployment within the CESEC region. Two pairs of scenarios have been assessed as described previously (cf. section 0):

- The first pair covers the Reference RES scenarios, where RES deployment follows national projections derived from (draft) NECPs or alternative energy and climate strategies of the CESEC countries. These Reference RES scenarios have two sub-cases:
  - **Reference RES – no cross-border RES cooperation (RefRES–NoCoop):** in this scenario 2030 RES deployment is based on domestic fulfilments of targeted RES efforts, implying that in this scenario every country is assumed to aim for achieving its targeted RES share for 2030 (and beyond) primarily by generation capacities located in the country's territory;
  - **Reference RES – cross-border RES cooperation (RefRES-Coop):** The other scenario follows a region-wide, least-cost approach for meeting targeted RES shares within the CESEC region. Consequently, cross-border RES cooperation is assumed to be enhanced when this is economically beneficial.
- The second pair of scenarios assesses the feasibility of reaching a higher level of RES deployment in the region, subsequently named as HighRES scenarios. The targeted future RES efforts are based on the 2030 RES shares to be achieved if the EU climate ambition is strengthened ("EU Green Deal perspective"). For distributing EU ambitions to a Member State level, the benchmark methodology is followed. A similar approach is applied to CPs of the Energy Community. Similar to above, two sub-cases are analysed:
  - The first scenario assumes domestic fulfilment of targets (**HighRES–NoCoop**);
  - The second scenario assumes increased cross-border RES cooperation (**HighRES-Coop**), implying expectably higher RES deployment in the identified RES zones compared to the previous case.

The future uptake of renewables in the electricity sector

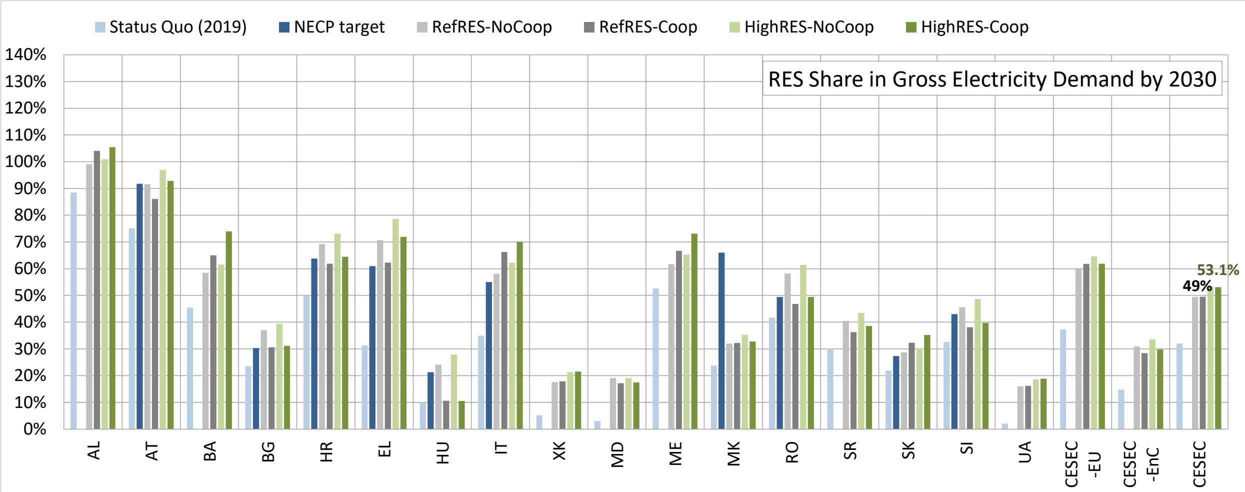
As a starting point for identifying promising cross-border RES zones within the electricity sector of the CESEC region, the performed assessment sheds light on the RES uptake proclaimed therein. Here modelling provides a sound basis for that since derived least-cost pathways of RES deployment provide, on the one hand, insights on the planned RES uptake within the electricity sector in accordance with NECP planning (**RefRES scenarios**) as well as on the likelihood of that. On the other hand, modelling also allows for identifying the needs arising from the Green Deal for a stronger increase of RES overall, and on the contribution of RES electricity to that (**HighRES scenarios**). Under both perspectives, the impacts arising from the use of RES cooperation mechanisms are subsequently illustrated. Within this section different aspects related to the RES uptake are discussed in topical order, starting with the aggregated picture in terms of projected future RES shares and the impacts of cross-border RES cooperation on those. Subsequently, a closer look is taken at the future RES technology mix and at installed RES capacities, followed by a discussion of corresponding investments needs and RES-related support expenditures where impacts of the overall RES ambition, RES cooperation and RES policy design are analysed.

The RES uptake in the CESEC region – the aggregated picture (RES shares)

Within the CESEC region, renewables are already at present a key contributor to meet the electricity demand. According to the latest statistical data available (Eurostat, 2021), RES achieved a share of ca. 32% in gross electricity demand by 2019. Historically, the RES share was steadily growing over the past decade, with differences across countries. This growth needs to be accelerated in future years, given the policy commitments have taken and the needs arising for a transformation of the energy sector to combat climate change.

The model-based analysis performed in the course of this study sheds light on the required, considering both NECP ambitions and Green Deal needs, and on the feasible uptake of renewables in the electricity sector within the CESEC region in the 2030 context and beyond (2050).

Figure 3.11 Status quo (2019), planned (NECP target) and modelled 2030 RES shares by CESEC country according to assessed scenarios (RefRES and HighRES scenarios)



Source: Eurostat, NCEP and Green-X modelling.

Figure 3.11 provides a recap of the status quo (2019) and informs on planned (NECP target (where defined)) and modelled RES shares by CESEC country in the 2030 context. As applicable from this graph, at present there are strong differences across the CESEC region concerning the power mix and specifically the contribution of renewables. While in countries like Austria, Albania, Montenegro or Croatia renewables, specifically hydropower, contribute already today (as of 2019) more than half of the electricity demand, within Kosovo, Moldova or the Ukraine the share of renewables in power generation is currently negligible.

The planned uptake of RES in the electricity sector by 2030, i.e. as proclaimed in NECPs (where applicable), appears feasible. A comparison of NECP targets with modelled 2030 RES shares according to RefRES scenarios, specifically where domestic overall RES target fulfilment is envisaged (NoCoop scenario variant), indicates that in several countries a slightly higher than planned RES uptake in the electricity sector would economically make sense for reaching the overall cross-sectoral RES target, defined as RES share in gross final energy demand, in a least-cost manner (as prescribed in modelling). An exception to that is North Macedonia. Here modelling reveals that the planned RES-E share as reported in the draft NECP appears hardly feasible, considering the pace of transition and market uptake required. RES cooperation with neighbouring countries would however allow for achieving the planned 2030 RES share under these circumstances.

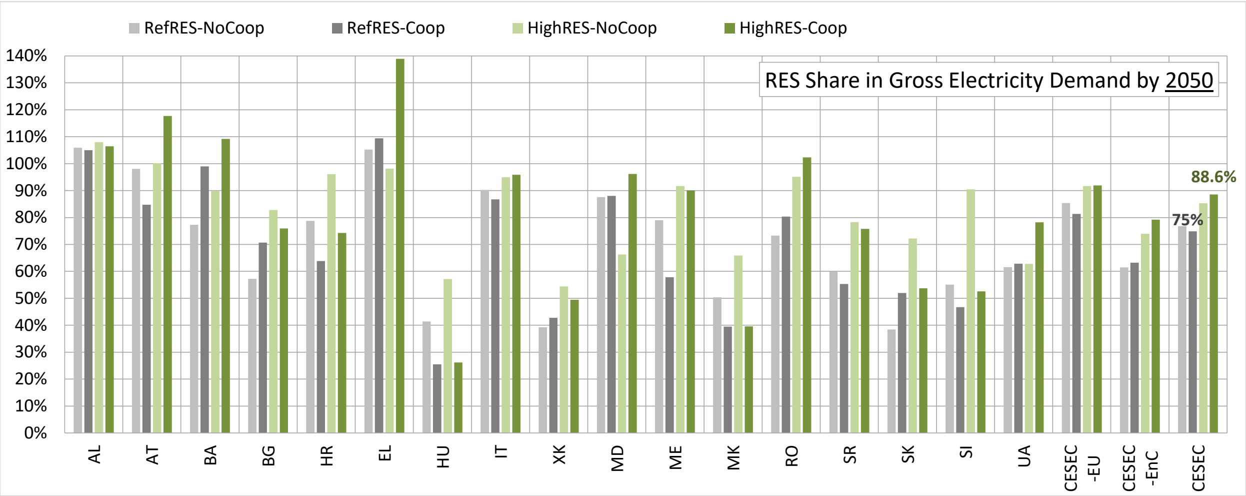
Complementary to planned RES deployment (i.e. NECP perspective and corresponding RefRES scenarios), Green Deal needs are also illustrated in Figure 3.11. Here the HighRES scenarios inform on the required stronger RES uptake under that perspective. Within the CESEC region, the difference compared to NECP planning and corresponding RefRES scenarios is however comparatively small in the short term (by 2030): According to modelling, the RES-E share at CESEC level would increase to 53.1% by 2030 (HighRES scenarios) under that perspective, instead of 49% (RefRES scenarios, in accordance with NECP planning). Reasons for that are, on the one hand, already ambitious policy planning as reflected in NECPs (cf. Austria, Greece, Italy, North Macedonia), and, on the other hand, the practical limits to market growth in several other countries like Kosovo, Moldova or Ukraine, representing emerging RES markets considering the low status quo.

Complementary to the above,

Figure 3.12 indicates the feasible RES uptake in the long term (2050), expressing modelled 2050 RES shares by CESEC country according to assessed scenarios (RefRES and HighRES scenarios). Compared to 2030, stronger differences among scenarios are applicable:

- The overall RES uptake differs to a larger extent between the RefRES and the HighRES scenarios, driven by the underlying scenario conception. Accordingly, a moderate climate and RES ambition as presumed in the RefRES scenarios would increase the RES share to about 75-77% by 2050 whereas following the climate neutrality objective (HighRES scenarios) implies an even stronger RES uptake (85-87%);
- Stronger differences are also applicable between the scenario variants, assuming either emphasis on domestic action (NoCoop scenarios) or cross-border RES cooperation (Coop scenarios). A "level playing field" for the RES uptake over a long period as assumed in the scenarios of full cooperation would lead to a strong reallocation of RES investments, given the partly vast renewable potentials applicable within certain countries or regions.

Figure 3.12 Modelled 2050 RES shares by CESEC country according to assessed scenarios (RefRES and HighRES scenarios)



Source: Green-X modelling.

Key findings are:

- For analysing the uptake of renewables in the electricity sector of the CESEC region, two perspectives have been assessed: One in accordance with national planning (NECP perspective and corresponding RefRES scenarios), and another one that reflects Green Deal needs (HighRES scenarios). For both scenarios, the impact of cross-border RES cooperation was analysed;
- In the short term (2030), only a small difference in the RES-E share is applicable within the CESEC region between these two perspectives: 49% (RefRES scenarios) vs 53.1% (HighRES scenarios). This is a consequence of ambitious policy planning in certain countries and/or practical limits to market growth in several others;
- By 2050, stronger differences in the RES-E shares at CESEC level are applicable: 75-77% with a moderate climate and RES ambition (RefRES scenarios) vs 85-87% when following the climate neutrality objective (HighRES scenarios);
- A "level playing field" for the RES uptake over a long period as assumed in the scenarios of full cooperation would lead to a strong reallocation of RES

investments, given the partly vast renewable potentials applicable within certain countries or regions.

Cross-border RES cooperation in the 2030 and 2050 context

In general, cross-border RES cooperation across the whole CESEC region, as modelled in the Cooperation variants of the RefRES scenario (RefRES-Coop) and the HighRES scenario (HighRES-Coop), would cause a reallocation of RES investments across countries and, in consequence, would contribute to lower the cost related to the RES uptake. Here in modelling the ultimate form of cross-border RES cooperation is presumed, implying free reallocation of future RES investments across all CESEC countries.

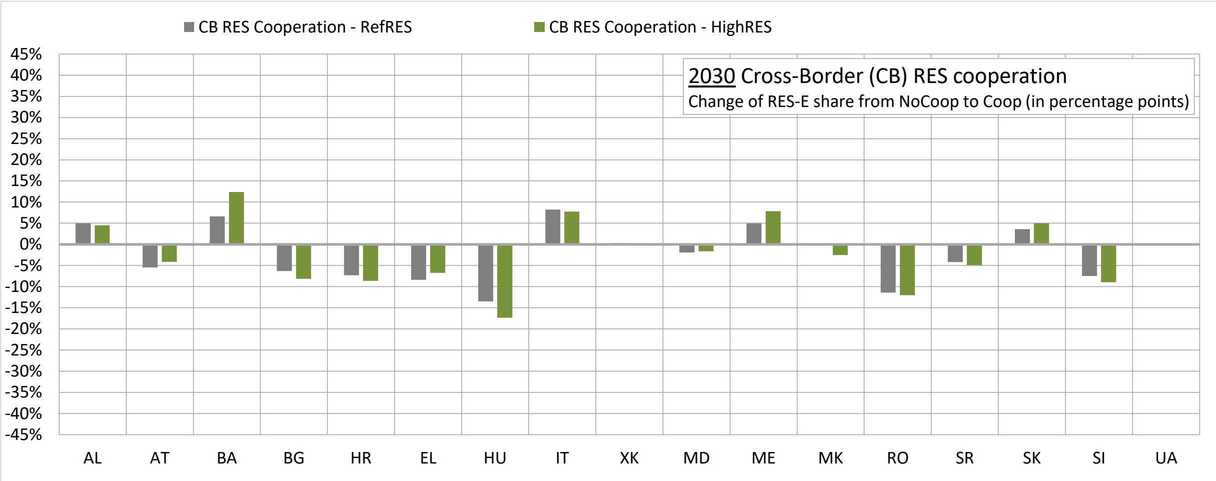
Figure 3.13 illustrates for the year 2030 the modelled cross-border RES cooperation by CESEC country according to assessed scenarios (RefRES and HighRES scenarios), indicating the change of RES-E share in percentage points that would arise when introducing cross-border cooperation (compared to domestic action as presumed in the NoCoop scenarios). A positive change implies that a stronger RES uptake would take place so that the country can act as a host. Contrarily, a negative change means that a decline of domestic RES investments can be expected and that the respective country would have to act as an off-taker in a cooperation agreement. The corresponding illustration for the year 2050 is provided in

Figure 3.14 .

Results indicate that in the 2030 context similar trends are applicable under both assessed policy perspectives, i.e. the NECP perspective as presumed in RefRES scenarios and the Green Deal needs, as assessed in the HighRES scenarios. Modelling reveals that Albania, Bosnia and Herzegovina, Italy, Montenegro and Slovakia may offer promising RES potentials not required for their own RES target achievement.

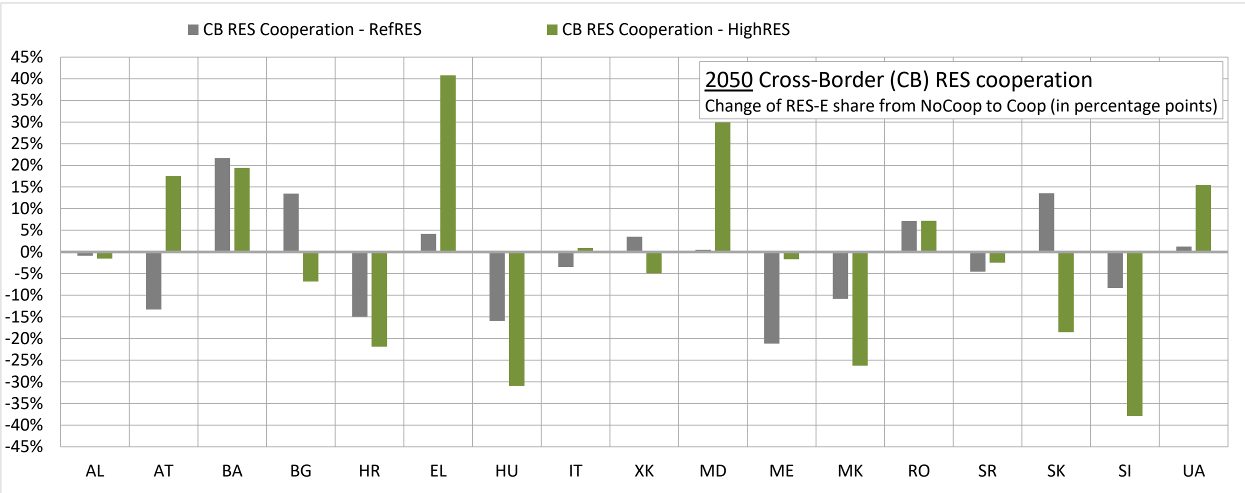
In the long term (2050) the picture partly changes, considering the limits in resource availability and the changing market readiness in countries like Moldova or Ukraine. Bosnia and Herzegovina may again act as host country for the future RES uptake but other countries like Greece, Moldova, Romania or Ukraine also enter the group of hosts under both policy perspectives (i.e. moderate RES ambition (RefRES scenario) or strong RES ambition (HighRES scenario). Austria may also act as host but only if a strong RES ambition is followed across the whole CESEC region (HighRES scenario), tackling resources that would not be required in a RefRES world. The opposite trend is applicable for Bulgaria, Kosovo and Slovakia, indicating the limits that certain low-cost RES potentials have within these countries.

Figure 3.13 Modelled cross-border RES electricity cooperation in 2030 by CESEC country according to assessed scenarios (RefRES and HighRES scenarios)



Source: Green-X modelling.
Remark: A positive number indicates a surplus (RES export) whereas a negative number indicates a deficit (RES import).

Figure 3.14 Modelled cross-border RES electricity cooperation in 2050 by CESEC country according to assessed scenarios (RefRES and HighRES scenarios)



Source: Green-X modelling.
Remark: A positive number indicates a surplus (RES export) whereas a negative number indicates a deficit (RES import).

Key findings are:

- In general, cross-border RES cooperation across the whole CESEC region, as modelled in the Cooperation variants of the RefRES scenario (RefRES-Coop) and the HighRES scenario (HighRES-Coop), would cause a reallocation of RES investments across countries and, in consequence, would contribute to lower the cost related to the RES uptake. Here in modelling the ultimate form of cross-border RES cooperation has been presumed, implying free reallocation of future RES investments across all CESEC countries;
- Within the CESEC region, modelling reveals that Albania, Bosnia and Herzegovina, Italy, Montenegro and Slovakia may offer promising RES potentials for export by 2030;
- In the long term (2050), the picture partly changes: Bosnia and Herzegovina may again act as host country for the future RES uptake but other countries like Greece, Moldova, Romania or Ukraine also enter that group.

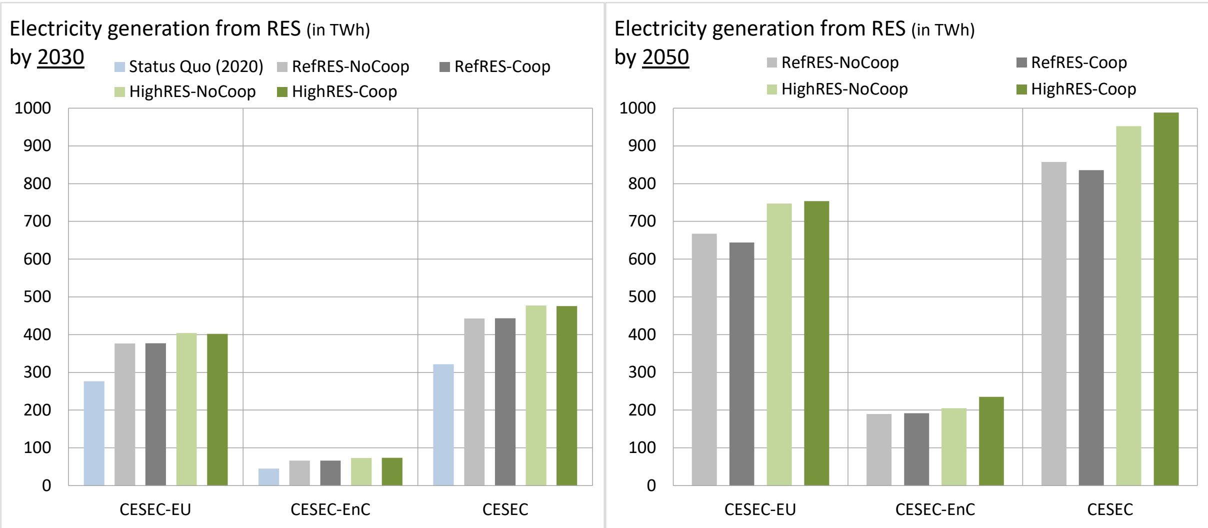
Details on the underlying technology mix in electricity supply

Electricity generation

This section informs on anticipated trends in future RES-based electricity supply within the CESEC region. As discussed previously, modelling reveals a strong uptake of renewables up to 2050 within all analysed scenarios. This is getting apparent from

Figure 3.15 . More precisely, this graph compares for all assessed scenarios total electricity generation from RES by 2030 (left) and by 2050 (right). Geographically, the comparison is provided for the whole CESEC region and for the sum of EU Member States as well as for the CPs of the EnC. While differences between EU and Energy Community countries remain, CPs have to accelerate RES deployment more strongly than EU Member States within forthcoming years: Within the EU Member States in CESEC, the imposed challenge implies slightly more than a doubling of RES generation whereas for the CPs within CESEC, RES generation has to increase by more than a factor of four.

Figure 3.15 Comparison of differences in total electricity generation from RES across scenarios by 2030 (left) and by 2050 (right)

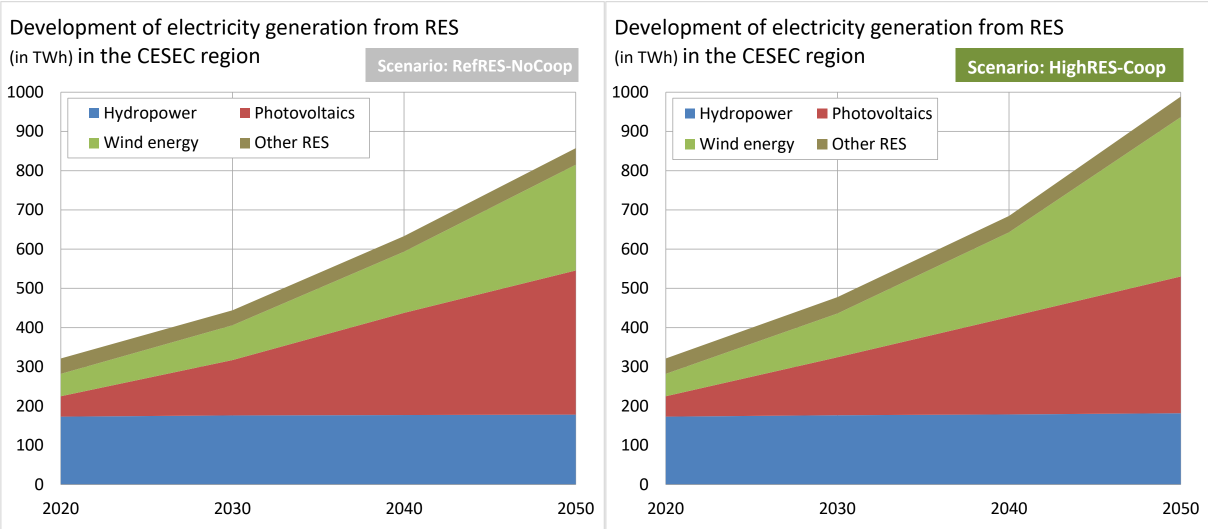


Details on the underlying technology mix in RES-based electricity generations are applicable from

Figure 3.16 . This graph illustrates the development of electricity generation from RES at CESEC level up to 2050, exemplified for the RefRES scenario (with domestic action – i.e. NoCoop) (left) and for the HighRES scenario (with cross-border RES cooperation – i.e. Coop) (right).

Results show that the dominance of hydropower in electricity supply is expected to diminish. Solar electricity (from photovoltaic systems) and wind power (onshore wind) will become the major contributors to future electricity supply. This trend is observable under all scenarios assessed. Of interest, despite its strong use throughout all scenarios, wind energy may act as a marginal generation option in economic terms, reaching the highest share among all technologies within total electricity generation from RES only if a strong RES ambition is imposed (HighRES scenarios). Contrarily, in the RefRES scenarios, photovoltaics would become the largest contributor to the total RES-based electricity supply by 2050.

Figure 3.16 Development of electricity generation from RES at CESEC level up to 2050, exemplified for the RefRES-NoCoop (left) and the HighRES-Coop scenario (right)



Installed capacities

This section complements the above by taking a closer look at capacity trends in the modelled RES transition within the CESEC region. As a starting point,

Figure 3.17 provides a comparison of differences in cumulative installed RES capacities for all assessed scenarios by 2030 (left) and by 2050 (right). Geographically, the comparison is provided for the whole CESEC region, and for the group of EU Member States within CESEC as well as for the corresponding group CPs of the EnC. Country details on modelled cumulative RES capacity developments are then provided by

Figure 3.18 for all assessed scenarios, offering a comparison for both 2030 and 2050. Next to that, insights on the country-specific technology mix of installed RES capacities[29] at present (2020) and in future (2030, 2050) are shown in

Figure 3.19 , exemplified here for the HighRES-Coop scenario.

These depictions indicate the following outcomes:

- As discussed above, the comparatively strong RES ambition is confirmed by the capacity trends: tthe cumulative installed RES capacity in CESEC has to increase by a factor of three to four compared to today (2020);
- Because of geographic size and population Italy remains the largest RES power producer within the CESEC region. Other countries of dominance in terms of market size are Austria, Greece, Romania and Ukraine;
- Strong changes in the underlying power technology mix can be expected for the whole CESEC region in forthcoming years. Specifically for decentral and central PV systems a strong uptake is observable in modelled scenarios. In general, these technologies are expected to become the largest contributors to power supply in capacity terms in almost all countries – the contribution to power supply in energy terms is however smaller, cf. Figure 3.16.

[29] More precisely, Figure 3.19 indicates the share of individual RES technologies on the cumulative sum of all RES installations, done in capacity terms.

Figure 3.17 Comparison of differences in cumulative installed RES capacities across scenarios by 2030 (left) and by 2050 (right)

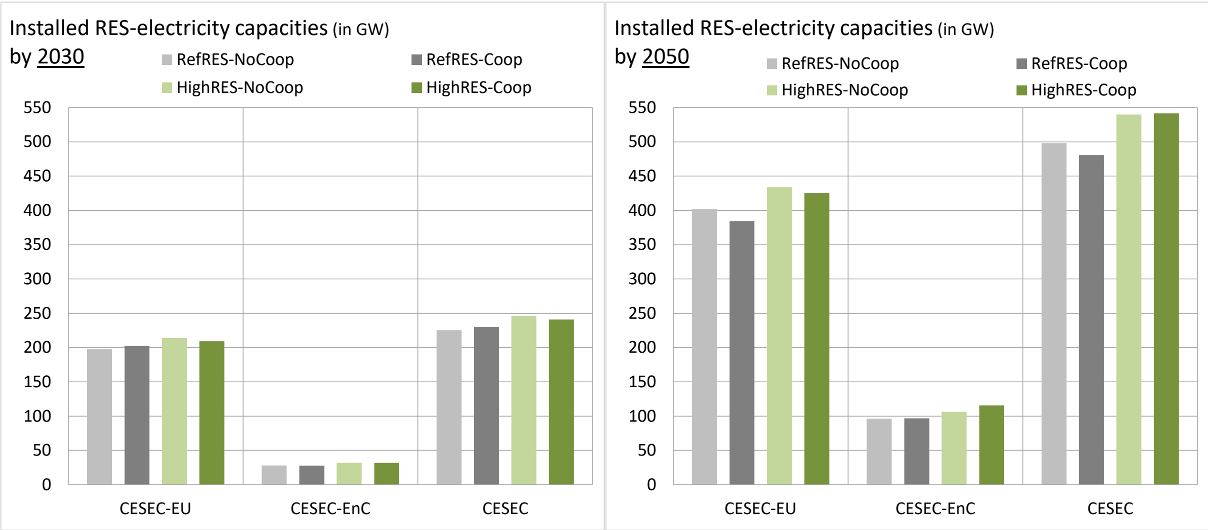


Figure 3.18 Country-specific comparison of differences in cumulative installed RES capacities across scenarios by 2030 (top) and by 2050 (bottom)

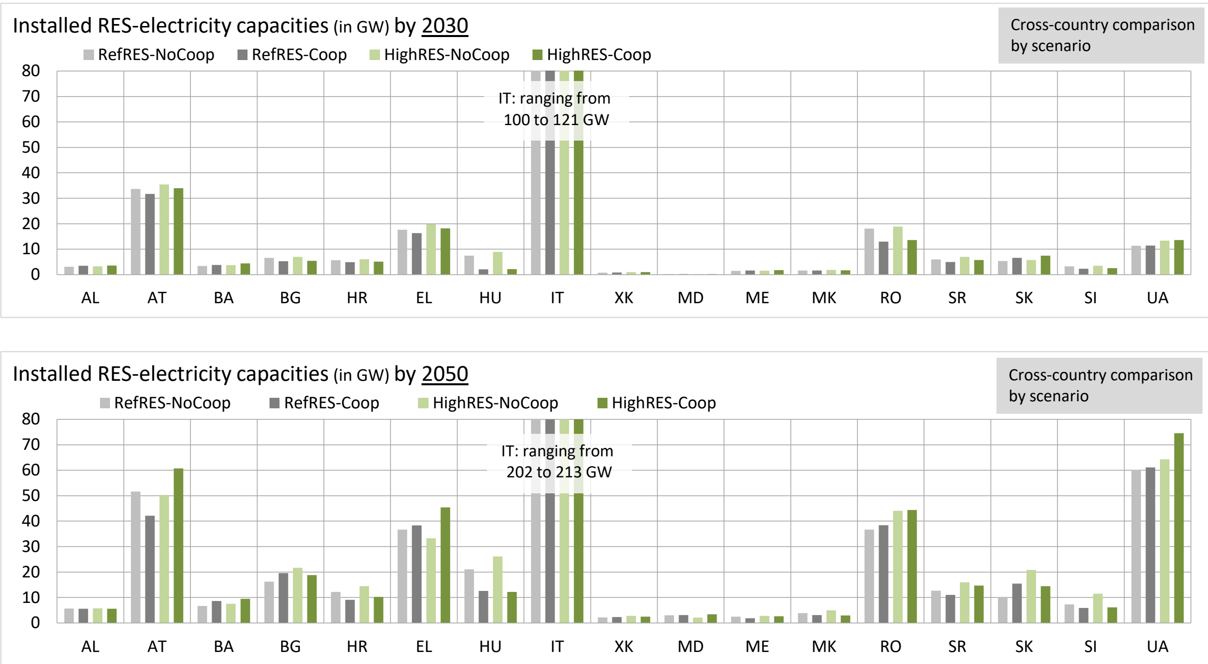
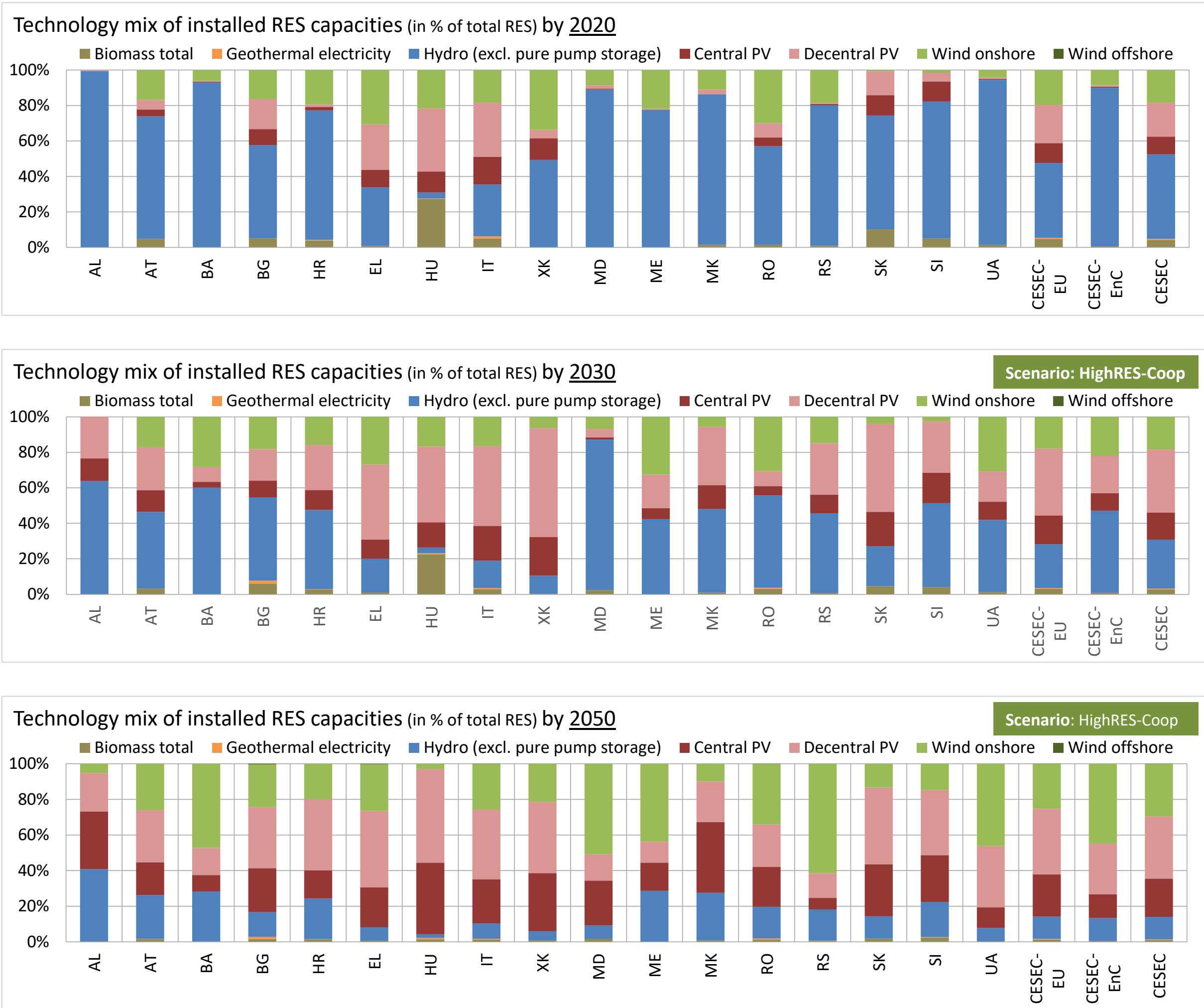


Figure 3.19 Country-specific technology mix of installed RES capacities at present (2020) and in future (2030, 2050), exemplified for the HighRES-Coop scenario



Key findings are:

- Technology-wise, results clarify that the dominance of hydropower in electricity supply is expected to diminish across the CESEC region. Solar electricity (from photovoltaic systems) and wind power (onshore wind) will become the major contributor to future electricity supply. This trend is observable under all scenarios assessed;
- Region-wise it can be concluded that the imposed challenge differs: EU Member States in the CESEC region have to achieve a doubling of RES generation whereas Contracting Parties of the Energy Community have to achieve an increase by more than a factor of four;
- Country-wise, Italy remains the largest RES power producer within the CESEC region. Other countries of dominance in terms of market size are Austria, Greece, Romania and expectably Ukraine;
- Generally, there are strong changes in the power technology mix: Both decentral and central PV systems are expected to become the largest contributor to power supply in capacity terms, imposing a challenge for grid integration.

Investments in RES technologies

Complementary to previously discussed capacity trends in the modelled RES transition within the CESEC region, this section is dedicated to inform on corresponding investment needs. In this context, Figure 3.20 offers a comparison of average yearly investments in RES technologies across scenarios for the period 2021 to 2030 (left) and for the period

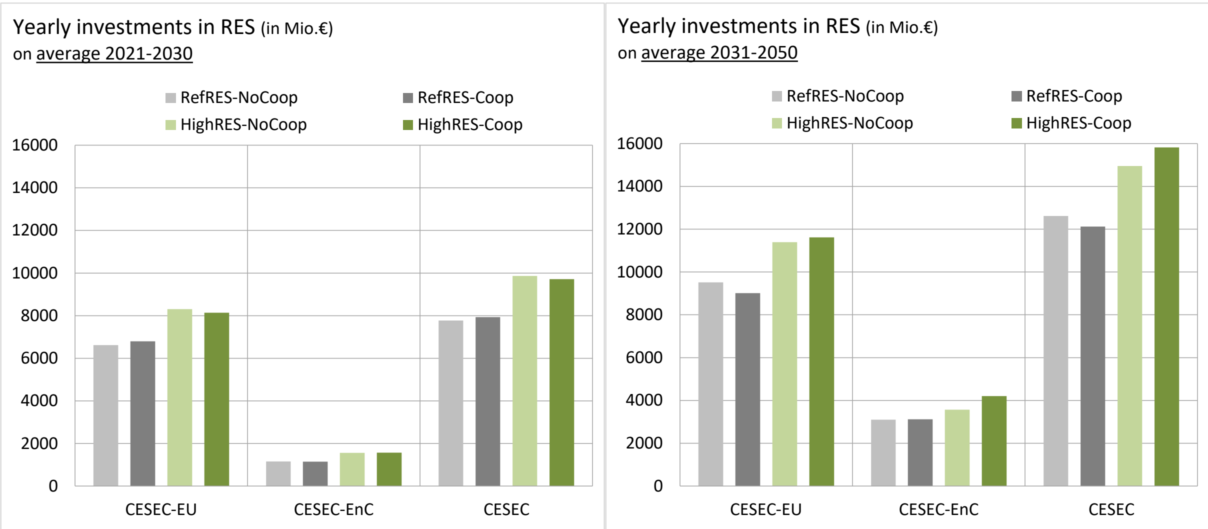
2031 to 2050 (right). Geographically, the comparison is provided for the whole CESEC region, and for the group of EU Member States within CESEC as well as for the corresponding group CPs of the EnC. Country details on modelled RES-related investment needs are then shown in

Figure 3.21 for all assessed scenarios, offering a comparison for both this decade (2021 to 2030) (top) and the period 2031 to 2050 (bottom).

These depictions indicate the following outcomes:

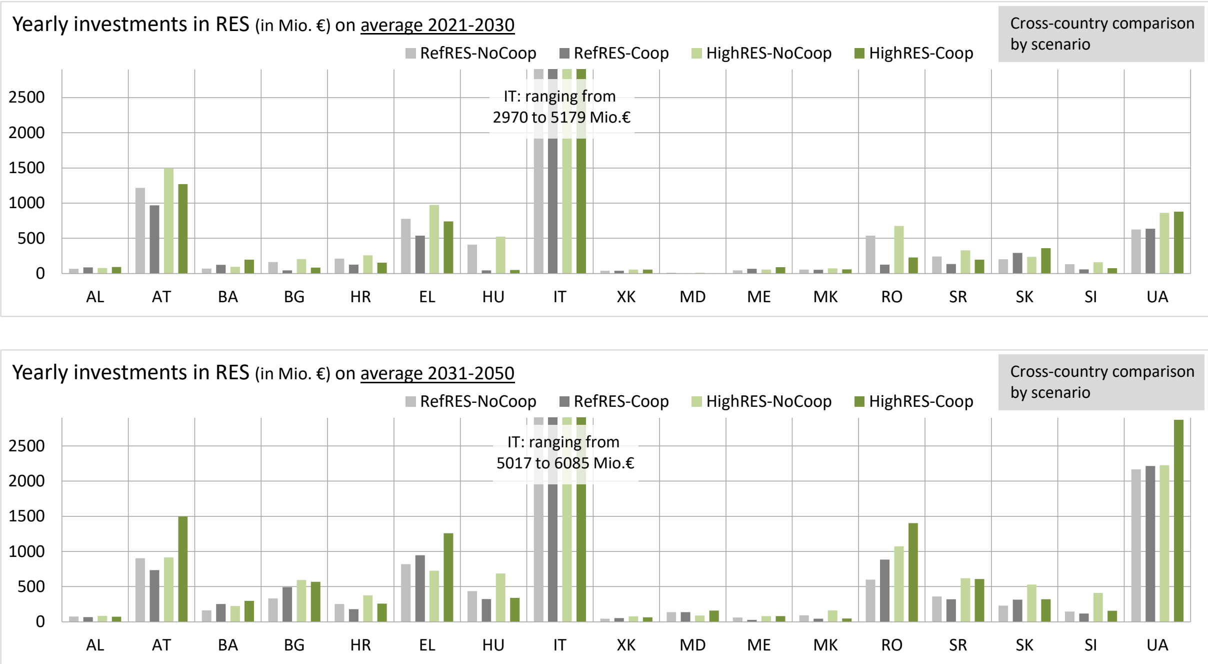
- In accordance with the above, the comparatively strong RES ambition under all assessed scenarios is also applicable in corresponding investment needs: within this decade (2021 to 2030) RES-related investments in the whole CESEC region vary from 7.7 billion € (RefRES-NoCoop) to 9.9 billion € (HighRES-NoCoop) on average per year. In later years, the amount of RES-related investments increases further, ranging from 12.1 billion € (RefRES-Coop) to 15.8 billion € (HighRES-NoCoop) on average per year;
- In accordance with RES deployment and corresponding capacity additions, within the CESEC region there is a strong difference between the EU Member States and the CP of the EnC applicable: RES-related investment volumes are by a factor of 5 to 6 larger within the EU part of CESEC compared to the EnC part in early years (up to 2030), in later years that difference is getting smaller (i.e. a factor of ca. three is then applicable). This is mainly a consequence of differences in geographic size and population but in early years also market readiness (i.e. currently prevailing barriers to RES deployment) play a role;
- A closer look at country-specific investment needs (cf.
- Figure 3.21) indicates that Italy acts as host of a large part of RES-related investments. This is because of geographic size and population, and, again, fits well to identified generation pattern – i.e. Italy remains being the largest RES power producer within the whole CESEC region up to 2050. Other countries of dominance in terms of investments (and corresponding market size) are Austria, Greece, Romania and Ukraine[30].

Figure 3.20 Comparison of average yearly investments in RES technologies across scenarios for the period 2021 to 2030 (left) and for the period 2031 to 2050 (right)



[30] Specifically in the years post 2030 RES-related investments are expected to increase significantly in Ukraine, boosting Ukraine on second place (after Italy) among all CESEC countries in the period 2031 to 2050.

Figure 3.21 Country-specific comparison of average yearly investments in RES technologies across scenarios for the period 2021 to 2030 (top) and for the period 2031 to 2050 (bottom)



Key findings are:

- The comparatively strong RES ambition under all assessed scenarios is also applicable in corresponding investment needs: within this decade (2021 to 2030) RES-related average yearly investments in the whole CESEC region vary from 7.7 to 9.9 billion €. In later years up to 2050, investments have to increase further, ranging from 12.1 to 15.8 billion € on average per year;
- At regional level, a strong difference between the EU Member States and the CP of the EnC is applicable: RES-related investment volumes are by a factor of 5 to 6 larger within the EU part of CESEC compared to the EnC part in early years up to 2030, in later years that difference is however getting smaller. Apart from differences in geographic size and population the lack of market readiness (i.e. currently prevailing barriers to RES deployment) is responsible for that;
- At country level, in accordance with generation pattern, Italy dominates the scene, acting as host of a large part of RES-related investments. Other countries of dominance in terms of investments (and corresponding market size) are Austria, Greece, Romania and, specifically in later years, Ukraine.

RES-related support expenditures

As final part in the discussion of the results concerning the future RES uptake within the CESEC region, this section is dedicated to inform on RES-related support expenditues. RES support is here defined as the difference between the required remuneration to cover the cost of a RES generation asset and the market value for the generated electricity. [31] That financial support is generally provided by a public support scheme like an auctioned feed-in premium system established at country level (or at a multinational level in case of RES cooperation). Support expenditures are then calculated by multipliyng the generation-specific support level with the amount of electricity generated over a certain time period (like a year). As common policy practice, RES-related support

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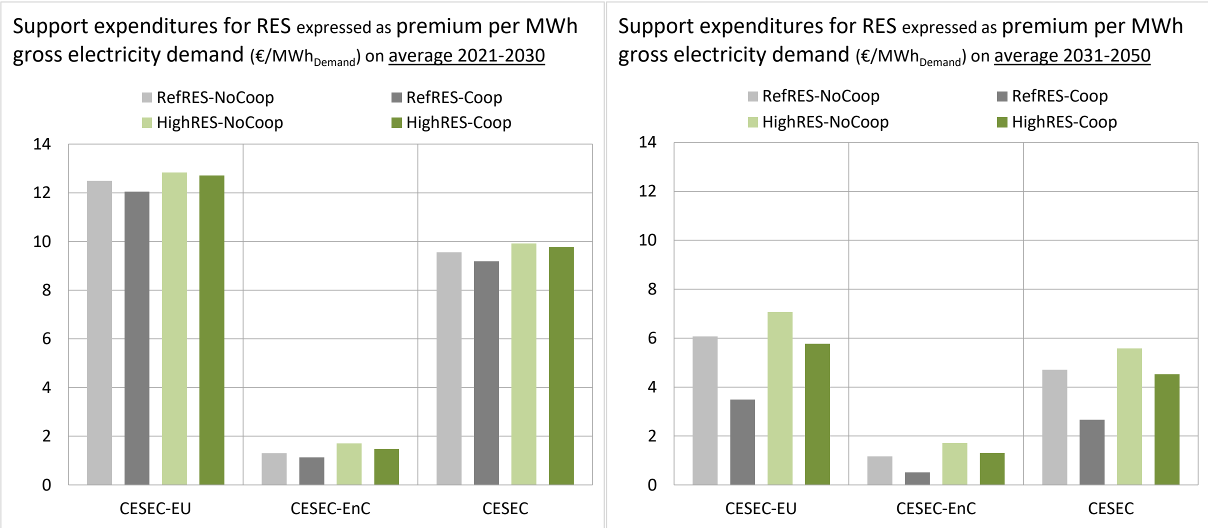
[31] Depending on details in policy design, support can however exceed the required remuneration of individual generation assets, for example if uniform support is provided for a set of generation assets to foster competition. Overcompensation may then arise for certain (low-cost) RES producer if the height of support is determined uniformly by the marginal generation asset required to meet the targeted RES deployment.

expenditures are then borne by electricity consumers via a levy on top of electricity prices.

As a starting point for the analysis of RES-related support expenditures, Figure 3.22, compares among all assessed scenarios the average RES-related support expenditures, expressed as premium per MWh gross electricity consumption. To indicate the development over time, a distinction is applied between early years, i.e. the period 2021 to 2030 (Figure 3.22, left), and later years, i.e. the period 2031 to 2050 (Figure 3.22, right). Complementary to that,

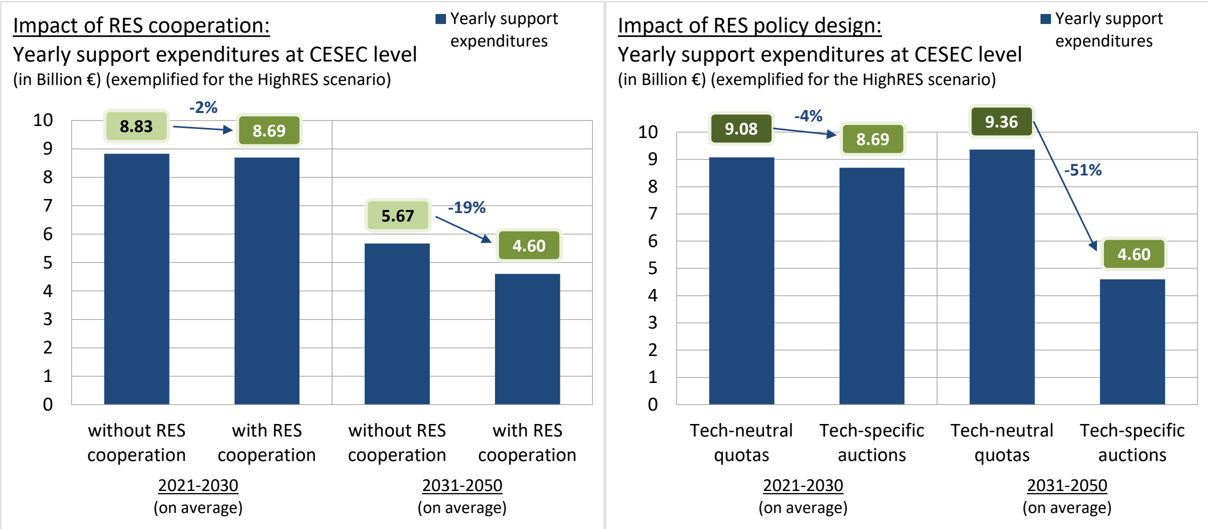
Figure 3.23 sheds light on two specific elements in RES policy practice that have an impact on the resulting direct policy cost, i.e. indicating average yearly RES-related support expenditures in absolute terms at CESEC level by time period: cross-border RES cooperation[32] and details in RES policy design – i.e., assessing whether a technology-specific or a technology-neutral policy instrument appears more appropriate for incentivicing the envisaged strong RES uptake.

Figure 3.22 Comparison of average RES-related support expenditures, expressed as premium per MWh gross electricity consumption, across scenarios for the period 2021 to 2030 (left) and for the period 2031 to 2050 (right)



[32] As discussed previously, here in modelling the ultimate form of cross-border RES cooperation is presumed, implying free reallocation of future RES investments across all CESEC countries in both scenarios RefRES-Coop and HighRES-Coop.

Figure 3.23 Impact of RES cooperation (left) and of RES policy design (right) on RES-related support expenditures, exemplified at CESEC level for the HighRES scenario



The graphs above provide valuable insights as summarised below:

- The strong RES uptake proclaimed under all assessed scenarios comes at cost – but these cost, here assessed by means of required RES-related support expenditures, are comparatively moderate and expected to decline over time. Within this decade (2021 to 2030) average RES-related support expenditures in the whole CESEC region translate into a premium (or levy/fee) on top of electricity prices ranging from 9.2 (RefRES-Coop) to 9.9 € per MWh electricity consumption (HighRES-NoCoop). In later years (2031 to 2050), the amount of RES-related support expenditures are expected to decline further so that the corresponding premium on top of electricity prices would then vary between 2.7 (RefRES-Coop) to 5.6 € per MWh electricity consumption (HighRES-NoCoop) on average across the whole CESEC region. Why can one expect such a strong decline in RES-related support despite the envisaged strong RES uptake? Reason for the declining trend is that the bulk of support expenditures for RES in the electricity sector in this decade (2021 to 2030) will be dedicated to those RES systems installed until 2020 – i.e. across all scenarios they are responsible for about 80% of total RES-related support expenditures during that period. New RES installations being deployed in forthcoming years are expected to come at lower cost (compared to past RES installations) and consequently require less financial support, thanks to technological progress achieved and expected in forthcoming years. Apart from technological progress also the assumed increase in carbon prices and the improved market readiness, i.e. the in modelling presumed removal of currently prevailing RES barriers, plays a role in that;
- In accordance with patterns identified in RES generation or RES-related investments, within the CESEC region there is a strong difference also in RES-related policy cost between the EU Member States and the CP of the EnC applicable: RES-related support premiums as expressed in Figure 3.22 are by a factor of 7 to 11 larger within the EU part of CESEC compared to the EnC part in early years (up to 2030), in later years that difference is getting smaller (i.e. down to a factor of 4 to 7). As stated previously, this is mainly a consequence of differenes in geographic size and population but in early years also the fact that in past years less policy-driven RES deployment has been achieved in the EnC part is of relevance in this respect;
- RES cooperation can help to lower the policy cost burden. By the assumed full use of RES cooperation (done e.g. via region-wide or cross-border RES auctions) at CESEC level, total support expenditures for RES can be reduced by 2% in early years (up to 2030), and by 19% in later years (2031 to 2050) compared to the

default case where no such cooperation was presumed. Please note that cost savings are smaller in magnitude in early years because of the dominance of support for past RES installations (installed up to 2020 and not affected by (future) RES cooperation) during that time period;

- The other key parameter is the selection of an appropriate policy framework: Here, modelling reveals that targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective uptake of RES in the electricity sector. In the case of a strong RES uptake as proclaimed in the HighRES scenarios modelling results show cost savings in size of 4% in early years (up to 2030), increasing to 51% in later years (2031 to 2050 on average), when comparing average support under targeted RES policy approaches (e.g. RES auctions) with umbrella policy approaches (e.g. technology-neutral quotas with certificate trading). The comparatively small savings in early years are again because support for existing RES (installed up to 2020) is not affected by the RES policy design for incentivising the RES uptake in future years.

For informing on overall consumer impacts of the proclaimed future RES uptake

Figure 3.24 subsequently indicates the impacts electricity consumers may face, showing how on average across the whole CESEC region yearly consumer cost in specific terms (per MWh electricity consumption) are affected by the underlying RES ambition – i.e. assuming either a moderate (RefRES) or a strong RES uptake (HighRES), both with RES cooperation. Similar to above, a distinction is made between early (2021 to 2030) and later years (2031 to 2050). The cost elements taken up in that comparison comprise the wholesale electricity price and the RES-related support.[33]

The impact of the underlying RES ambition on consumer cost as shown in

Figure 3.24 is remarkable. Despite higher direct RES-related policy cost, i.e. higher support expenditures for RES, overall cost for consumer may in later years (2031 to 2050) even be lower under a strong RES uptake (HighRES) compared to a moderate one (RefRES). This is caused by lower wholesale electricity prices in the case of a stronger RES uptake – since variable RES with low operating cost dominate the wholesale market during more hours than in under reference conditions.

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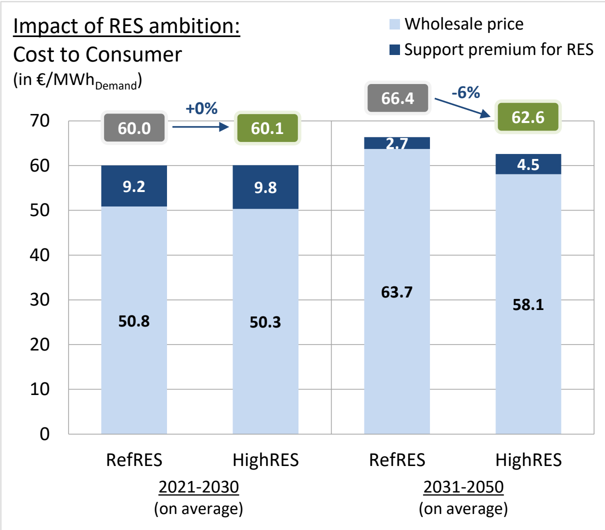
[33] The comparison of cost impacts on electricity consumer does however not provide the "full picture" since network charges as well as energy-related or general taxes are not taken into consideration. Taking these missing elements into consideration would require a detailed analysis by country, distinguishing between the various customer groups (e.g. households, industry, tertiary) for the tax or charging practices.

Figure 3.24 Impact of RES ambition on consumer cost in specific terms (per MWh electricity consumption), exemplified at CESEC level for the RefRES and the HighRES scenario (with RES cooperation)



Key findings are:

- The strong RES uptake proclaimed under all assessed scenarios comes at policy cost – but these cost, here assessed by means of required RES-related support expenditures, are comparatively moderate and expected to decline over time: support expressed as premium (or levy/fee) on top of electricity prices is expected to decline from 9.2-9.9 € per MWh electricity consumption in early years (2021-2030) to 2.7-5.6 € per MWh electricity consumption in later years (2031-2050);
- On average about 80% of total RES-related support expenditures within this decade (up to 2030) refer to existing RES (installed up to 2020). New RES installations deployed from 2021 onwards are much cheaper and consequently require less financial support compared to the bulk of existing RES plants;
- RES cooperation can help to lower the cost burden significantly. At CESEC level, policy cost savings in size of 19% can then be achieved in later years (2031 to 2050);
- The selection of an appropriate policy framework is of key importance: targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective strong RES uptake in the electricity sector. According to modelling, the difference in RES-related support expenditues is significant in the long term (until 2050): RES-related support expenditues can be cut to the half by applying targeted technology-specific RES policies instead of umbrella type of policy approaches.

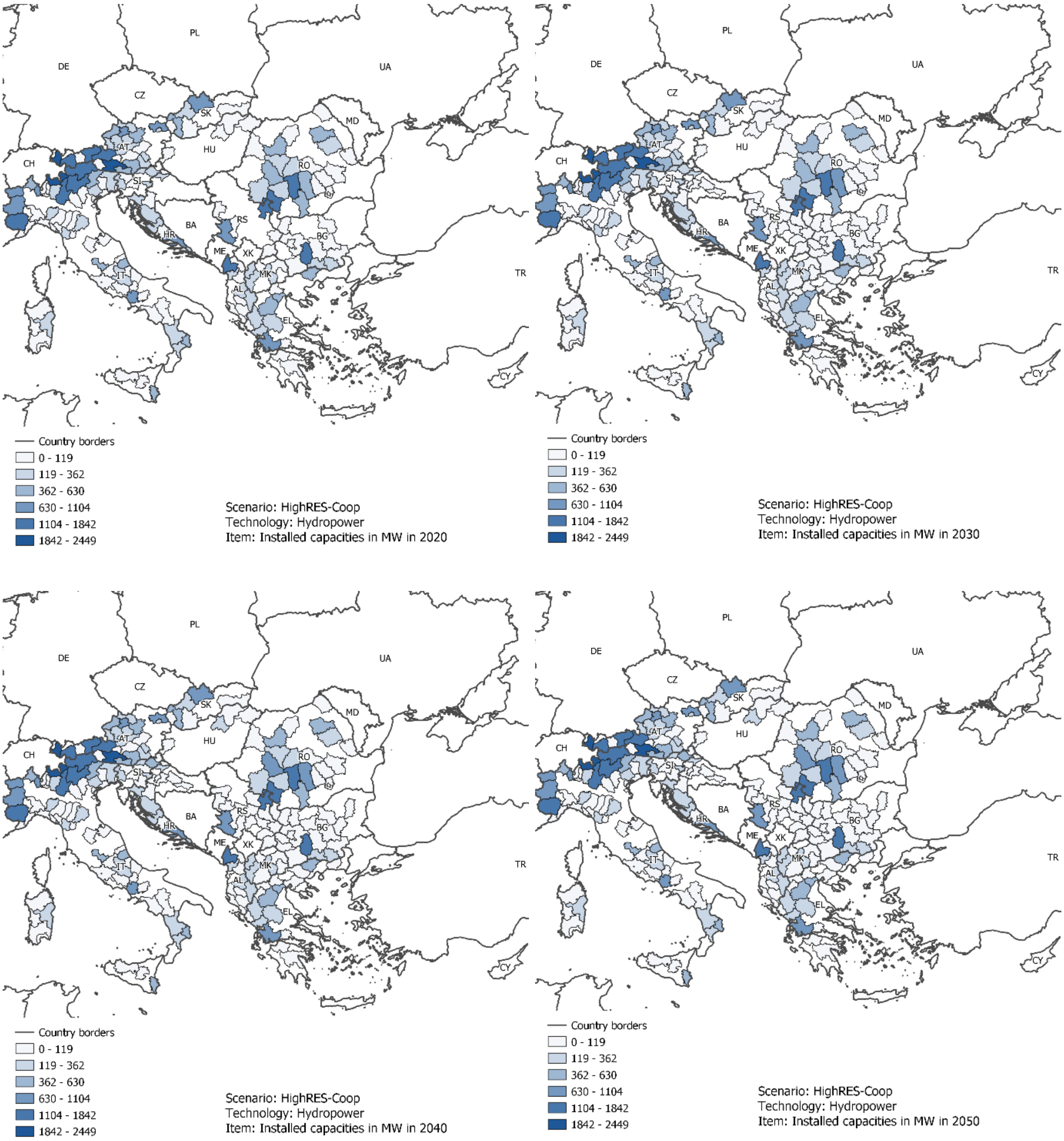
Identification of promising cross-border RES zones in the CESEC region

This section is dedicated to inform on the identified promising cross-border RES projects within the CESEC region, done here from a resource perspective that considers the economic viability as generation asset. The ultimate short-list of cross-border RES & infrastructure projects followed the grid-related analysis of this study.

The identification of promising RES projects and regions requires a detailed geographical mapping of the previously discussed modelling results on the future uptake of renewables in CESEC countries. This mapping exercise was performed for all key RES technologies from a current and forward-looking perspective, comprising hydropower, photovoltaics and wind energy[34]. The graphs below,

Figure 3.25 to Figure 3.28 , illustrate the development over time (2020 to 2050) in terms of cumulative installed capacities for all key RES technologies identified, exemplified for the scenario HighRES-Coop. Complementary to these graphs, Figure 3.29 offers a comparison of the long term (2050) deployment of RES among all assessed scenarios, indicating for each scenario the detailed regional distribution of cumulative installed capacities for the sum of key RES technologies (i.e. hydropower, photovoltaics and wind energy) by NUTS3 area within the CESEC region.

Figure 3.25 Mapping of current (2020) (left-top) and future (2030 (right-top), 2040 (left-bottom), 2050 (right-bottom)) hydropower installations in the CESEC region according to modelling (HighRES-Coop scenario)



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[34] Concerning wind energy, the mapping is constraint to onshore wind since modelling indicates that from a least-cost perspective (looking at generation assets) offshore wind would achieve only a negligible share in future power supply within the CESEC region. Technology-wise offshore wind is however ready for a stronger uptake, for example if barriers for other RES technologies like onshore wind prevail in certain countries.

Figure 3.26 Mapping of current (2020) (left-top) and future (2030 (right-top), 2040 (left-bottom), 2050 (right-bottom)) photovoltaic installations in the CESEC region according to modelling (HighRES-Coop scenario)

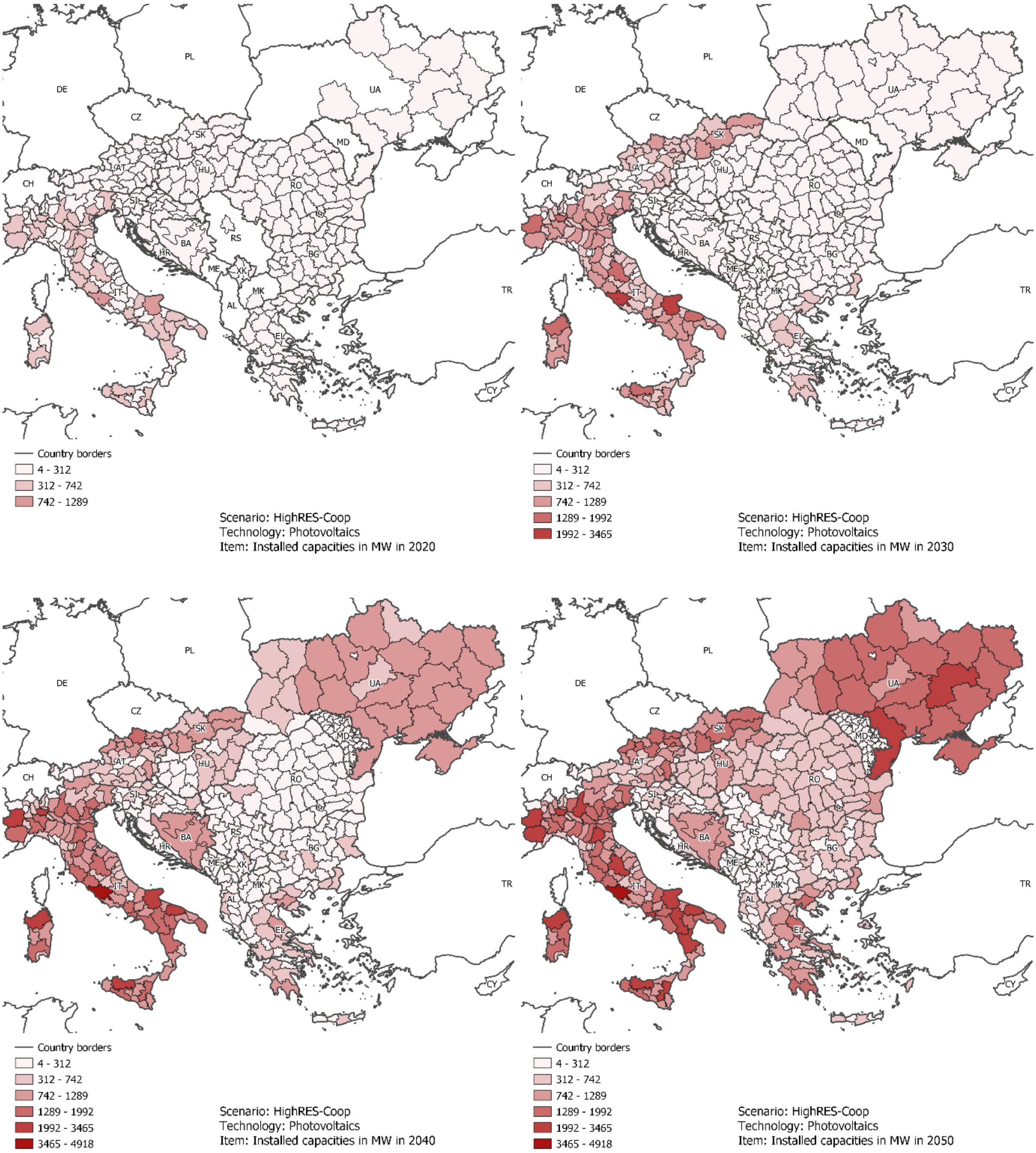


Figure 3.27 Mapping of current (2020) (left-top) and future (2030 (right-top), 2040 (left-bottom), 2050 (right-bottom)) wind onshore installations in the CESEC region according to modelling (HighRES-Coop scenario)

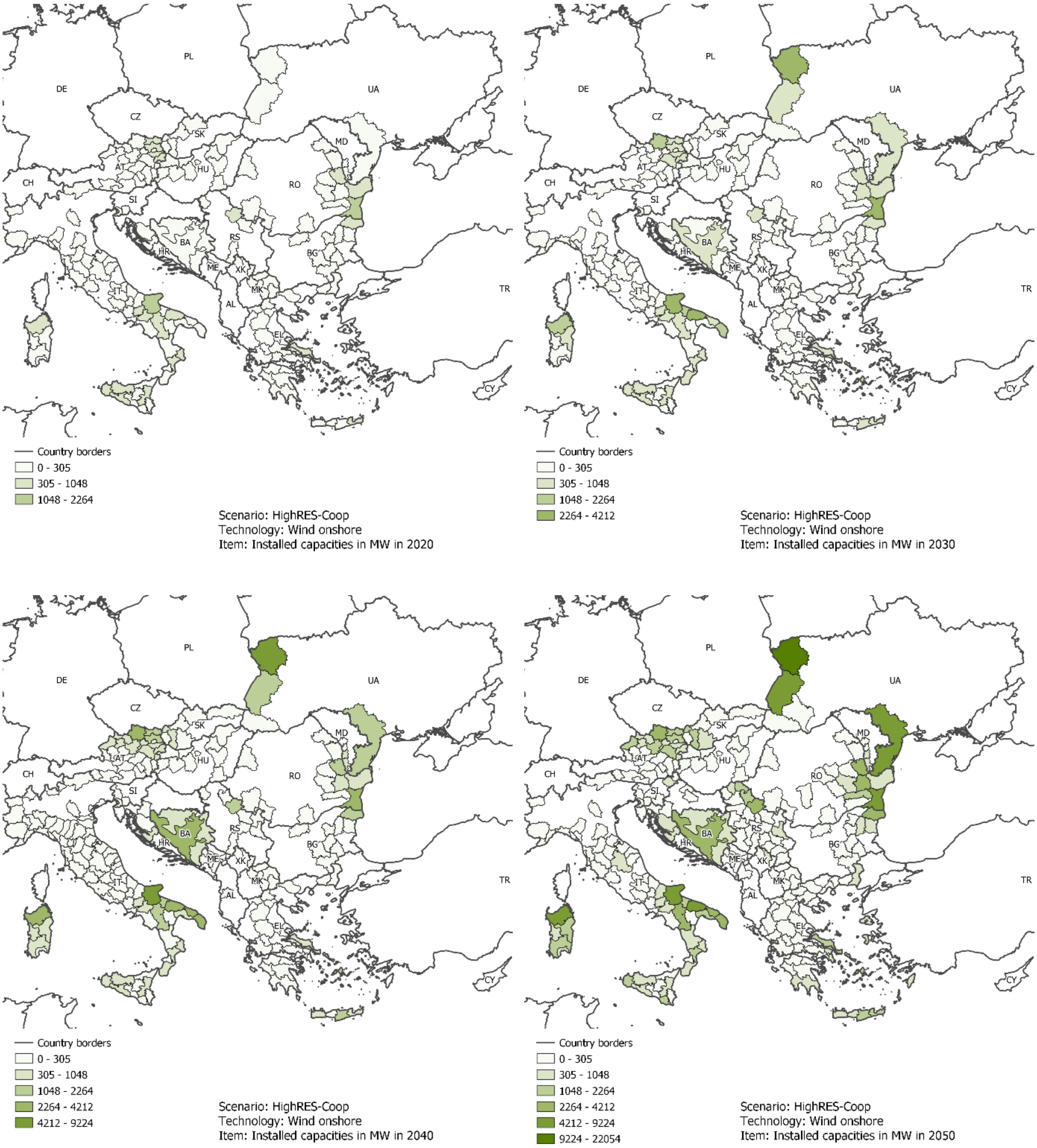


Figure 3.28 Mapping of current (2020) (left-top) and future (2030 (right-top), 2040 (left-bottom), 2050 (right-bottom)) installed capacities of <u>key RES technologies in total</u> (incl. wind, solar, hydro) in the CESEC region according to modelling (HighRES-Coop scenario)

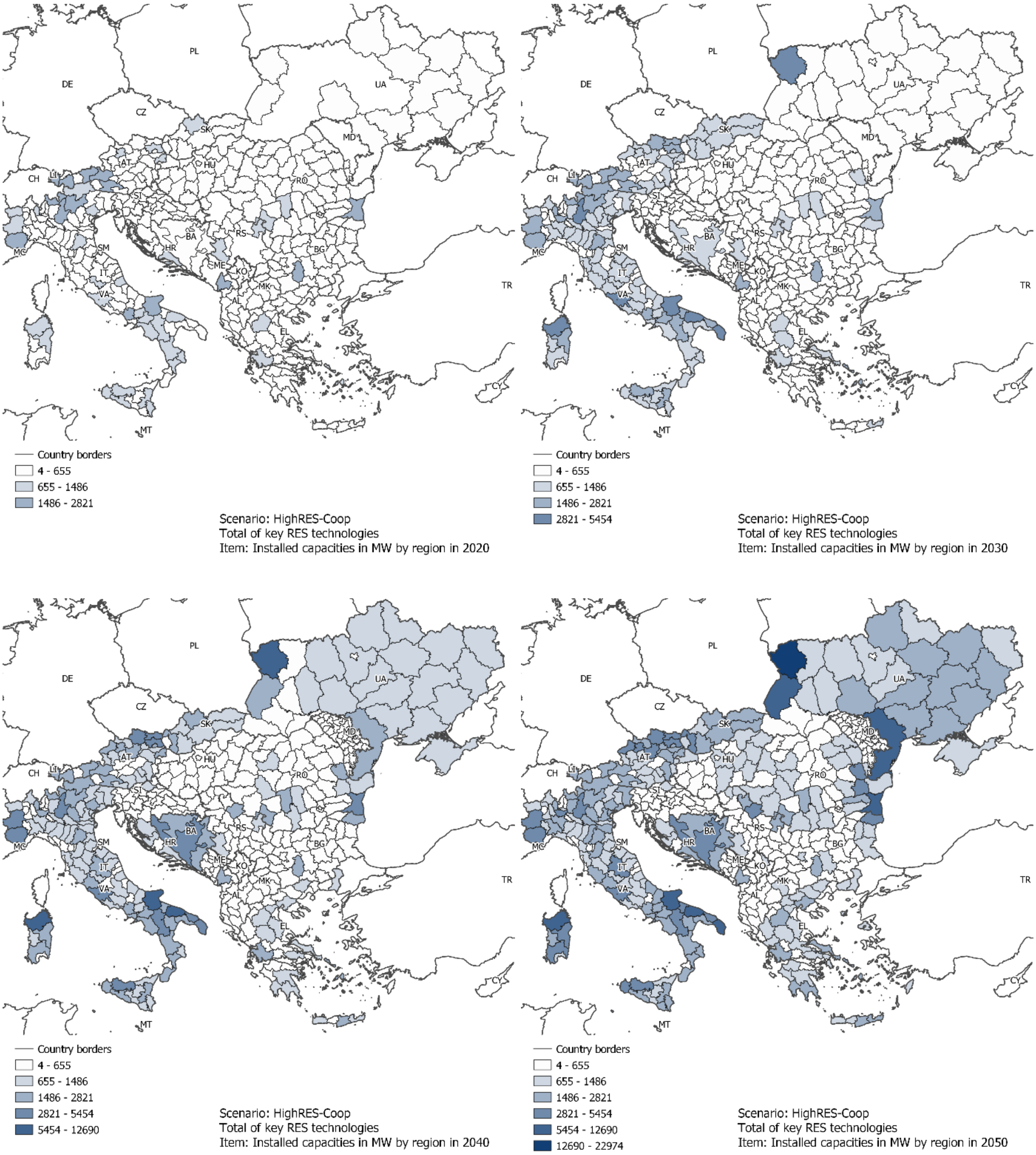
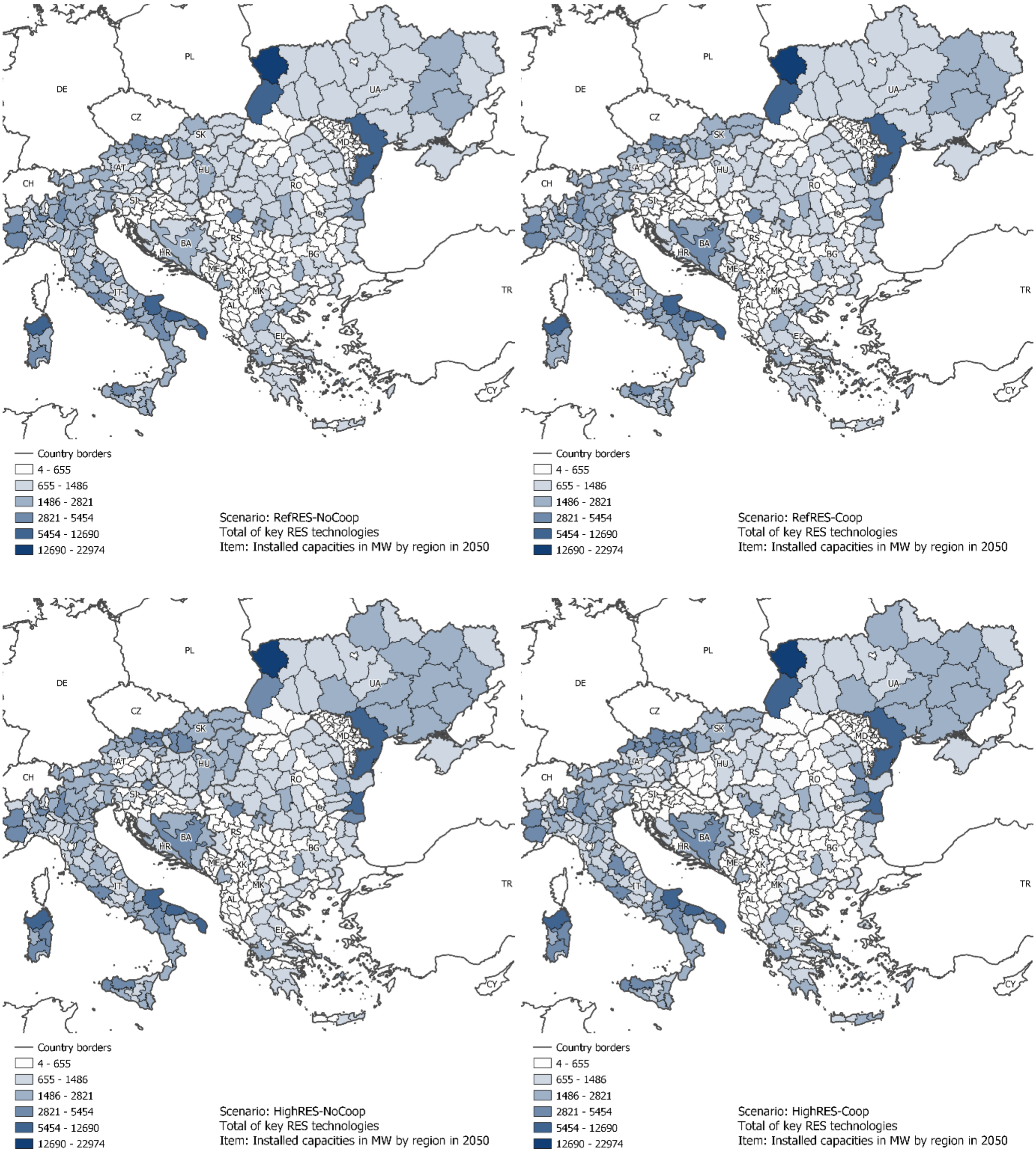


Figure 3.29 Comparison of the mapping of the installed capacities of key RES technologies in total (incl. wind, solar, hydro) in the CESEC region by 2050 according to all modelled RES scenarios (RefRES and HighRES, with and without cross-border RES Cooperation)



The mapping exercise performed within this study for the CESEC region reveals the massive energy transition envisaged. Renewables are expected to dominate the power supply in the future and this is getting apparent also in the widespread of their geographical distribution. Thanks to photovoltaics, a key technology already today and in future, which represents a promising generation asset at a local level, one can identify the broadened geographical distribution of RES installations. If certain areas offer economically viable potentials also for other key RES technologies like onshore wind the power density increases significantly. This is applicable from the graphs above across the whole CESEC region. Thus, the combination of solar PV and wind energy at regional, partly accompanied by mainly existing hydropower installations, allows identifying those areas with the most promising site conditions, serving as a basis for further elaboration of cross-border RES and infrastructure cooperation.

The outcomes of that ex-post analysis of modelling results are illustrated in

Figure 3.30 . This graph provides at NUTS3 level a mapping of the installed capacities of key RES technologies in total (incl. wind, solar, hydro) in the CESEC region by 2050, using averages across all assessed scenarios (i.e RefRES and HighRES scenarios, with and without cooperation) for that purpose. Moreover, this graph also maps the identified promising cross-border RES zones in accordance with the approach described above. Here identified RES zones are framed in red and numbered (A to K). Complementary to

Figure 3.30 , Table 3.19 provides an overview of these zones, informing on their location, the characteristics of the underlying renewable sources and their projected use by 2050. Further details on identified promising cross-border RES zones, including for example a NUTS3 coding and naming) are provided in Annex 4.

Figure 3.30 Detailed overview on the mapping of the installed capacities of key RES technologies in total (incl. wind, solar, hydro) in the CESEC region by 2050, indicating averages across all scenarios (RefRES and HighRES, with and w/o cooperation) and <u>mapping of identified promising cross-border RES zones</u>

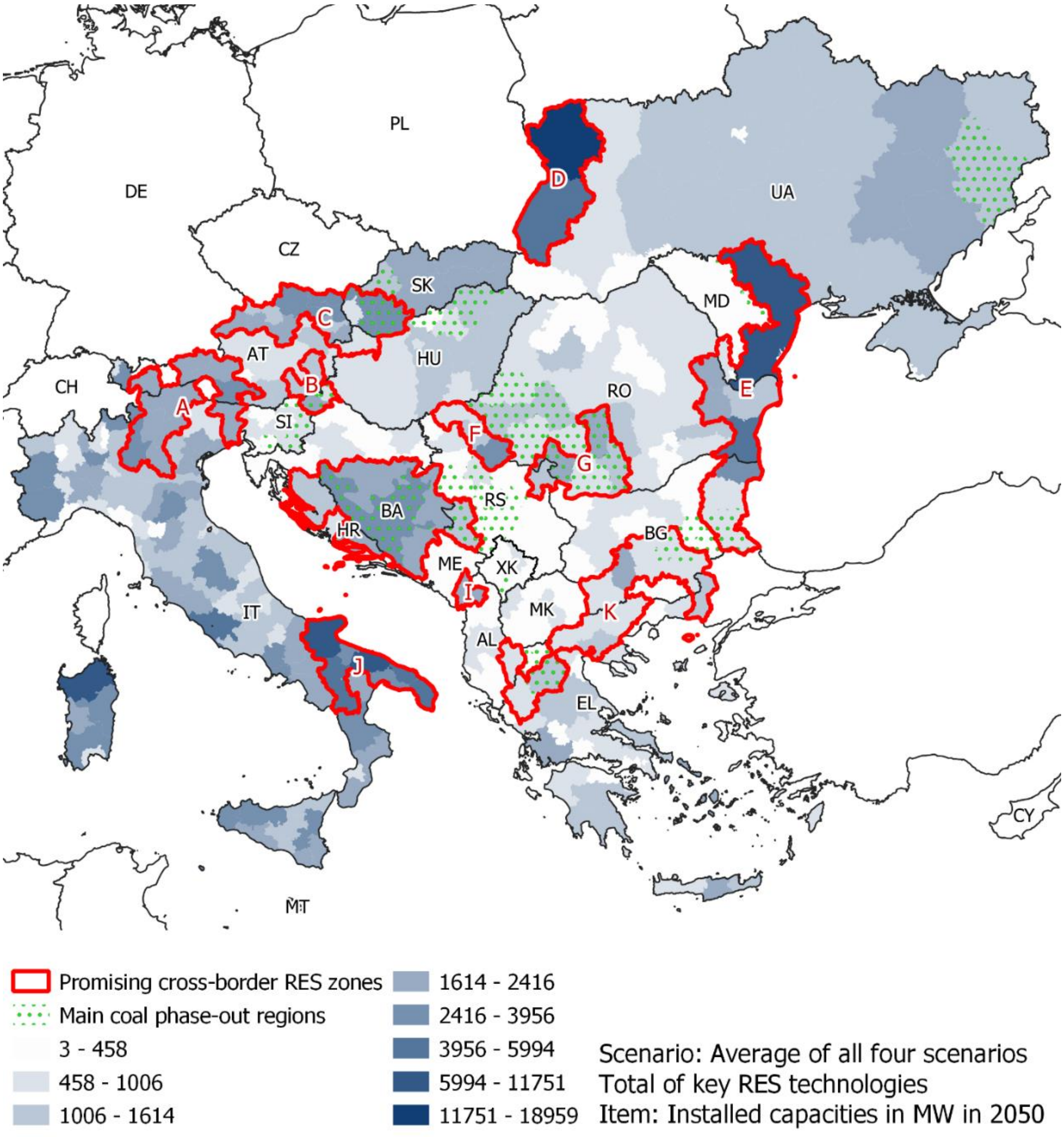


Table 3.19 Overview on identified promising cross-border RES zones in the CESEC region

Cross-border RES zone: A

Location: Cross-border region at the Western part of Austria and the North-East of Italy

RES characterics: Strong dominance of storage hydropower in mountainous parts, complemented by photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	18	11377	8823	20218
Maximum	18	11489	9872	21375
Average	18	11443	9404	20865

Cross-border RES zone: B

Location: Cross-border region at the Southern part of Austria and the North of Slovenia

RES characterics: Balanced mix of wind, hydropower and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	118	655	2642	3562
Maximum	2974	659	3830	7463
Average	1004	658	3329	4991

Cross-border RES zone: C

Location: Cross-border region at the North-Eastern part of Austria, the South of Slovakia and the North-Western part of Hungary

RES characterics: Wind is available at several hotspots at favourable conditions (despite not used equally in all three countries involved), combined with run-of-river hydropower and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	6519	3361	13543	23423
Maximum	14513	3465	22062	39825
Average	9785	3419	18059	31263

Cross-border RES zone: D

Location: Western part of Ukraine, close to the Slovakian and Hungarian border

RES characterics: Wind is available in this region at favourable conditions, waiting to be exploited at large scale and complemented by some photovoltaics in mainly rural areas.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	20513	0	1692	22526
Maximum	28025	0	2017	30042
Average	22973	0	1865	24838

Cross-border RES zone: E

Location: Black sea region involving the Southern part of Ukraine and Moldova as well as the Eastern coast areas of Bulgaria and Romania

RES characterics: Wind is generally available in this region at favourable conditions, waiting to be exploited at large scale. Furthermore, this is complemented by photovoltaics and minor small-scale hydro developments.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	8642	41	6392	16121
Maximum	24079	46	7993	31158
Average	16139	43	7352	23535

Cross-border RES zone: F

Location: The Northern part of Serbia at the border to Hungary and Romania

RES characterics: Wind offers promising potentials in this area, complemented by photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	3161	0	568	3993
Maximum	7460	0	1069	8275
Average	5386	0	821	6207

Cross-border RES zone: G

Location: The South(-East)ern border region of Romania, combined with the Serbian border region Borska oblast.

RES characterics: Hydropower and photovoltaics are the major renewable sources available, complemented by comparatively limited wind resources.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	154	4454	2170	6999
Maximum	271	4823	2731	7578
Average	209	4593	2534	7335

Cross-border RES zone: H

Location: Cross-border region involving the Southern part of Croatia, Bosnia & Herzegovina and the Serbian province Zlatiborska oblast.

RES characterics: Balanced mix of wind, hydropower and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	2691	2429	2740	8037
Maximum	6888	2452	3914	13112
Average	4730	2445	3321	10496

Cross-border RES zone: I

Location: The Albanian region Shkoder at the border to Montenegro.

RES characterics: This region offers promising potentials for hydropower, complemented by wind and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	10	1501	278	1807
Maximum	178	1510	290	1969
Average	103	1506	285	1894

Cross-border RES zone: J

Location: Provinces at the Eastern stretch of Italy, directly at or close to the Adriatic coast and in close distance to Albania.

RES characterics: This region offers favourable potentials for wind, complemented by photovoltaics and a comparatively negligible amount of small-scale hydropower.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	23083	115	14078	37967
Maximum	29074	115	14942	43337
Average	26592	115	14510	41217

Cross-border RES zone: K

Location: Cross-border region involving Southern provinces of Bulgaria, regions in the North of Greece and the Eastern stretch of Albania.

RES characterics: This region offers favourable potentials for photovoltaics and hydropower, complemented by wind at certain hotspots.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	305	3622	8096	12186
Maximum	499	3785	10530	14673
Average	353	3702	9503	13559

*Remark on installed capacities:
Tables show ranges for cumulative installed capacities of key RES technologies by 2050, stemming from the four RES scenarios analysed in this study (i.e. RefRES and HighRES scenarios - both with and without cross-border RES cooperation).

3.3 Key Findings

- **The CESEC region offers promising potentials for renewables.** This was applicable from a literature review and **confirmed by the complementary GIS-based analysis** conducted in the course of this study for two of the most promising generation assets, solar and wind:
  - For solar PV, promising site conditions are widely spread but specifically in the Southern parts of the CESEC region and of each respective country. Thanks to significant technological progress achieved throughout past decades, this generation asset became however economically viable even under less promising resource conditions as actual market developments have proven across the whole continent and worldwide. Thus, it can be expected that solar PV will become an important generation asset at the local and central level in future years;
  - Onshore wind energy offers promising site conditions in several CESEC countries. The site quality in the Ukraine is remarkable, where according to the meteorological data at hand, similar conditions to offshore developments in the North of Europe are applicable. Promising sites are also applicable in several parts of Italy, in Bosnia and Herzegovina, at the border of Austria, Hungary and Slovakia, at the North-Eastern border of Bulgaria, in Eastern parts of Romania and at several locations within Greece to name a few examples. In general, wind onshore has become a major generation asset within Europe and globally thanks to achieved technological progress and the related economic viability;
  - Offshore wind offers promising site conditions in the Adriatic / Mediterranean Sea between Italy and Albania, at several locations within the Greek sea territory and in the Black sea area of Romania and Ukraine. There is however a strong competition to onshore wind which is available at comparatively similar site conditions but comes at present at significantly lower cost, specifically in the Black Sea area (within Ukraine).
- **The mapping exercise performed within this study for the CESEC region reveals the massive energy transition envisaged**. For analysing the uptake of renewables in the electricity sector of the CESEC region, two perspectives have been assessed: One in accordance with national planning (NECP perspective and corresponding RefRES scenarios), and another one that reflects Green Deal needs (HighRES scenarios). For both scenarios, the impact of cross-border RES cooperation was analysed:
  - In the short term (2030), only a small difference in the RES-E share is applicable within the CESEC region between these two perspectives: 49% (RefRES scenarios) vs 53.1% (HighRES scenarios) as a consequence of ambitious policy planning in certain countries and/or practical limits to market growth in several others;
  - By 2050, stronger differences in the RES-E shares at CESEC level are applicable: 75-77% with a moderate climate and RES ambition (RefRES scenarios) vs 85-87% when following the climate neutrality objective (HighRES scenarios);
  - A "level playing field" for the RES uptake over a long period as assumed in the scenarios of full cooperation would lead to a strong reallocation of RES investments, given the partly vast renewable potentials applicable within certain countries or regions.
- **The power mix is expected to change significantly** within the CESEC region:
  - Technology-wise, results clarify that the dominance of hydropower in electricity supply is expected to diminish across the CESEC region. Solar electricity (from photovoltaic systems) and wind power (onshore wind) will become the major contributor to future electricity supply. This trend is observable under all scenarios assessed;
  - Region-wise it can be concluded that the imposed challenge differs: EU Member States in the CESEC region have to achieve a doubling of RES generation whereas Contracting Parties of the Energy Community have to achieve an increase by more than a factor of four;

    - Country-wise, Italy remains the largest RES power producer within the CESEC region. Other countries of dominance in terms of market size are Austria, Greece, Romania and expectably Ukraine;
    - The changes in power technology mix indicate, apart from wind, the proclaimed strong uptake of photovoltaics within the whole CESEC region: Both decentral and central PV systems are expected to become the largest contributor to power supply in capacity terms, imposing a challenge for grid integration.
- **The uptake of renewables requires strong investments and comes at moderate policy cost** since new RES installations deployed from 2021 onwards are much cheaper and consequently require less financial support compared to the bulk of existing RES plants. Key findings related to investments and policy cost are:
    - Strong investments are required to let the uptake of renewable become a reality: RES-related average yearly investments in the whole CESEC region vary from 7.7 to 9.9 billion € within this decade (up to 2030). In later years up to 2050, investments have to increase further, ranging from 12.1 to 15.8 billion € on average per year;
    - The strong RES uptake proclaimed under all assessed scenarios comes at policy cost – but these costs, here assessed by means of required RES-related support expenditures, are comparatively moderate and expected to decline over time. Within this decade (2021 to 2030) average RES-related support expenditures in the whole CESEC region translate into a premium (or levy/fee) on top of electricity prices ranging from 9.2 to 9.9 € per MWh electricity consumption. In later years (2031 to 2050), the amount of RES-related support expenditures is expected to decline further so that the corresponding premium on top of electricity prices would then, depending on the underlying RES ambition, vary between 2.7 to 5.6 € per MWh electricity consumption on average across the whole CESEC region;
    - RES cooperation can help to lower the policy cost burden. At CESEC level only small cost savings in size of ca. 2% appear feasible in the period up to 2030 – but in the long term, once an adequate market readiness is achieved across the whole region and once support for past RES installations (installed up to 2020) has been phased out, RES cooperation may trigger savings up to 19% in total RES-related support expenditures;
    - The selection of an appropriate RES policy framework is of key importance: targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of technology-specific auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective uptake of RES in the electricity sector. By doing so, in modelling policy cost savings compared to a technology-neutral policy approach (that applies a marginal pricing concept) range up to 51% in the long term (2031 to 2050).
- **The mapping exercise performed reveals a broad set of promising highest-potential renewable zones spread across the CESEC region**, serving as a basis for further elaboration of cross-border RES and infrastructure cooperation. A shortlist of such areas/zones – identified from a techno-economic resource perspective - comprises:
    A. (AT-IT): Cross-border region at the Western part of Austria and the North-East of Italy – with strong dominance of storage hydropower in mountainous parts, complemented by photovoltaics;
    B. (AT-SI): Cross-border region at the Southern part of Austria and the North of Slovenia – offering a balanced mix of wind, photovoltaics and hydropower;
    C. (AT-HU-SK): Cross-border region at the North-Eastern part of Austria, the South of Slovakia and the North-Western part of Hungary – with wind available at several hotspots at favourable conditions (despite not used equally in all three countries involved), combined with run-of-river hydropower and photovoltaics;

D. (UA): Western part of Ukraine, close to the Slovakian and Hungarian border – with favourable wind conditions, waiting to be exploited at large scale and complemented by some photovoltaics in mainly rural areas;
E. (BG-MD-RO-MD): Black sea region involving the Southern part of Ukraine and Moldova as well as the Eastern coast areas of Bulgaria and Romania – with wind generally available at favourable conditions, waiting to be exploited at large scale, complemented by photovoltaics and minor small-scale hydropower developments;
F. (RS): Northern part of Serbia at the border to Hungary and Romania – with promising wind potentials, complemented by photovoltaics;
G. (RO-RS): South(-East)ern border region of Romania, combined with the Serbian border region Borska oblast – offering a balanced mix of hydropower and photovoltaics, complemented by some wind developments at best available sites;
H. (BA-HR-RS): Cross-border region involving the Southern part of Croatia, Bosnia & Herzegovina and the Serbian province Zlatiborska oblast – offering a balanced mix of wind, photovoltaics and (mainly existing) hydropower;
I. (AL): Albanian region Shkoder at the border to Montenegro – providing a balanced mix of wind and photovoltaics, complemented by (mainly existing) hydropower;
J. (IT): Provinces at the Eastern stretch of Italy, directly at or close to the Adriatic coast and in close distance to Albania – with favourable wind sites still waiting to be exploited and room for a strong uptake of photovoltaics;
K. (AL-BG-EL): Cross-border region involving Southern provinces of Bulgaria, regions in the North of Greece and the Eastern stretch of Albania – offering favourable potentials for photovoltaics and (mainly existing) hydropower, complemented by wind at certain hotspots.

4 Connecting infrastructure needs

In this section, the results of the scenario with existing (subsection 4.1) and already planned infrastructure projects (subsection 4.2) are presented, followed by the identification of further infrastructure needs in the region (subsection 4.3). As shown above, several projects are already foreseen to come into operation in the oncoming years, thus it is important to evaluate whether these capacities would be sufficient to enhance the integration of an ambitious amount of renewable energy in the coming decades.

Market integration effects of infrastructure projects are measured through the changes in wholesale electricity prices, price differences between markets and commercial congestions as already planned projects are proven to help market integration significantly. RES integration is first of all captured through changes in RES curtailment, which shows a different pattern country by country. The analysed projects seem to have a less significant effect on CO2 emissions (typically between 1-6%[35]) and the reserve capacity mix. Security of supply is captured by quantifying missing reserve capacities and energy not supplied values. In this dimension, only a few problematic markets are identified, and the results indicate that the analysed projects cannot solve these issues alone.

Finally, socio-economic (welfare) changes are also presented to assess the effects of already planned projects, and those needed ones identified in this assessment. The results indicate that if the already planned projects are realised (e.g. CESEC initiative and PECIs), only a limited number of additional projects are required to cope with the increasing RES deployment in the region, and realise most of the attainable welfare benefits. It seems that the average cost of projects the region plans and needs are lower compared to e.g. the average cost of PCI projects, and they generate higher net welfare gains if the RES penetration grows faster in the future.

4.1 Identification of potential grid bottlenecks

Market integration and price developments

Present market integration levels are best characterised by converging wholesale price levels. In the CESEC region, market integration obviously cannot be maintained in the long-run without investing in new infrastructure projects. This is visible from the projected prices already in 2030, but price differences are much higher in 2050 if no new infrastructure elements are put in place besides the ones already under construction.

The overall average price level in the CESEC region is quite stable across the scenarios in 2030: the weighted average baseload wholesale price is 54-56 €/MWh in all RES scenarios. There are significantly higher differences in 2050: in the Reference RES scenarios the average prices are 100 and 102 €/MWh respectively in case of cooperation and no-cooperation in achieving targets, while high RES penetration helps reducing wholesale prices to the 72-73 €/MWh range. Prices in individual countries spread over a wider range, in 2050 in some scenarios reaching extreme levels, especially in the Western Balkan six (WB6) countries (see country details in Annex 6). It should be emphasised, that the grid infrastructure assumed in these model runs is highly unrealistic, with no new lines put in place other than the ones that are already under construction. The high price differences – and thus very high prices in some countries – indicate that the existing grid alone is not enough to sufficiently serve the efficient functioning of electricity markets in the region in 2050.

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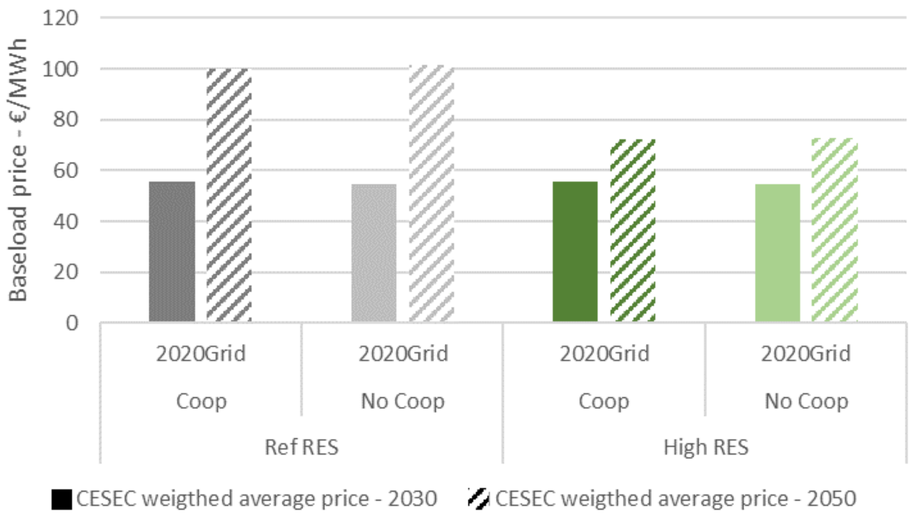
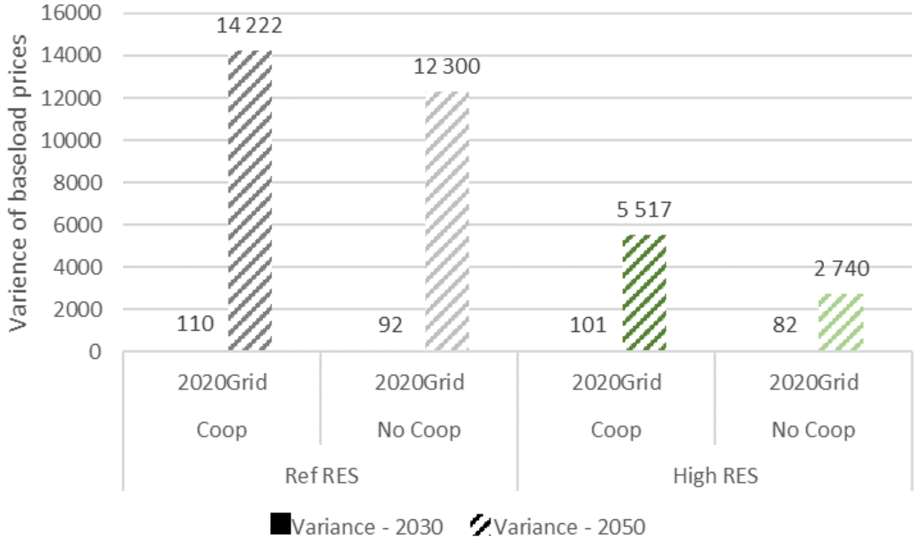
[35] there is only one scenario and year, where a higher, 36% emission reduction takes place as a result of infrastructure developments.

Figure 4.1 Weighted average wholesale baseload prices in the CESEC region, with existing grid, 2030, 2050



The variance of prices can be an indicator to measure market integration in a region. Figure 4.2 shows that in 2050 not only prices are the highest in the Reference RES case, but also the variance of prices is extremely high. Higher RES penetration significantly limits the price increase from 2030 to 2050, by reducing the number of hours when non-renewable plants are price setters. In case of more ambitious renewable targets, the region-wide cost-effective installation of renewable plants in the cooperation case leads to somewhat higher differences among prices than what is observable in the more balanced no-cooperation case. Still, without new infrastructure power markets are much more segmented in the CESEC region in 2050 than today.

Figure 4.2 Variance of wholesale baseload prices in the CESEC region, with existing grid, 2030, 2050

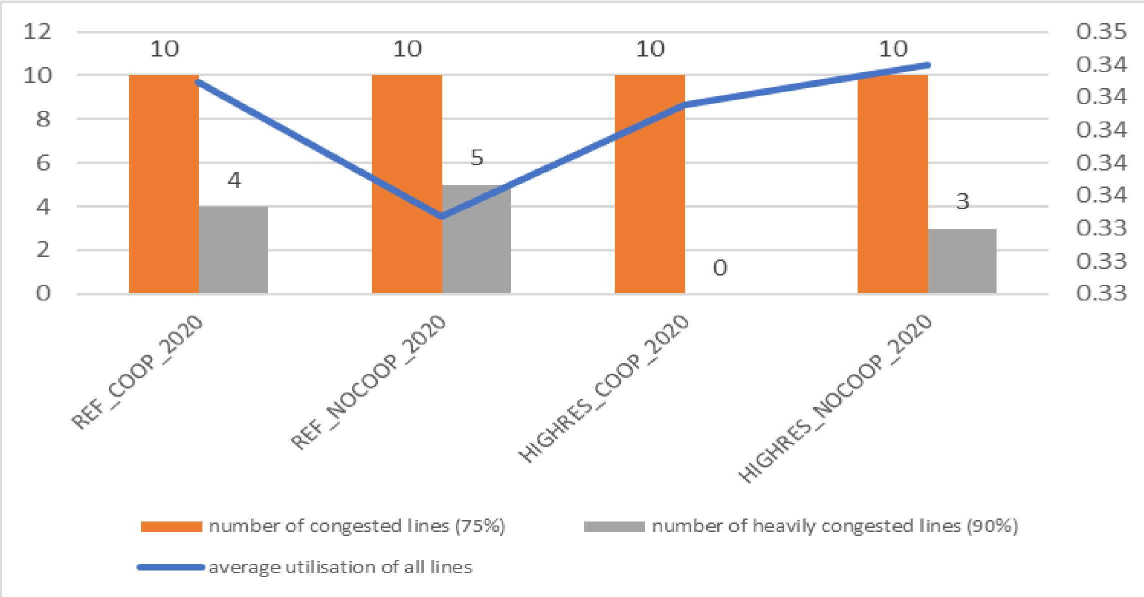


In parallel with wholesale electricity prices, it is also important to analyse commercial congestions on the European grid. Two main indicators were defined helping to identify and evaluate congestions. These are the number of fully congested hours at a given border, and the yearly average utilisation of the power lines.

Yearly average utilisation was defined as a ratio of the total energy transferred in the selected year in one direction divided with the total yearly available transfer capacity of the same direction. Those lines were considered commercially congested, where the yearly average utilisation exceeded 75%. Also, a category "heavily congested lines" was created, for those interconnectors where this utilisation rate was higher than 90%.

In this section, the results associated with the currently existing grid are presented. Figure 4.3 summarises the results with respect to interconnector congestion in all four renewable scenarios in 2030. For the four scenarios, the first column shows the number of congested, while the second column indicates the number of heavily congested interconnectors. The number of congested lines in the graph also incorporates the heavily congested ones. On the secondary axis, the total average utilisation of all lines is measured (indicated by the blue line in the Figure), considering those interconnectors which connect two CESEC countries.

Figure 4.3 Number of commercially congested and heavily congested borders (left axis) and average utilisation of all lines (right axis, %) with existing infrastructure, 2030



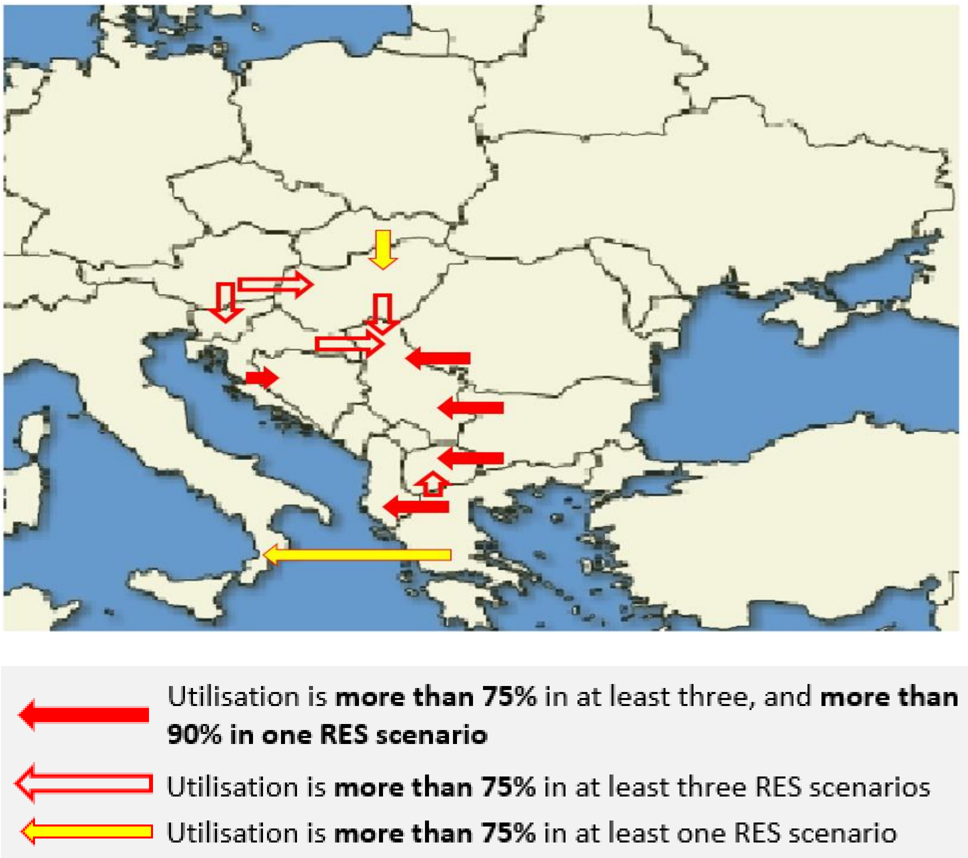
The graph illustrates, that the average utilisation of all interconnectors associated with the CESEC region is stable across the four scenarios. In all cases, this value lies between, 33% and 35%. The number of commercially congested lines are also relatively similar in the four investigated scenarios, serious differences are not identifiable neither with respect to cooperation nor in relation with reference or high RES penetration in 2030.

In all scenarios, a total of 10 borders where the utilisation rate is more than 75% were identified in the CESEC region. This large yearly utilisation means that, at these borders, commercial congestion occurs throughout a whole year, which makes price convergence within the affected countries impossible. In terms of borders with more than 90% of utilisation, the four scenarios slightly differ, with no such borders in the high RES and cooperation scenario, and four borders in the Reference RES no cooperation case.

This finding is in line with the conclusions formulated based on the analysis of wholesale electricity prices. At the beginning of this subsection, when price differences were analysed, the result showed that when higher RES penetration is assumed, renewable power sources more often act as price determinants, therefore price differences between countries are smaller and less common. As a result of smaller price differences, it is less likely that congestions occur.

Beyond the number of lines, it is more important to identify those borders where commercial congestion occur, which is shown in Figure 4.4 The map aggregates all four RES scenarios in 2030 and identifies those borders, where interconnectors are congested in most or some scenarios.

Figure 4.4 List of commercially congested borders with existing infrastructure, 2030



Dark red lines represent those borders where out of the four RES scenarios average yearly utilisation was larger than 75% in at least three cases while in at least one case the yearly utilisation even surpassed 90%. The analysis showed that with existing infrastructure significant commercial congestion is present in the system, with many lines which are fully used in the whole year. The most congested lines (dark red) are mainly centred in the Balkan region, where Greece-Albania, Bulgaria-North Macedonia, Bulgaria-Serbia, Romania-Serbia, and Croatia-Bosnia are the most commercially congested borders. In addition, there are several borders where the average utilisation rate does not reach 90% but is more than 75% in at least three scenarios (light red), so can be considered as commercially congested in 2030 with existing infrastructure. Such borders are the Austria-Slovenia, Austria-Hungary, Hungary-Serbia, Croatia-Serbia, and Greece-Macedonia ones. Finally, there are two borders where commercial congestion only occurs in one RES scenario, which are Slovakia-Hungary and Greece-Italy borders.

Yearly average utilisation however, can be a misleading indicator as it is not able to fully cover for seasonal variation. Therefore, the number of fully congested hours was also calculated from the model results. Table 4.1 shows the five most commercially congested borders based on this calculation in the CESEC region, with existing infrastructure assumed in 2030. The table shows average values across the four modelled RES scenarios.

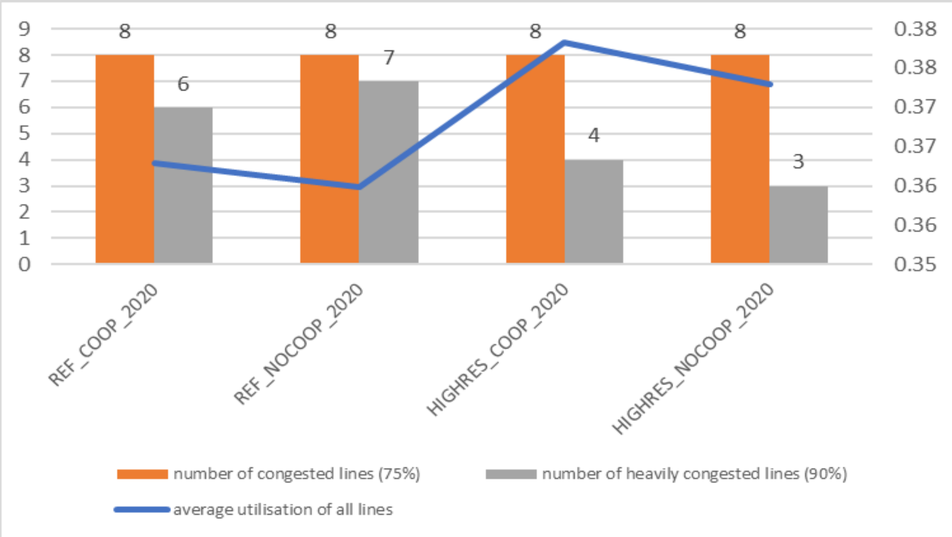
Table 4.1 Five most commercially congested borders based on the number of fully congested hours in the existing grid scenario, 2030

Existing grid		
Country A	**Country A**	**Number of congested hours**
EL	EL	7 103
BG	BG	6 845
RO	RO	6 761
HR	HR	5 658
AT	AT	5 564

The identified borders are the same which were highlighted based on yearly average utilisation, but the number of congested hours present a more sophisticated view on commercial congestion. Based on the calculations, the most congested border in 2030 - if no new infrastructure was to be built - is the Greece (EL)-Albanian (AL) lines, where full commercial congestion occurs in more than 7100 hours of the year out of the total 8760. More than 6000 fully congested hours were modelled for Romania (RO)-Serbia (RS) and Bulgaria (BG) – Serbia (RS), while more than 5000 for Croatia (HR)-Bosnia (BA) and Austria (AT) -Slovenia (SI).

The same calculations of yearly average utilisation and number of commercially fully congested hours were made for the year 2050 as well, with existing cross-border projects assumed. Figure 4.5 shows the average yearly utilisation of CESEC region interconnectors in the four different RES scenarios.

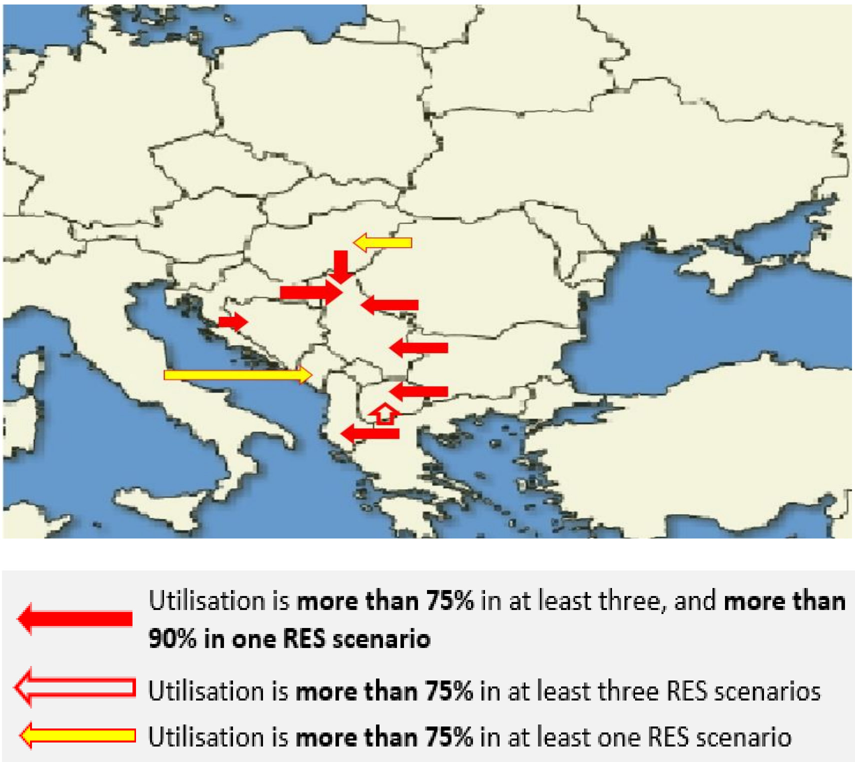
Figure 4.5 Number of commercially congested and heavily congested borders (left axis) and average utilisation of all lines (right axis, %) with existing infrastructure, 2050



The Figure shows that similar to 2030 - if no new projects will be built in the CESEC region - the number of heavily utilised lines will be approximately the same in the four RES scenarios in 2050. However, several important changes can be observed which are different in the 2050 results. First the total number of congested lines slightly decrease relative to 2030, as in all scenarios there are only 8 borders where yearly average utilisation is larger than 75%. On the other hand, these borders became more commercially congested as significant portion of them (depending on scenario) operates with a utilisation rate more than 90% as well, which is a clear representation of serious grid bottlenecks. This tendency is more severe when Reference renewable penetration was assumed and less so with higher RES penetration.

From Figure 4.6 it is also visible that the location of the heavily commercially congested lines in 2050 slightly changed relative to 2030.

Figure 4.6 List of commercially congested borders with existing infrastructure, 2050



In 2050 the heavily congested borders disappear from the Western CESEC region (Austria, Slovenia, Hungary, Slovakia), however, very serious congestion is indicated by the modelling results in the Balkan. Very high yearly average utilisation rate occurred (dark and light red) in the modelling at the Hungarian-Serbian, Croatian-Serbian, Croatian-Bosnian, Romanian-Serbian, Bulgarian-Serbian, Bulgarian-North Macedonian, Greek-North Macedonian and Greek-Albanian borders. Also, commercial congestion was detected in at least one scenario (yellow) in the Italian-Montenegrin and the Romanian-Hungarian interconnectors. These results show that, with existing infrastructure, there will be no price convergence within the Western Balkan countries as almost all borders between them are expected to be commercially congested with infrastructure development in 2050.

As a final point for 2050 the number of fully congested hours were also calculated and summarised in Table 4.2

Table 4.2 Five most commercially congested borders based on the number of fully congested hours in the existing grid scenario, 2050

Existing grid		
Country A	**Country B**	**Number of congested hours**
RO	RS	7 090
BG	RS	6 960
EL	AL	6 921
HU	RS	6 609
IT	ME	6 016

The figure shows that the number of fully congested hours increased significantly in the most commercially utilised borders, as in 2050 even the 5th highest utilised border experienced more than 6000 fully congested hours, while this number was around 5500 in 2030. According to the calculation, the most congested border is the Romania (RO)-Serbia (RS) lines, where more than 7000 fully commercially congested hours are expected to occur. Other borders with more than 6000 hours of congestion are Bulgaria

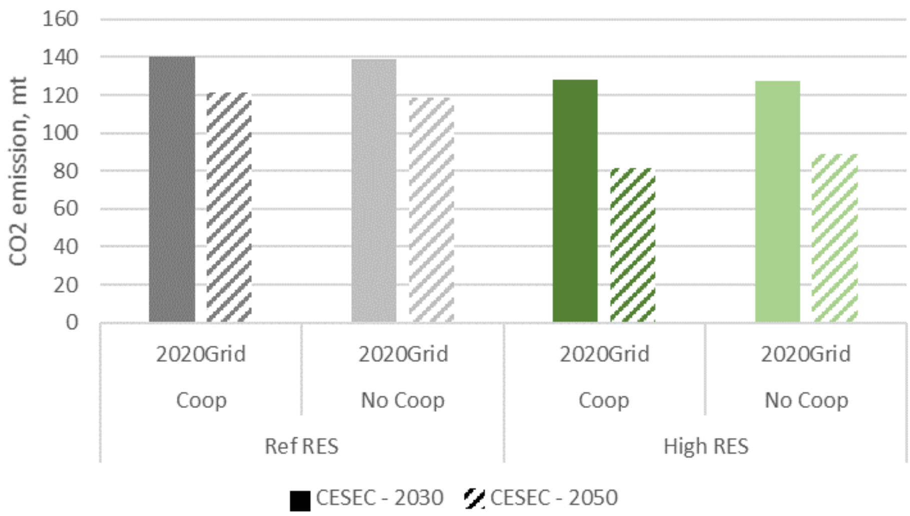
(BG)-Serbia (RS), Greece (EL)- Albania (AL), Hungary (HU) – Serbia (RS) and Italy (IT) – Montenegro (ME). It is interesting to note, that based on the average utilisation rates the Italy-Montenegro line only reached 75% in one RES scenario in 2050 but based on the number of fully utilised hours it was ranked as the 5th most commercially congested line, across all RES setups.

Based on the modelling result, it can be concluded that existing infrastructure is not sufficient to guarantee the trade of electricity without commercial congestions neither in 2030 nor in 2050. The results show that in both years serious commercial bottlenecks are present in the CESEC region, which is mostly centred at the Western Balkan. These bottlenecks are present regardless of which RES scenario is considered. In 2050, the number of congested borders in the region is less than in 2030, but in 2050 more serious bottlenecks can be identified. These congested cross-border situations also lead to very fragmented wholesale power markets in 2050, with huge price differences among countries, especially in the Reference RES scenarios.

CO2 emissions

In the case of the reference renewable scenario, only a smaller decrease of CO2 emission is visible (13-15%) from 2030 to 2050 in the entire CESEC region, as can be seen in Figure 4.7 . In the High RES scenario 30-36% emission reduction takes place already in the less integrated "existing grid" scenario, where infrastructural constraints prevent countries to utilise all of their resources on their full availability (see details on RES curtailment later). Cooperation helps to decrease emissions further in the more ambitious RES scenario.

Figure 4.7 Total CO2 emission of electricity generation in the CESEC region, with existing grid, 2030, 2050



Security of supply

According to the EPMM modelling results, in most of the countries no security of supply issue arises under the assumed market-based operation of the electricity markets and interconnectors in the region. While energy not supplied values are zero across all scenarios (including different grid topologies) and years for all countries, there are two countries that lack a small part of their reserve requirements. In Albania, the missing upwards capacity in 2030 is around 0.2 MW on average throughout the year, and by 2050 there is no deficit. In Ukraine in the Western part (Burshtyn Island)[36] there are

[36] As only B2B stations are assumed to be built, no synchronisation is foreseen, the Western (Burshtyn Island) and Eastern parts of Ukraine procure their reserve capacities separately.

missing reserve capacities both up (less than 2 MW in 2030) and downward (3-6 MW both in 2030 and 2050), as old power plants are not replaced by sufficient new flexible capacities. While the numbers are low, they indicate that in these two countries there might be difficulties in the safe operation of the system.

The following Figure 4.8 shows the shares of different technologies in procured spinning reserve capacities altogether in the CESEC region. Both upward and downward reserves are presented, for 2030 and 2050. As cross-border balancing capacity procurement is not assumed in the model, only national capacities are used for this purpose, there are only slight differences between the values across the different grid topologies, so the results are only presented for the existing grid scenarios.

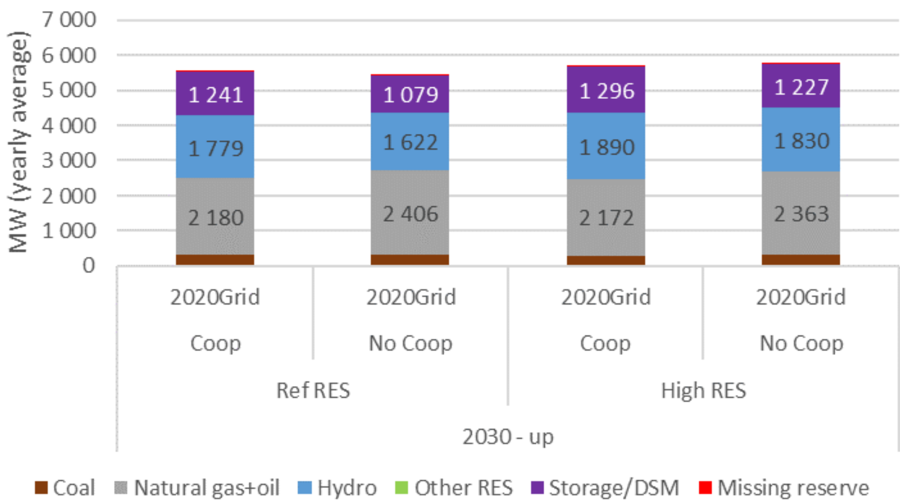
The figure includes the yearly average procured spinning reserve capacities (in MW) for the different technologies altogether in the CESEC region. It means, that e.g. in 2030 on average for each hour of the year 236 MW natural gas -fired capacity is procured in the upward direction in the region.

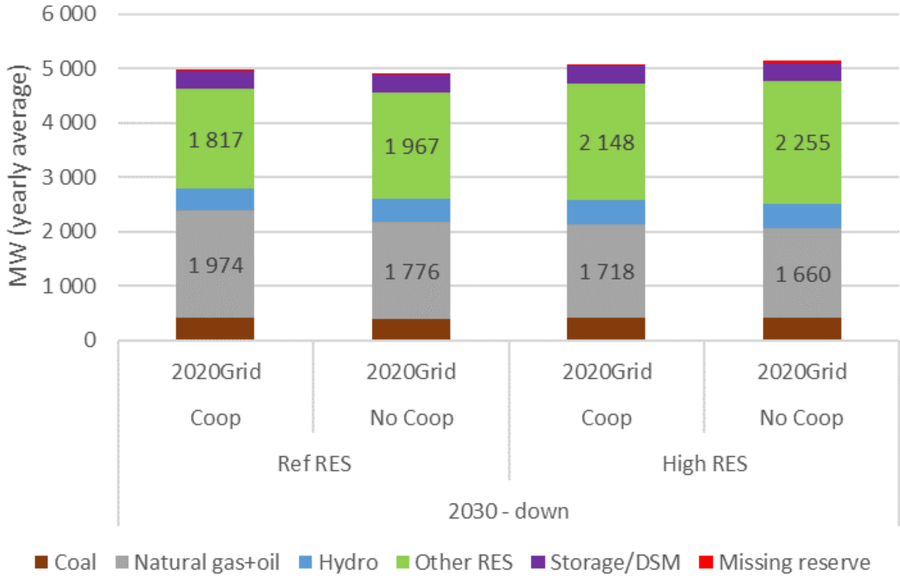
DSM and storage technologies are not in the focus of this study, however these are important renewable integration enablers. We assume that by 2030, 8%, and by 2050, 25% of total electricity demand will react actively to price signals, from which 10% will be capable to provide actual flexibility services. The total storage (including pumped storage) capacities in the CESEC region are assumed to reach 20 GW by 2030 and 30 GW by 2050. As it is shown, by 2050 around 40% of upward flexibility might come from DSM or storage. It means that the future development of these innovative solutions is an important prerequisite of enabling RES integration in the region.

From 2030 to 2050, a significant increase is visible in the shares of other renewables (mostly wind and solar) in the downward direction). The share of hydro energy remains relatively stable. Therefore, storage, DSM and renewable technologies will mostly replace fossil capacities. Actual realisation of this replacement will require not only technological developments and increasing renewable penetration but also ineedan adequate regulatory environment, that enables the participation of all these technologies in the reserve markets.

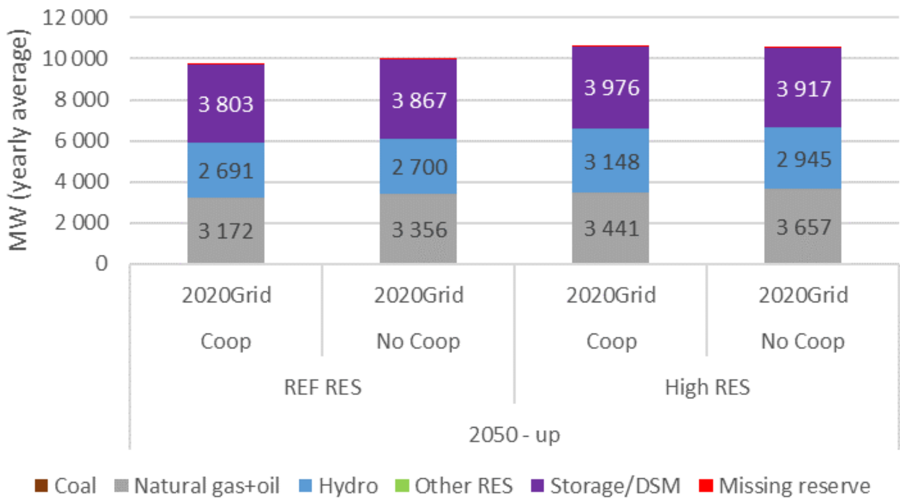
Coal only plays a role in the 2030 reserve market. In 2050, natural gas remains the only fossil fuel in the whole region used to satisfy flexibility needs. There are only slight differences across the renewable scenarios, both cooperation and more renewables help to lower the share of overall fossil capacities in the reserve markets of the region.

Figure 4.8 Shares of technologies in procured reserve capacities in the CESEC region (upwards 2030, downwards 2030, upwards 2050, downwards 2050)

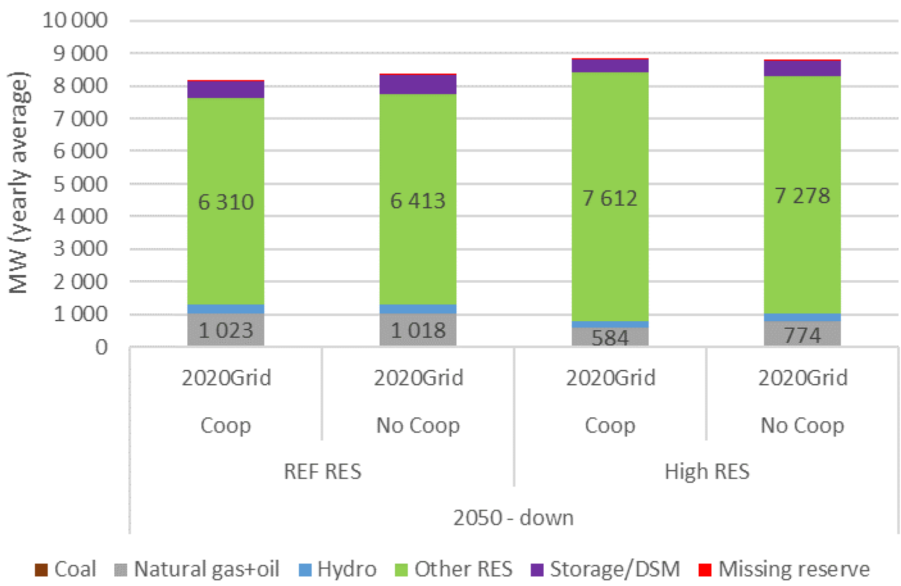




6 000
5 000
4 000
3 000
2 000
1 000
0
MW (yearly average)
1 817
1 967
2 148
2 255
1 974
1 776
1 718
1 660
2020Grid
Coop
2020Grid
No Coop
2020Grid
Coop
2020Grid
No Coop
Ref RES
High RES
2030 - down
Coal
Natural gas+oil
Hydro
Other RES
Storage/DSM
Missing reserve



12 000
10 000
8 000
6 000
4 000
2 000
0
MW (yearly average)
3 803
3 867
3 976
3 917
2 691
2 700
3 148
2 945
3 172
3 356
3 441
3 657
2020Grid
Coop
2020Grid
No Coop
2020Grid
Coop
2020Grid
No Coop
REF RES
High RES
2050 - up
Coal
Natural gas+oil
Hydro
Other RES
Storage/DSM
Missing reserve



10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
MW (yearly average)
6 310
6 413
7 612
7 278
1 023
1 018
584
774
2020Grid
Coop
2020Grid
No Coop
2020Grid
Coop
2020Grid
No Coop
REF RES
High RES
2050 - down
Coal
Natural gas+oil
Hydro
Other RES
Storage/DSM
Missing reserve

Zones and technologies with RES curtailment

The results of the EPMM provide for each RES scenario and modelled year in which bidding zone of the CESEC region there is the necessity of RES curtailment. This means that in these zones the full RES generation cannot be transported to the demand centres due to insufficient grid capabilities.

By simulating an additional export of bidding zones with RES curtailment (equivalent to an increase of the share of RES generation in the zone's net position) over the borders where NTCs are used by the market, the flow-based capacity model discloses the potential bottlenecks that are limiting the amount of RES generation that can be carried by the grid. Note that these identified bottlenecks are different from the commercial congestions identified in the previous section. These are limitations of the grid preventing full RES integration, while the commercial congestions indicate non-realisable trade opportunities between different price zones.

Table 4.3 below introduces the zones and technologies with notable RES curtailment (i.e. >5% of forecasted yearly infeed) for the considered RES scenarios and target years.

Table 4.3 Zones and technologies with notable necessity of RES curtailment (today's grid topology)

Country	2030				2040				2050			
	RefRES		HighRES		RefRES		HighRES		RefRES		HighRES	
	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop
AL						PV	PV	PV	PV	PV	PV Wind	PV
AT												PV
BA												
BG					PV		PV		PV Wind	PV Wind Hydro	PV Wind Hydro	PV Wind
EL					PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro
HR									PV		PV Wind	
HU							PV Wind				PV Wind	
IT		PV			PV Wind Hydro	PV Wind	PV Wind	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro	PV Wind Hydro
MD									PV	PV	PV	PV
ME				PV	PV	PV	PV	PV	PV	PV	PV	
MK												
RO							PV Wind		PV Wind	PV Wind	PV Wind Hydro	PV Hydro
RS									PV Wind			
SI							PV		PV		PV Wind	PV
SK							PV		PV		PV Wind	PV
UA					PV		PV Wind		PV	PV	PV Wind	PV
XK					PV		PV		PV	PV	PV Wind	PV

PV Wind Hydro

The results show that RES curtailment becomes relevant in 2030 where only PV in Italy (in scenario RefRES_Coop) or Montenegro (High_RES_Coop) is affected. In 2040 and 2050, the number of regions and technologies with a need for curtailment increases significantly as well as the amount of RES curtailment (up to more than 50% depending on the assumed RES deployment). In addition to that, it can be observed that cooperation leads to a partial shift of zones and technologies that are mainly affected by RES curtailment.

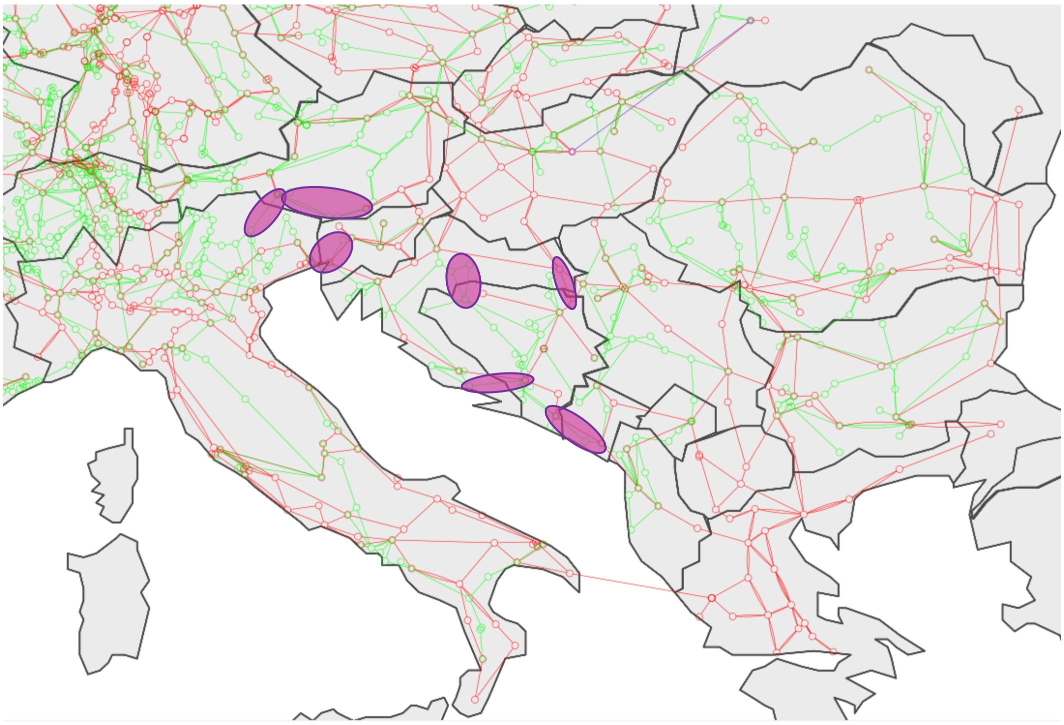
Regions with potential bottlenecks

Figure 4.9 to Figure 4.12 show the regions where congestion would occur most likely assuming that the forecasted RES generation would be carried by the grid (evaluation covers RES deployment until 2040 according to the considered four RES scenarios).

Scenario "RefRES_NoCoop"

Figure 4.9 shows regions with potential bottlenecks which could occur due to the forecasted RES generation. These bottlenecks were identified within the TGM capacity calculations and reflect lines which are binding capacity constraints. To reflect the general accuracy of the modelling and related uncertainties, results are given as geographical regions rather than as specific lines. Congestion observed is mainly driven by additional RES infeed in Italy and Greece with cross-border lines being more affected than internal lines. The most affected regions are the borders of Bosnia-Herzegovina to Croatia and Montenegro as well as the borders from Italy to Austria and Slovenia. Furthermore, internal lines in the vicinity of these borders are affected in Austria, Slovenia, Croatia and Montenegro.

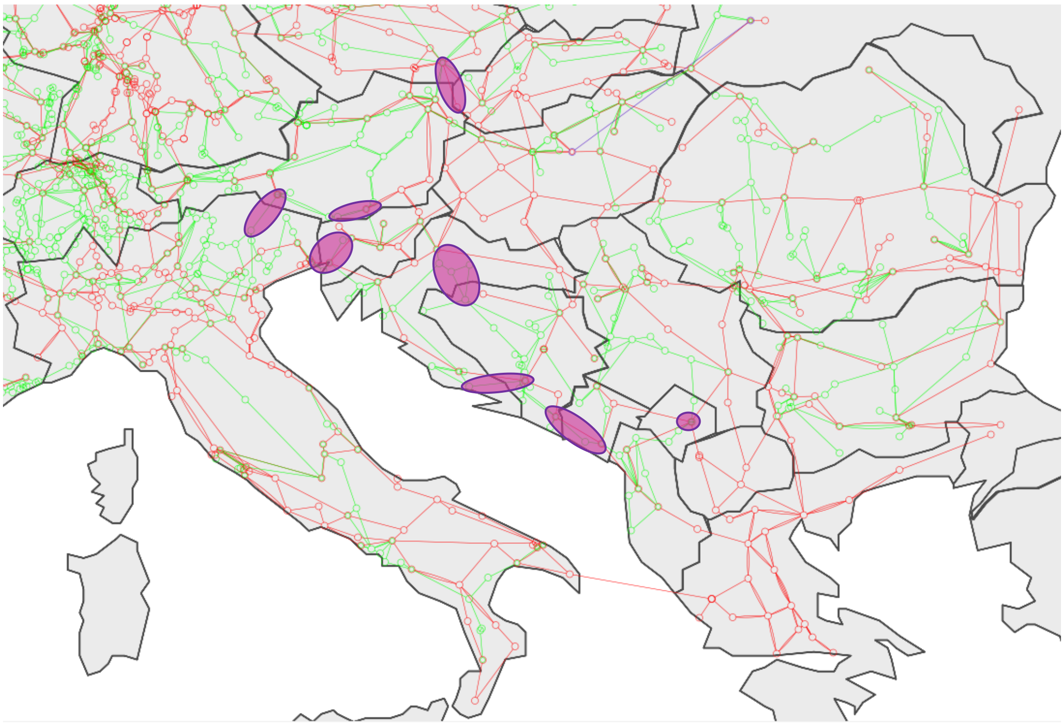
Figure 4.9 Potential bottlenecks for scenario "RefRES_NoCoop"



Scenario "RefRES_Coop"

Assuming cooperation in the reference scenario for RES deployment causes some shift of forecasted RES generation in the region such that the location of bottlenecks slightly changes (Figure 4.10). While one of the interconnectors between Bosnia-Herzegovina and Croatia and internal lines in the South of Austria are not congested anymore, further bottlenecks appear in the border region between the Czech Republic and Slovakia as well as for internal lines in Kosovo and Croatia.

Figure 4.10 Potential bottlenecks for scenario "RefRES_Coop"

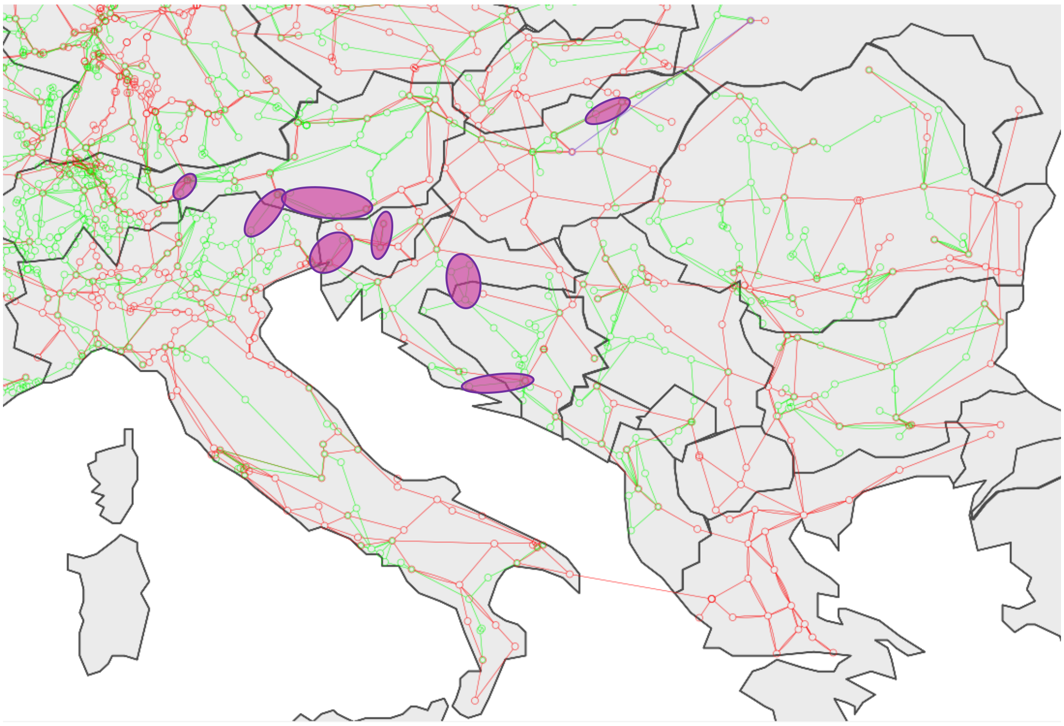


Scenario "HighRES_NoCoop"

Compared to the corresponding RefRES scenario the number of zones where RES curtailment is necessary increases notably. Thus, the location of potential bottlenecks also changes when simulating that the forecasted RES generation would be carried by the grid as illustrated in Figure 4.11 .

The main differences to the scenario "RefRES-NoCoop" are that the regions of Montenegro (interconnection to Bosnia-Herzegovina as well as internal lines) and Bosnia-Herzegovina (regarding the Eastern interconnector to Croatia) are uncritical in this scenario while potential overloads on internal lines in the Western part of Austrian and the North-Eastern region of Hungary can be observed.

Figure 4.11 Potential bottlenecks for scenario "HighRES_NoCoop"

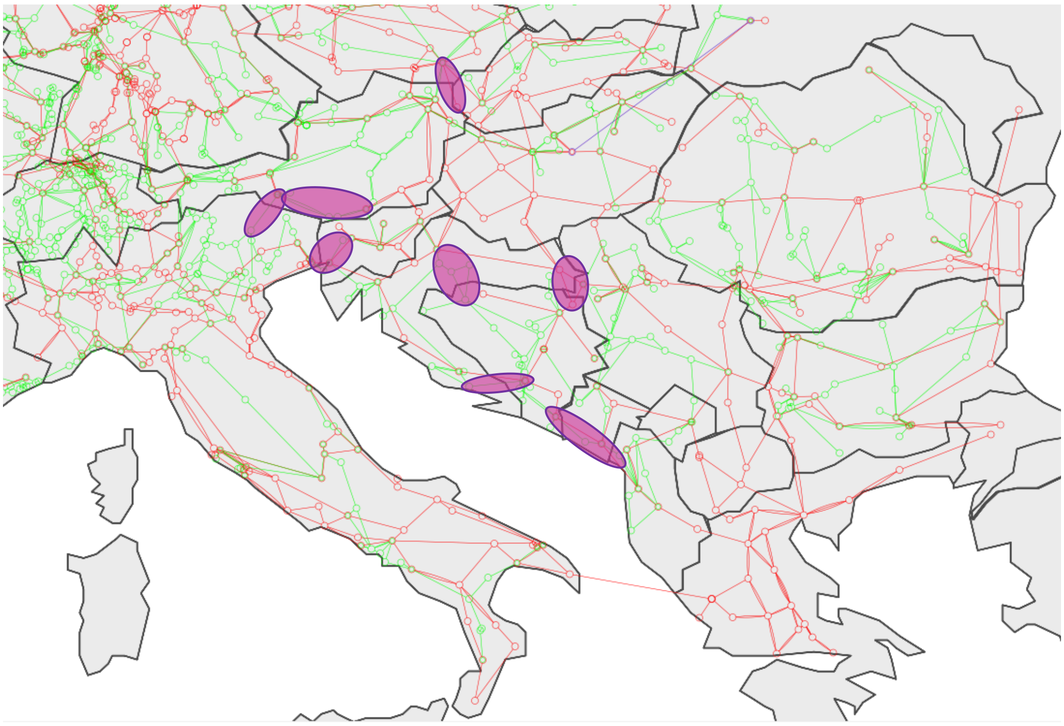


Scenario "HighRES_Coop"

Assuming cooperation in the scenarios of RES deployment leads to similar results as for the "RefRES_Coop" scenario with respect to the zones mainly affected by required RES curtailment. Consequently, the set of identified lines to be potentially overloaded also shows analogies to the potential bottlenecks for the scenario "RefRES_Coop" (Figure 4.12). Due to the more optimistic RES deployment modelled in this scenario, there are additional overloads identified in the border regions of Montenegro/Albania, Bosnia-Herzegovina/Croatia/Serbia and in internal lines in the Southern part of Austria.

Compared to the HighRES scenario without cooperation, there are rather substantial changes regarding the location of potential bottlenecks reflecting the differences of zones with a need for RES curtailment between the two HighRES scenarios.

Figure 4.12 Potential bottlenecks for scenario "HighRES_Coop"



Summary

- The main findings of the analysis are:
- Without further grid reinforcement, bottlenecks are most likely to appear in the Western Balkans as well as in Austria and its neighbouring countries;
- Potential bottlenecks are mainly located on cross-border interconnections, but also some internal lines are affected;
- Locations of bottlenecks mirror the centres of forecasted RES generation in the region for each considered scenario;
- With a higher number of countries with the need for RES curtailment, more regions with potential bottlenecks are identified.

4.2 Identification of CESEC infrastructure priority projects contributing to further integration of renewables

Market integration and price developments

Market integration is improved significantly if the already planned infrastructure is put in place in the CESEC region. Average wholesale prices also decrease by 2-3% in 2030 and around 17-42% in 2050 in the different scenarios if all new planned interconnectors are realised (also, differences are smaller between the High RES than between the REF RES cases), but the most important change is visible in the variance of prices. It still stands, that the High RES case helps the highest level of price harmonisation, mostly in the long run, although divergence between markets is very small even in the REF RES cases, compared to the high values in the existing grid scenarios, as can be seen in

Figure 4.13 and Figure 4.14 . Yearly average wholesale prices vary between 35 and 68 €/MWh on a country level in 2030 and between 52 and 86 €/MWh in 2050.

Figure 4.13 Weighted average wholesale baseload prices in the CESEC region, with extended grid, 2030, 2050

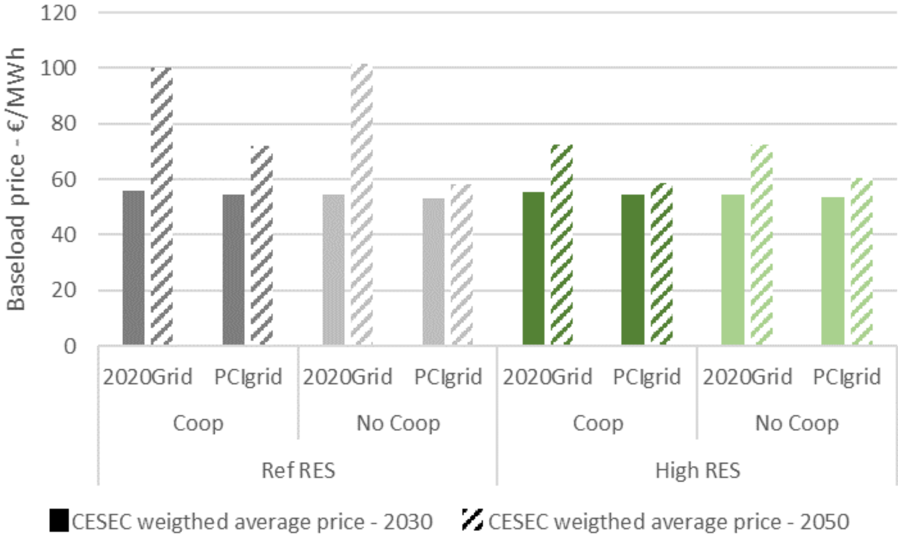
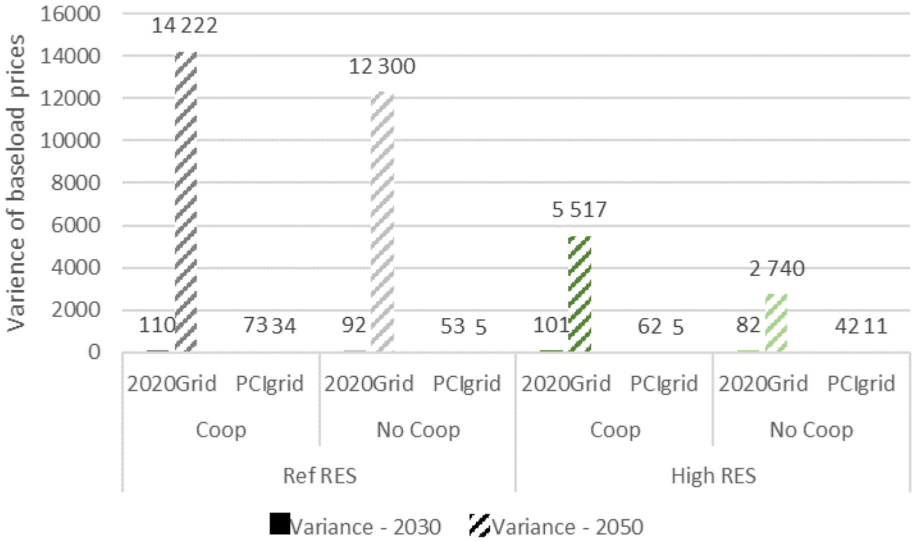


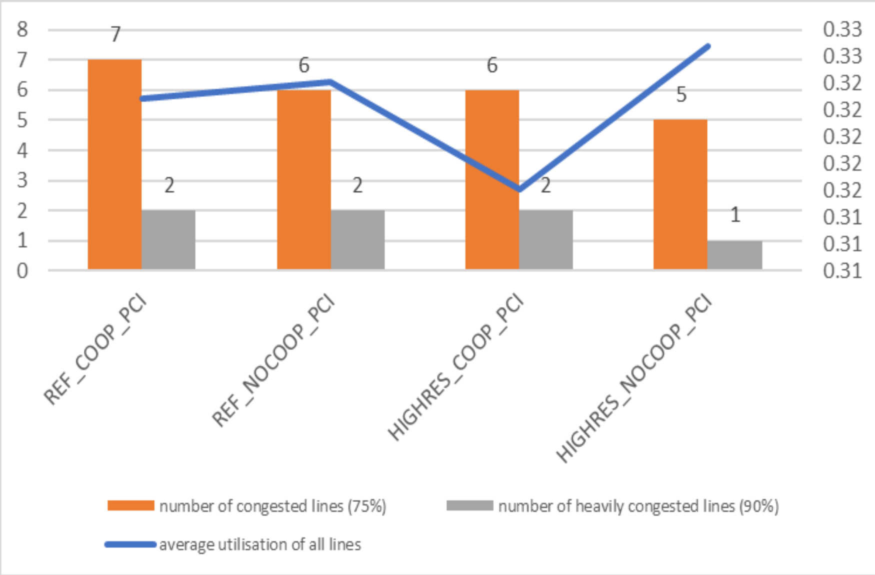
Figure 4.14 Variance of wholesale baseload prices in the CESEC region, with extended grid, 2030, 2050



Similarly, to existing electricity infrastructure case the following paragraphs analyse the yearly average utilisation and the number of fully utilised hours of the interconnectors of the CESEC region to identify commercial congestion in 2030 and 2050 with the planned new infrastructure projects also considered.

Figure 4.15 shows the number of borders where the yearly utilisation rate was larger than 75% (congested) or larger than 90% (heavily congested) in all four setups when proposed future infrastructure elements are consider in the modelling. The secondary axis shows the average utilisation off all interconnectors of the CESEC region.

Figure 4.15 Number of commercially congested and heavily congested (left axis) borders and yearly average utilisation of all lines (right axis, %) with new infrastructure projects completed, 2030

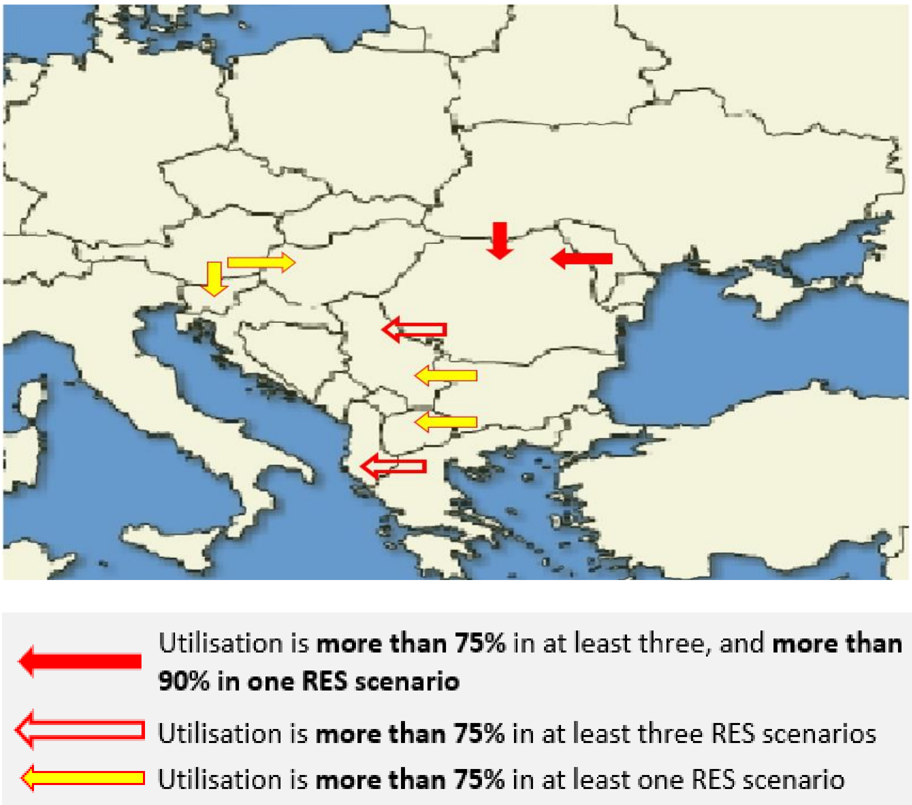


With the new proposed infrastructure development, the average utilisation of all lines decreases by 1-2% points relative to the estimation when the existing grid was considered. Across the four scenarios, no significant differences in average utilisation can be detected.

The most important conclusion of figure 4.15 is that the new infrastructure project will help to relieve congested borders as the number of lines utilised more than 75% of their transfer capacity has decreased in all setups. With the existing infrastructure, there were 10 heavily utilised borders which decreased to 5-7 depending on RES scenario with planned investments considered in 2030. This means that even with the completed new projects, commercially congested lines remained in the system even though new infrastructure may drastically support price convergence, some additional specific projects may be required to further reduce commercial congestion. Concerning the RES deployment levels, there is no significant difference between the analysed RES scenarios. This indicates that rather the expected market developments in the region (increasing consumption and intensified trade) are the main drivers of the infrastructure development than the RES growth alone, at least at the beginning of the period.

Figure 4.16 shows the borders with the highest utilisation across all RES scenarios. Compared to the existing grid cases, the completion of new infrastructure projects reduces the number of congested borders in 2030. Based on the map there are only two borders, where average utilisation is more than 75% in at least three scenarios and more than 90% in at least one (dark red), which are the Ukraine-Slovakia and Moldova-Romania. Both interconnectors are a new line completed between 2020 and 2030, meaning that the completion of these new projects resulted in the emergence of new congested lines.

Figure 4.16 List of commercially congested borders with planned infrastructure projects completed, 2030



On top of these special lines, there are only two additional borders, where the average commercial utilisation of the interconnectors is larger than 75% in at least three scenarios, which are the Romania-Serbia and Greece-Albania lines. In addition, commercial congestion was identified in at least one case between Austria and Hungary, Austria and Slovenia, Bulgaria and Serbia and Bulgaria-North Macedonia.

Besides commercial utilisation rates, the number of fully congested hours in the year were also analysed for 2030 in comparison with the existing grid case in Table 4.4

Table 4.4 5 most commercially congested borders based on the number of fully congested hours in the existing grid and planned infrastructure scenarios, 2030

Existing grid			Planned infrastructure projects		
Country A	**Country B**	**Number of congested hours**	**Country A**	**Country B**	**Number of congested hours**
EL	AL	7103	MD	RO	8218
BG	RS	6845	UA	RO	8218
RO	RS	6761	EL	AL	5695
HR	BA	5658	AT	SI	5024
AT	SI	5564	AT	HU	4994

The Table shows that relative to the existing grid case the number of fully congested hours reduces significantly with respect to the most used lines in 2030. The only exceptions are the two newly built projects (Moldova-Romania and Ukraine-Slovakia), where in almost all hours of the year the interconnectors are 100% utilised, indicating that the transfer capacities of these new lines might be insufficient. Except for these two borders, the most congested connection remains between Greece and Albania however the number of fully congested hours are almost 1500 fewer than 7100, the number of congested hours with existing grid case. Austria-Slovenia and Austria-Hungary are the 4th a 5th most congested borders, with around 5000 hours of full utilisation.

The same analysis is conducted for 2050 in relation to commercial congestion when the modelling assumed that all planned infrastructure projects will be finished. In 2050 however, drastic changes occur in the CESEC electricity system as between 2030 and 2050 several new lines are planned to be completed. As a result, our modelling shows, that there will be no such RES scenario where any of the analysed borders operate with a utilisation rate of 75%.

Planned new infrastructure projects completely remove those bottlenecks from the CESEC region where a border connection is utilised at a very high rate throughout the whole calendar year, irrespective of the analysed RES scenario. This however does not mean that there is no commercial congestion in the CESEC region, which can be identified by calculating the number of fully congested hours in Table 4.5

Table 4.5 5 most commercially congested borders based on the number of fully congested hours in the existing grid and planned infrastructure scenarios, 2030

Existing grid			Planned infrastructure projects		
Country A	**Country B**	**Number of congested hours**	**Country A**	**Country B**	**Number of congested hours**
RO	RS	7090	SI	IT	3932
BG	RS	6960	AT	IT	3931
EL	AL	6921	EL	IT	3795
HU	RS	6609	AT	HU	3651
IT	ME	6016	AT	SI	2948

By comparing the results with the existing grid setup, it is clearly indicated that the completion of the planned new infrastructure projects significantly reduces the total number of fully congested hours. With the existing grid setup considered the Romania-Serbia border was the most commercially congested with more than 7000 hours of full utilisation while with the new projects Italy (IT) and Slovenia (SI) is the most congested but not reaching 4000 of fully utilised hours. So, this analysis strengthens the previous conclusion, that the new projects contribute greatly to eliminate commercial bottlenecks in the CESEC region in 2050. It is important to highlight, that the most utilised lines experience congestion in approximately 45% of the hours of a year, which means, that by completing the planned infrastructure projects, commercial congestions are not eliminated from the CESEC region. Additionally, the geographical location of the most significant bottlenecks changes by finishing the new projects. Without them, commercial congestion was centred mainly at the Balkan, but with the planned projects, congestion occurs mainly at the Western CESEC region in 2050. The most problematic borders based on the modelling are Slovenia (SI) – Italy (IT), Austria (AT)- Italy (IT), Greece (EL) – Italy (AL), Austria (AT) – Hungary (HU), and Austria (AT)-Slovenia (SI).

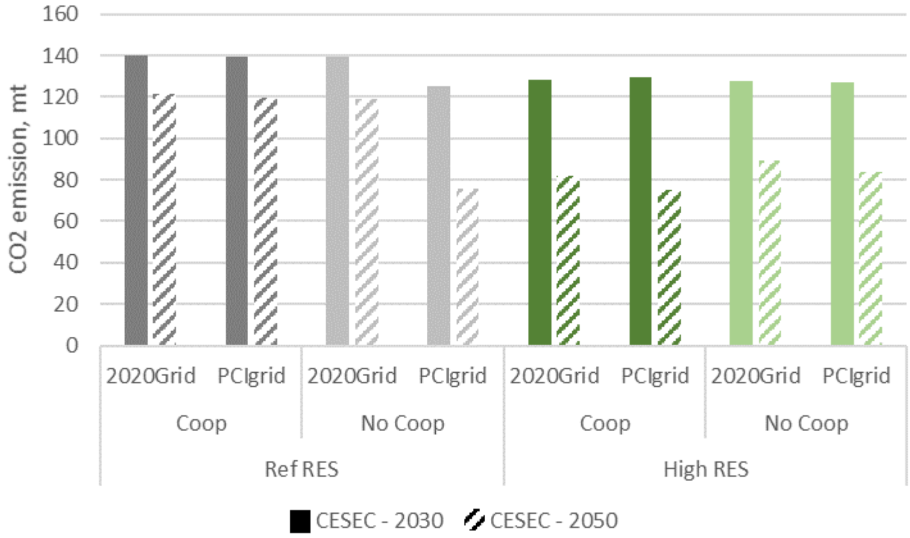
Conclusions

To conclude this assessment, the modelling results show that completion of planned PCI, ENTSO-E TYNDP and other Energy Community infrastructure projects are contributing to the reduction of electricity grid bottlenecks in the CESEC region in 2030 and drastically in 2050. With the planned projects the number of very highly utilised lines reduces, however many such borders remain such as Romania-Serbia and Greece-Albania where very highly utilised interconnectors will operate in the system. In 2050 in none of the RES scenarios were any border where yearly average utilisation exceeded 75%. This does not mean, that commercial congestion will be completely removed with the completion of planned infrastructure projects, as at the most utilised borders are expected to face congestion in 45% of the hours of the year. Price differences among countries, however, are drastically reduced with the realisation of already planned infrastructure projects. With the existing grid setup, commercial congestion was mainly centred at the Balkan, but with the new projects, bottlenecks mainly present at the western part of the CESEC region including Italy, Slovenia, Austria and Hungary.

CO_2 emissions

Overall CESEC CO_2 emissions from electricity generation in 2030 are around 10% lower in the High RES case than in the Ref RES case in most scenarios. If compared to the No cooperation-PCIgrid scenario emissions are even slightly, 1% higher in 2030, if the grid extension takes place as it is planned compared to the existing grid scenarios. The surprising increase is mostly the result of further export possibilities in place for some countries with more fossil intensive mixes, such as the Eastern part of Ukraine (it has the highest effect) and to a lesser extent Bulgaria, and in some scenarios Romania. By 2050 the overall CO2 emission of the region decreases by 2-36% in the reference RES cases, and around 6-8% in the High RES cases compared to the existing grid scenario, meaning in the long run market integration does help the reduction of emissions. It is important to note, however, that the desired effects of interconnection are only achievable if the share of renewable energy is already sufficiently high – that is the case by 2050 in all analysed scenarios.

Figure 4.17 CO2 emission in the CESEC region, with extended grid, 2030, 2050



Evaluation of planned infrastructure projects in the CESEC region

The planned grid expansion projects as specified in Table 4.6 reflect infrastructure needs with the general objective to reduce the likeliness of congestions and to increase trading possibilities in the CESEC region.

To filter those projects that in particular contribute to further integration of RES out of the complete set, the EPMM results of identical target years, but different assumptions related to grid topology are compared. In particular, the amount of necessary RES curtailment per bidding zone as well as NTC usage is evaluated for the case with and without new grid expansion projects assumed to be realised until the respective target year. If RES curtailment in a zone is reduced for the case with new grid infrastructure due to increased grid capabilities, those projects of the initial list with an NTC increasing effect on the relevant borders/directions constitute the projects contributing to further RES integration.

As regards RES curtailment, the following table shows that with extended grid RES curtailment is necessary for fewer zones and fewer technologies compared to the situation assuming that today’s grid topology will remain unchanged, and the necessary amount of RES curtailment is reduced by up to 10-25 percentage points depending on the respective RES scenario.

Table 4.6 Zones and technologies with the notable necessity of RES curtailment (enhanced grid topology)

	2030				2040				2050			
	RefRES		HighRES		RefRES		HighRES		RefRES		HighRES	
Country	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop	NoCoop	Coop
AL							PV		PV	PV	PV	PV
AT											PV	PV
BA							PV					
BG							PV		PV	PV	PV, Wind	PV
EL			PV, Wind, Hydro		PV, Wind	PV, Wind	PV, Wind	PV, Wind, Hydro	PV, Wind, Hydro	PV, Wind, Hydro	PV, Wind, Hydro	PV, Wind, Hydro
HR							PV		PV		PV, Wind	
HU							PV, Wind		PV, Wind		PV, Wind	
IT					PV, Wind	PV, Wind	PV, Wind	PV, Wind	PV, Wind, Hydro	PV, Wind, Hydro	PV, Wind, Hydro	PV, Wind, Hydro
MD									PV	PV	PV	PV
ME					PV		PV		PV	PV	PV	
MK					PV		PV		PV	PV	PV	PV
RO									PV		PV, Wind	PV
RS												
SI		PV	PV	PV	PV		PV	PV	PV	PV	PV	PV
SK							PV			PV	PV, Wind	PV
UA					PV		PV		PV	PV	PV, Wind	PV
XK							PV		PV	PV	PV, Wind	PV

PV Wind Hydro

Based on the aforementioned findings the following tables introduce the preliminary lists of projects (both internal and cross-border lines) identified to contribute to the reduction of RES curtailment for the considered scenarios of RES deployment.

Scenario "RefRES_NoCoop"

Table 4.7 Priority projects contributing to RES integration (scenario RefRES_NoCoop)

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Albania-Greece capacity extension *		AL-EL		x	x
Albania-Kosovo capacity extension *		AL-XK		x	x
Reschenpass Interconnector Project *	26	AT-IT		x	x
Black Sea Corridor *	138	BG-RO		x	x
CSE4 *	142	BG-RO		x	x
Transbalkan Corridor	227	RS-ME		x	x
Prati (AT) – Steinach (AT) *	336	AT-IT		x	x
Lienz-Venetto region	375	AT-IT		x	x
Refurbishment of the 400kV Meliti (EL)-Bitola(MK) interconnector	376	EL-MK		x	x
new interconnector UA_W-SK		UA_W-SK			x
Romania-Moldova interconnector (Vulcanesti-Chisnau)		RO-MD			x
Suceava-Balti new interconnector		RO-MD			x
new interconnector UA_E-RO		UA_E-RO			x

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Mid Continental East corridor	144	RO-RS			x
Mid Continental East corridor	144	RO-HU			x
HU-RO	259	RO-HU			x
Slovenia-Hungary/Croatia interconnection *	320	SI-HU			x
Obersielach-Podlog	325	SI-AT			x
Pannonian Corridor	1074	HU-RS			x

* already under construction.

Scenario "RefRES_Coop"

Table 4.8 Priority projects contributing to RES integration (scenario RefRES_Coop)

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Reschenpass Interconnector Project *	26	AT-IT	x	x	x
Prati (IT) – Steinach (AT) *	336	AT-IT	x	x	x
Lienz-Venetto region	375	AT-IT	x	x	x
Albania-Greece capacity extension *		AL-EL		x	x
Albania-Kosovo capacity extension *		AL-XK		x	x
CSE4 *	142	BG-EL		x	x
Transbalkan Corridor	227	RS-ME		x	x
South Balkan Corridor *	350	MK-AL		x	x
Refurbishment of the 400kV Meliti(EL)-Bitola(MK) interconnector	376	EL-MK		x	x
Suceava-Balti new interconnector		RO-MD			x
Romania-Moldova interconnector (Vulcanesti-Chisnau)		RO-MD			x
new interconnector UA_E-RO		UA_E-RO			x
Black Sea Corridor *	138	BG-RO			x
Mid Continental East corridor	144	RO-HU			x
Mid Continental East corridor	144	RO-RS			x
HU-RO	259	RO-HU			x

* already under construction.

Scenario "HighRES_NoCoop"

Table 4.9 Priority projects contributing to RES integration (scenario HighRES_NoCoop)

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Romania-Moldova interconnector (Vulcanesti-Chisnau)		RO-MD		x	x
Suceava-Balti new interconnector		RO-MD		x	x
Albania-Greece capacity extension *		AL-EL		x	x
new interconnector UA_W-SK		UA_W-SK		x	x
new interconnector UA_E-RO		UA_E-RO		x	x
Reschenpass Interconnector Project *	26	AT-IT		x	x
Black Sea Corridor *	138	BG-RO		x	x
CSE4 *	142	BG-EL		x	x
Mid Continental East corridor	144	RO-RS		x	x
Mid Continental East corridor	144	RO-HU		x	x
HU-RO	259	RO-HU		x	x
Slovenia-Hungary/Croatia interconnection *	320	SI-HU		x	x
Obersielach-Podlog	325	SI-AT		x	x
Prati (IT) – Steinach (AT) *	336	AT-IT		x	x
Lienz-Venetto region	375	AT-IT		x	x
Refurbishment of the 400kV Meliti(EL)-Bitola(MK) interconnector	376	EL-MK		x	x
CSE1 New	1074	HU-RS		x	x
South Balkan Corridor *		AL-XK			x

* already under construction.

Scenario "HighRES_Coop"

Table 4.10 Priority projects contributing to RES integration (scenario HighRES_Coop)

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Transbalkan Corridor	227	RS-ME	x	x	x
Albania-Greece capacity extension *		AL-EL		x	x
Reschenpass Interconnector Project *	26	AT-IT		x	x
CSE4 *	142	BG-EL		x	x
Prati (IT) – Steinach (AT) *	336	AT-IT		x	x
Lienz-Venetto region	375	AT-IT		x	x

Project name	TYNDP ID	Border	Contribution to RES integration in		
			2030	2040	2050
Refurbishment of the 400kV Meliti(EL)-Bitola(MK) interconnector	376	EL-MK		x	x
new interconnector UA_W-SK		UA_W-SK			x
Romania-Moldova interconnector (Vulcanesti-Chisnau)		RO-MD			x
Suceava-Balti new interconnector		RO-MD			x
Black Sea Corridor *	138	BG-RO			x
Mid Continental East corridor	144	RO-RS			x
Mid Continental East corridor	144	RO-HU			x
HU-RO	259	RO-HU			x

* already under construction.

Summary

The detailed results can be summarised as follows:

- Except for the scenario RefRES-Coop most of the identified projects would contribute to RES integration only after 2030;
- For RES scenarios without cooperation, the number of projects contributing to further RES integration is higher when assuming a high level of RES deployment in the region. In the case of cooperation, the number of beneficial projects is smaller for both, Reference and HighRES scenario, compared to the respective cases without cooperation. This indicates that the planned projects are more appropriate assuming a national fulfilment of RES targets;
- Depending on the assumed RES deployment the projects contributing to RES integration show significant differences related to their location in the CESEC region and the target year when they become relevant.

According to the individual results for the different scenarios, the infrastructure projects identified to contribute to further integration of the RES projects identified in this study show different values at least related to the scenarios for which they are beneficial and the target years where there is a significant contribution to RES integration. In the following Table 4.11 a ranking of the projects is introduced where the leading parameter is the number of scenarios for which the respective project contributes to RES integration (in the sense of prioritising so-called "no regret" projects) and the earliest year when the project becomes beneficial is considered afterwards.

Table 4.11 Potential ranking of CESEC infrastructure priority projects identified to contribute to further RES integration

Project name	Border	Contribution to RES integration	
		Number of scenarios	Earliest year
Prati (IT) – Steinach (AT) *	AT-IT	4	2030
Reschenpass Interconnector Project *	AT-IT	4	2030
Lienz-Venetto region	AT-IT	4	2030
Albania-Greece capacity extension *	AL-EL	4	2040
CSE4 *	BG-EL	4	2040

Project name	Border	Contribution to RES integration	
		Number of scenarios	Earliest year
Black Sea Corridor	BG-RO	4	2040
Refurbishment of the 400k V Meliti (GR)-Bitola (MK) interconnector	EL-MK	4	2040
Mid Continental East corridor	HU-RO	4	2040
HU-RO	HU-RO	4	2040
Romania-Moldova interconnector (Vulcanesti-Chisnau)	MD-RO	4	2040
Suceava-Balti new interconnector	MD-RO	4	2040
Mid Continental East corridor	RO-RS	4	2040
Transbalkan Corridor	ME-RS	3	2030
Albania-Kosovo capacity extension *	AL-XK	3	2040
New interconnector UA_E-RO	RO-UA_E	3	2040
New interconnector UA_W-SK	SK-UA_W	3	2040
South Balkan Corridor *	AL-MK	2	2040
Obersielach-Podlog	AT-SI	2	2040
Pannonian Corridor	HU-RS	2	2040
Slovenia-Hungary/Croatia interconnection *	HU-SI	2	2040
Upgrading of existing 220 kV line between HR and BA to 400 kV	BA-HR	1	2050
CSE1 New	BA-HR	1	2050
New 400 kV interconnection line between Serbia and Croatia	HR-RS	1	2050

* already under construction.

Welfare effects of planned infrastructure

The socio-economic welfare effect of the already planned projects (PCIgrid) was also quantified through modelling[37]. The net welfare changes of producers and consumers are added to changes in TSO rents, so the total social-economic welfare change can be quantified[38]. It is important to note, that the already planned infrastructure elements are modelled together, so only the total effects of the infrastructure developments (and no individual effects) are quantified. The 2020 present value[39] of this welfare change in the different modelled years is then compared to the total annualised cost of the projects (also in 2020 net present values) that are already assumed to be realised by the given year. This way the total net gains and total costs can be compared. Most of the planned projects are part of the latest ENTSO-E TYNDP 2020, which contains the planned investment and operation costs of the lines. Additionally, several of the projects were a candidate for the Project of Energy Community Interest (PECI), where the project submissions contained the relevant cost data. For those projects where no cost information was available, the relevant cost measures were benchmarked based on the Energy Community (2020).

The comparison of annualised costs and benefits are visible on the following graph, where the red bars represent costs, and other bars represent net welfare changes (in consumer and producer surplus and TSO rent) in the various renewable scenarios. Whenever total costs are lower than the total benefit it means welfare gains from the

[37] The welfare calculation was carried out with the EEMM - European Electricity Market Model, which is a predecessor of EPMM. The same input setup (supply side, demand side, interconnectors) is used in the two models, but the EEMM is a partial equilibrium microeconomic model that maximizes total welfare of market participants (consumers, producers and TSOs), thus it is capable to quantify the welfare effects of the new infrastructure elements.

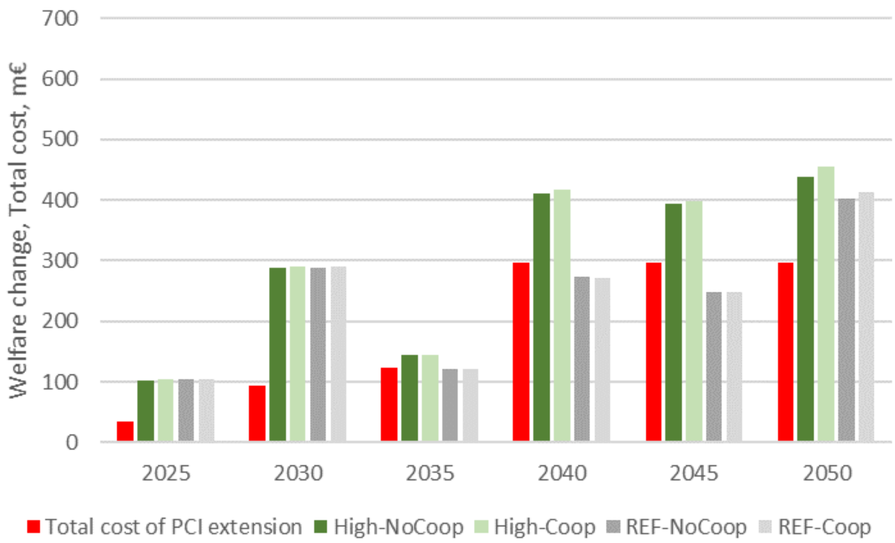
[38] Changes in CO_2 emissions are not monetised, they are presented separately and are not part of this welfare calculation.

[39] Using 4% social discount rate, based on former ENTSO-E CBA methodology.

new infra package. This net gain is clearly visible at the beginning of the period (when not too many projects are realised), and also at the end of the modelled period when there is much more need for new infrastructure. The significant jump in costs from 2035 to 2040 comes from only one larger sized project, most of the other projects are relatively small and cheap ones (average investment cost is around 135 m€). Also, in the High RES scenarios – so in a world with more and faster renewable penetration – the already planned schedule (including the larger sized project) seems to be adequate, benefits are higher than costs for all years. The results indicate that it is worth scheduling infrastructure investments in line with the developments of renewable capacities, however, a just in time infrastructure development means a higher risk for project delays.

The welfare gain means a high increase in total regional consumer surplus, and a decrease in producer surplus, and to some extent in TSO rents, meaning the new projects' main beneficiaries are the consumers, who will face lower prices through the RES and infrastructure developments in many of the assessed countries.

Figure 4.18 Welfare effect and cost of already planned infrastructure elements



4.3 Identification of new infrastructure and cross-border interconnections projects needed to ensure the RES integration in the CESEC region

Infrastructure projects in the CESEC region being beneficial for enhanced RES integration

The results introduced in

Table 4.6 demonstrate that even with an enhanced transmission grid in the CESEC region RES curtailment is still necessary for several bidding zones and for one or more technologies to avoid congestions. The number of affected zones and technologies depends on the considered scenario regarding RES deployment and target year.

Based on the flow-based parameters calculated with the TGM for the different scenarios and target years, specific transmission grid projects have been determined that would increase trading capacities at the borders of countries that are affected by a notable amount of RES curtailment (i.e. >5% of the forecasted yearly infeed) such that the forecasted RES generation can be (almost) fully transported and is not notably limited by insufficient grid capabilities anymore.

The following tables shall be understood such that the given grid infrastructure projects describe the full needs for each target year separately. This means that projects e.g. specified for 2050 are not in addition to 2040, but constitute the total requirements for 2050 compared to the "extended grid" topology in 2050. However, the infrastructure projects have been determined in a way that projects identified to be beneficial for an earlier target year have been considered with higher priority for later target years than further potential projects that would have similar effects on avoiding RES curtailment.

Note that the specified projects are not meant to be an ultimate list of grid infrastructure needs in the CESEC region but constitute a feasible configuration for (long-term) RES integration in the given framework. Thus, the results systematically underlie a couple of uncertainties arising from assumptions and modelling to be carefully taken into account when evaluating the cost and benefit of the respective infrastructure project.

Scenario "RefRES_NoCoop"

Table 4.12 Infrastructure projects suitable for RES integration (scenario RefRES_NoCoop)

Year	Start/end	Country/border	Layout	Length
2030	Redipuglia-Divaca	IT-SI	1x400 kV OHL	60 km
2040	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Italy-Montenegro	IT-ME	1x600 MW HVDC	445 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
2050	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Italy-Montenegro	IT-ME	3x600 MW HVDC	445 km
	Thessaloniki-Dubrovo	EL-MK	1x400 kV OHL	125 km
	Meliti-Bitola	EL-MK	1x400 kV OHL	71 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
	Feistritz-Obersielach	AT	1x220 kV OHL	30 km
	Blagoevgrad-Ch. Mogila	BG	1x400 kV OHL	55 km
	Ch. Mogila-SofiaZapad	BG	1x400 kV OHL	35 km
	Amyndeo-Meliti	EL	1x400 kV OHL	35 km
	Cordignano-Udine	IT	1x400 kV OHL	19 km
	Dugale-Sandrigo	IT	1x400 kV OHL	31 km

Scenario "RefRES_Coop"

Table 4.13 Infrastructure projects suitable for RES integration (scenario RefRES_Coop)

Year	Start/end	Country/border	Layout	Length
2030	Redipuglia-Divaca	IT-SI	1x400 kV OHL	60 km
2040	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	Italy-Montenegro	IT-ME	1x600 MW HVDC	445 km
2050	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Italy-Montenegro	IT-ME	3x600 MW HVDC	445 km
	Thessaloniki-Dubrovo	EL-MK	1x400 kV OHL	125 km

Year	Start/end	Country/border	Layout	Length
	Meliti-Bitola	EL-MK	1x400 kV OHL	71 km
	Sisak-Prijedor	HR-BA	1x220 kV OHL	70 km
	Meduric-Prijedor	HR-BA	1x220 kV OHL	70 km
	Zukuzak-Mostar	HR-BA	1x220 kV OHL	100 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
	Feistritz-Obersielach	AT	1x220 kV OHL	30 km
	Blagoevgrad-Ch. Mogila	BG	1x400 kV OHL	55 km
	Ch. Mogila-SofiaZapad	BG	1x400 kV OHL	35 km
	Amyndeo-Meliti	EL	1x400 kV OHL	35 km
	Cordignano-Udine	IT	1x400 kV OHL	19 km
	Dugale-Sandrigo	IT	1x400 kV OHL	31 km

Scenario "HighRES_NoCoop"

Table 4.14 Infrastructure projects suitable for RES integration (scenario HighRES_NoCoop)

Year	Start/end	Country/border	Layout	Length
2030	Redipuglia-Divaca	IT-SI	1x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
2040	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	Italy-Montenegro	IT-ME	2x600 MW HVDC	445 km
	Sisak-Prijedor	HR-BA	1x220 kV OHL	70 km
	Tuzla-Zenica	BA	1x220 kV OHL	15 km
	Mraclin-Sisak	HR	1x220 kV OHL	20 km
2050	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Italy-Montenegro	IT-ME	4x600 MW HVDC	445 km
	Padriciano-Divaca	IT-SI	2x220 kV OHL	14 km
	Thessaloniki-Dubrovo	EL-MK	1x400 kV OHL	125 km
	Meliti-Bitola	EL-MK	1x400 kV OHL	71 km
	Sisak-Prijedor	HR-BA	1x220 kV OHL	70 km
	Meduric-Prijedor	HR-BA	1x220 kV OHL	70 km
	Zukuzak-Mostar	HR-BA	1x220 kV OHL	100 km
	Ernestinovo-Sremska Mitrovica	HR-RS	1x400 kV OHL	95 km
	Bekescsaba-Nadab	HR-RO	1x400 kV OHL	33 km
	Sandorfalva-Arad	HU-RO	1x400 kV OHL	90 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
	Feistritz-Obersielach	AT	1x220 kV OHL	30 km
	Tuzla-Zenica	BA	1x220 kV OHL	15 km
	Slakovac-Mostar 3	BA	1x220 kV OHL	20 km
	Blagoevgrad-Ch. Mogila	BG	1x400 kV OHL	55 km
	Metalurgichna-Stolnik	BG	1x400 kV OHL	15 km
	Amyndeo-Meliti	EL	1x400 kV OHL	35 km
	Mraclin-Sisak	HR	1x220 kV OHL	20 km
	Cordignano-Udine	IT	1x400 kV OHL	19 km
	Dugale-Sandrigo	IT	1x400 kV OHL	31 km

Scenario "HighRES_Coop"

Table 4.15 Infrastructure projects suitable for RES integration (scenario HighRES_Coop)

Year	Start/end	Country/border	Layout	Length
2030	Redipuglia-Divaca	IT-SI	1x400 kV OHL	60 km
2040	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	Thessaloniki-Dubrovo	EL-MK	1x400 kV OHL	125 km
	Italy-Montenegro	IT-ME	3x600 MW HVDC	445 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Sisak-Prijedor	HR-BA	1x220 kV OHL	70 km
	Meduric-Prijedor	HR-BA	1x220 kV OHL	70 km
	Zukuzak-Mostar	HR-BA	1x220 kV OHL	100 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
	Blagoevgrad-Ch. Mogila	BG	1x400 kV OHL	55 km
	Cordignano-Udine	IT	1x400 kV OHL	19 km
	Dugale-Sandrigo	IT	1x400 kV OHL	31 km
2050	Redipuglia-Divaca	IT-SI	2x400 kV OHL	60 km
	Thessaloniki-Blagoevgrad	EL-BG	1x400 kV OHL	155 km
	Thessaloniki-Dubrovo	EL-MK	1x400 kV OHL	125 km
	Meliti-Bitola	EL-MK	1x400 kV OHL	71 km
	Italy-Montenegro	IT-ME	4x600 MW HVDC	445 km
	San Fiorano-Kaunerta	IT-AT	1x220 kV OHL	26 km
	Sisak-Prijedor	HR-BA	1x220 kV OHL	70 km
	Meduric-Prijedor	HR-BA	1x220 kV OHL	70 km
	Zukuzak-Mostar	HR-BA	1x220 kV OHL	100 km
	Kosovo B-Skopje	XK-MK	1x400 kV OHL	70 km
	Kaunertal-Westtirol	AT	1x220 kV OHL	30 km
	Feistritz-Obersielach	AT	1x220 kV OHL	30 km
	Blagoevgrad-Ch. Mogila	BG	1x400 kV OHL	55 km
	Ch. Mogila-SofiaZapad	BG	1x400 kV OHL	35 km
	Amyndeo-Meliti	EL	1x400 kV OHL	35 km
	Cordignano-Udine	IT	1x400 kV OHL	19 km
	Dugale-Sandrigo	IT	1x400 kV OHL	31 km

Summary and recommendations

Table 4.16 gives an overview of the detailed results derived from the tables introduced before:

Table 4.16 Infrastructure projects suitable for RES integration (summary)

Year	Scenario	Number of projects (cross-border | internal)	Total length of projects
2030	RefRES-NoCoop	1 | 0	60 km
	RefRES-Coop	1 | 0	60 km
	HighRES-NoCoop	2 | 0	215 km
	HighRES-Coop	1 | 0	60 km
2040	RefRES-NoCoop	4 | 1	776 km
	RefRES-Coop	3 | 0	720 km
	HighRES-NoCoop	4 | 2	1270 km
	HighRES-Coop	8 | 4	2136 km
2050	RefRES-NoCoop	6 | 7	2067 km

Year	Scenario	Number of projects (cross-border | internal)	Total length of projects
	RefRES-Coop	9 | 7	2307 km
	HighRES-NoCoop	13 | 10	3033 km
	HighRES-Coop	10 | 7	2822 km

The main findings are as follows:

- Infrastructure needs for RES integration are higher for the HighRES scenarios than for the RefRES scenarios which reflects the expected impact of the assumed RES deployment in the different scenarios;
- Cooperation vs. no cooperation related to the fulfilment of RES targets has only a moderate effect on the infrastructure needs for enhanced RES integration;
- The lists contain cross-border interconnections as well as internal lines which underlines that import/export capabilities are not only dependent on the amount of cross-border transmission capacities;
- The infrastructure projects identified to be beneficial in the considered scenarios are widely spread over the CESEC region. However, some of the countries (e.g. IT, BG, EL) are stronger affected than others;
- RES integration in 2030 and 2040 requires low to moderate grid reinforcements, highlighting that the already planned projects seem to be suitable to integrate expected RES deployment until 2040 to a high extend. Infrastructure needs for RES integration in 2050 become significant, except for scenario "HighRes_Coop" where infrastructure needs are also significant in 2040.

Regarding the potential realisation of infrastructure projects, the highest priority should be assigned to those projects in the most affected countries and at the same time to projects that would be beneficial in the highest number of RES deployment scenarios as these projects likely provide the highest benefit related to RES integration.

Especially with respect to the results for 2050, the conclusions shall be periodically verified and, if necessary, evaluated again taking into account the actual future developments in the energy sector in the CESEC region.

Market integration, price developments and CO2 emission

The above-presented projects have a less significant effect on wholesale price developments, market integration and CO2 emissions, if compared to the setup where the already-planned infrastructure projects are realised, their most important contribution is enhancing renewable integration. On the following figure only, slight changes are visible. Regional average baseload prices decrease by around 0.5-1 €/MWh in 2050 as a result of further grid extension. The variance of wholesale power prices in the region is already rather low if the already planned infrastructure is in place, so the further projects only have a less sizeable effect, which further enhances market integration. Electricity generation related CO2 emission decreases by 1-3% in 2050 as a result of new infrastructure elements on top of the already planned lines.

Figure 4.19 Wholesale prices in the CESEC region with already planned infrastructure (PCI) and further extension (Extended)

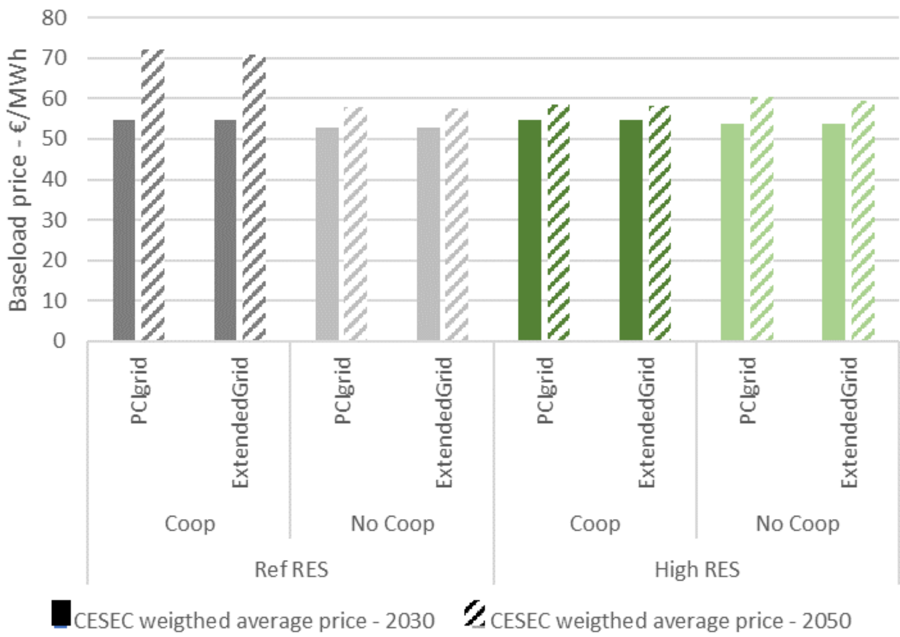
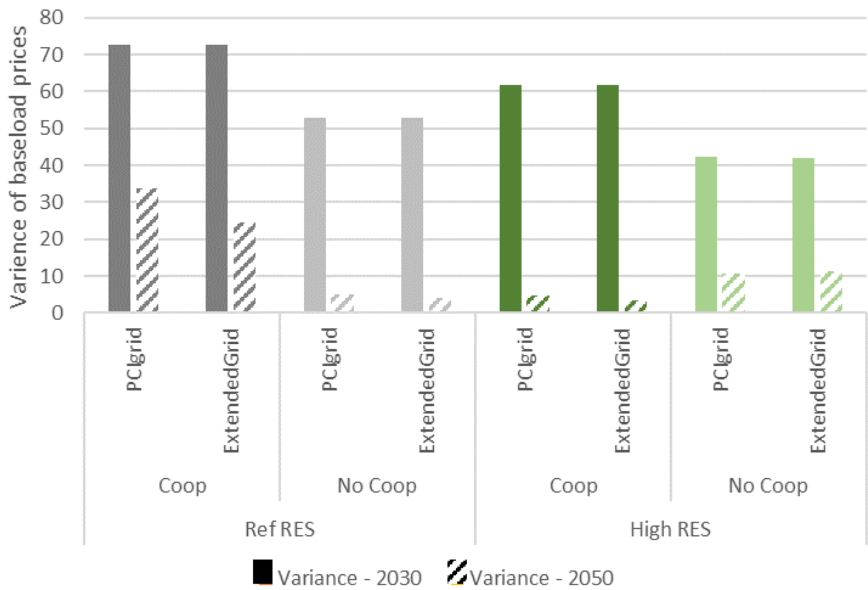


Figure 4.20 Variance of baseload prices in the region with already planned infrastructure (PCI) and further extension (Extended)



To evaluate commercial congestion with the further extended grid, the average yearly utilisation of all lines and the numbers of fully congested hours were calculated, similarly to the previous infrastructure scenarios, for 2030 and 2050. The modelling results show that completion of new proposed lines does not significantly affect congestion, relative to the infrastructure scenario of newly proposed PCI, ENTSO-E TYNDP, and Energy Community projects. Figure 4.21 , shows that both in 2030 and 2050, the lines with very high yearly utilisation are the same, as they were in the planned projects scenario.

Figure 4.21 List of commercially congested borders with proposed new infrastructure projects, 2030 (left) & 2050 (right)

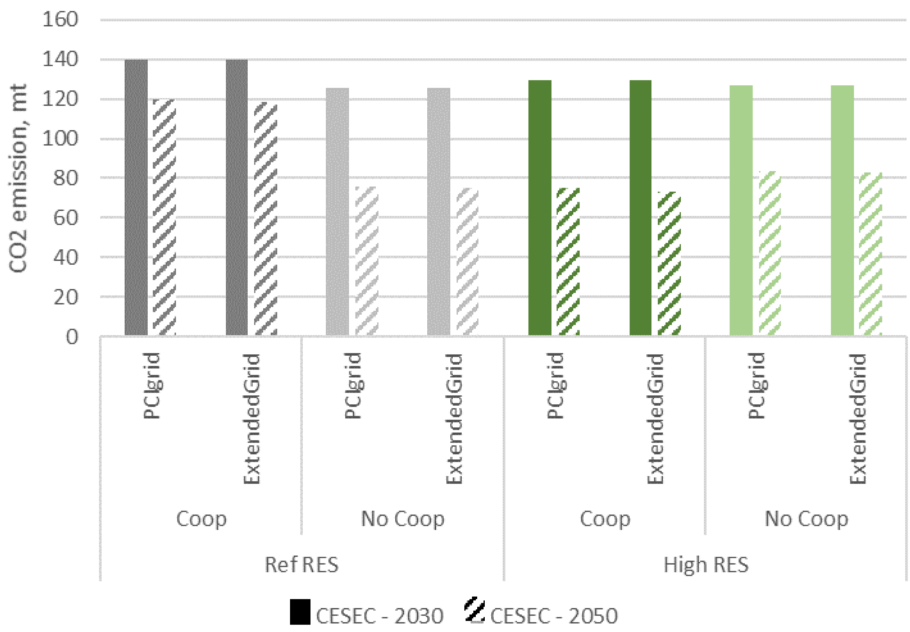
Table 4.17 compares the five most commercially congested borders based on the total number of fully congested hours in 2030 and 2050, between the planned projects and extended grid infrastructure scenarios. The tables strengthen the previous conclusion as there are only slight differences identifiable in terms of commercial congestion between the two infrastructure scenarios.

Table 4.17 5 most commercially congested borders based on the number of fully congested hours in the planned infrastructure and extended grid scenarios, 2030 (upper) & 2050 (lower)

Planned infrastructure projects (2030)			**Extended grid (2030)**		
Country A	Country B	Number of congested hours	Country A	Country B	Number of congested hours
SI	IT	3 932	AT	IT	3 990
AT	IT	3 931	SI	IT	3 983
EL	IT	3 795	EL	IT	3 633
AT	HU	3 651	AT	HU	3 490
AT	SI	2 948	ME	IT	3 004
Planned infrastructure projects (2050)			**Extended grid (2050)**		
Country A	Country B	Number of congested hours	Country A	Country B	Number of congested hours
MD	RO	8 218	MD	RO	8 213
UA	RO	8 218	UA	RO	8 213
EL	AL	5 695	EL	AL	5 694
AT	SI	5 024	AT	SI	5 039
AT	HU	4 994	AT	HU	5 010

Therefore, the analysis highlights a very important conclusion: solving renewable curtailment problems does not target those borders in the CESEC region where commercial congestion is expected to be the highest. Even though the new proposed projects reduce renewable curtailment need significantly, there are only minor effects identified for commercial congestion. To highlight the most important infrastructure needs that would benefit the whole CESEC region an in-depth analysis for commercial bottlenecks is also required, but this type of evaluation is not in the scope of the current report.

Figure 4.22 Total electricity generation related CO2 emission in the CESEC region with the already planned infrastructure (PCI) and the further extension (Extended)

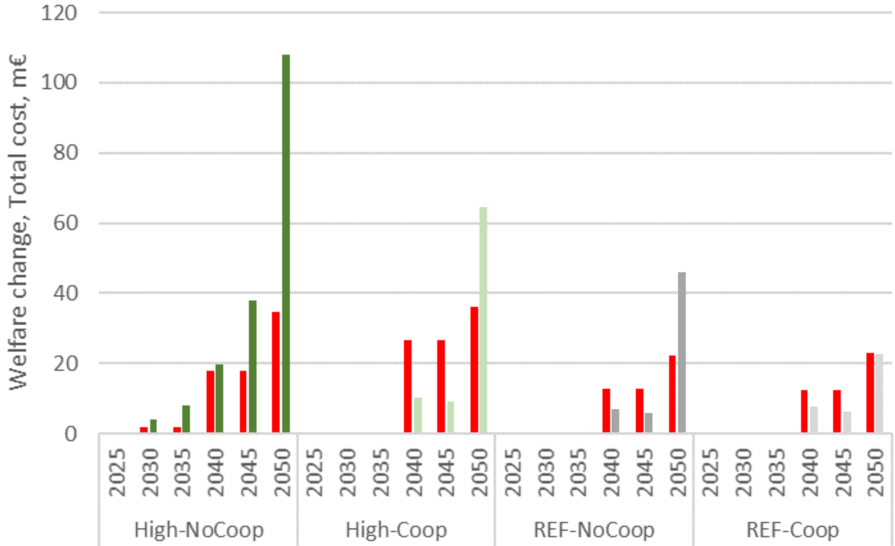


Welfare effects of identified new infrastructure

The same welfare and cost calculation as presented before is carried out for the identified projects on top of already planned infrastructure (ExtendedGrid vs. PCIgrid). In this setup the analysed infrastructure elements are different for the four renewable scenarios, so costs also differ. For the extended grid investment costs were benchmarked for mainland cables based on Energy Community (2020), while for subsea cables and converter stations based on Acer (2015). Operation costs were estimated as 1.05% percent of the total investment cost yearly, based on ENTSO-E TYNDP 2020 average project costs for the CESEC region.

The results indicate, that the projects helping renewable integration provide much higher benefits than costs by 2050 in almost all four cases, the only exception is the Reference RES, Cooperation scenario, where costs are more or less equal to benefits. However, between 2040 and 2050 only the High RES no-cooperation scenario welfare gains are higher than the estimated cost of identified new infrastructure elements, which underlines the importance of adequate timing of infrastructure investments. The highest benefits can be identified for consumers and in 2050, similarly as in the case of the already planned projects, but in some years and scenarios the modelling shows that producers are the main beneficiaries, and consumers' welfare decreases. TSO rent decrease is the least significant but is somewhat higher in the case of the cooperation scenarios. It has to be noted though, that the consumer and producer surplus change and TSO rent change can be considered as part of overall socio-economic welfare, thus these gains are rather a lower bound of total gains. It is also visible, that while more projects are identified in case of higher renewable scenarios, the benefits are also much higher if more renewables are in the system.

Figure 4.23 Welfare changes and total annualised costs of identified infrastructure projects on top of already planned projects



Source: REKK modelling.

4.4 Key findings

The results of the grid assessment modelling show that the CESEC region would face significant commercial congestion issues and RES integration bottlenecks if the already planned (TYNDP, PECI and CESEC priority list) grid infrastructure projects would not be realised. With the existing grid topology congestions would occur at the West Balkan region, while with the realisation of the planned projects remaining congestions would be centred at the borders of Italy, Austria and Slovenia. Without the planned extensions, there are significant congestions in the system, reaching a critical level by 2050 at many borders.

For further RES integration purposes, several internal and cross-border lines (of which most are AC connections) are identified on top of the already planned projects. Commercial congestion and RES integration issues appear at different borders, therefore those lines which play important role in RES integration are not necessarily those which reduce commercial congestion the most.

The integration impact of the additional projects depends on the assumed RES deployment and the cooperation level of the countries. The infrastructure projects identified to be beneficial in the considered scenarios are widely spread over the CESEC region. However, some of the countries (e.g. IT, BG, EL) are stronger affected than others. Beyond 2040 the reinforcement needs significantly increase. Highest priority should be assigned to those projects in the most affected countries and at the same time to projects that would be beneficial in the highest number of RES deployment scenarios. Especially concerning the results for 2050, the conclusions shall be periodically verified and, if necessary, evaluated again taking into account the actual future developments in the energy sector in the CESEC region.

The welfare analysis carried out on the planned and on the proposed new infrastructure projects shows, that the planned (TYNDP, PECI and the CESEC priority list) projects are beneficial from a socio-economic point of view. These socio-economic benefits are clearly positive in the high renewable deployment scenarios.,With a lower level of RES deployment infrastructure development costs might be higher than the economic benefits for a given period of time, between 2030 and 2050. This underlines the importance of the iterative planning: infrastructure developments should follow the RES capacity developments to reach economically and socially optimal pathways. The welfare assessment shows, that consumers are the main beneficiaries of the new infrastructure developments, where their gain is driven through the reduced electricity prices.

Already planned projects (TYNDP, PECI and CESEC priority projects), would improve market integration significantly. This is indicated by the price convergence of the CESEC power markets, where significant wholesale price reductions and even more sizeable reduction in price variance is observable if the planned grid projects are realised. The further expansion of the CESEC power grid with the proposed new lines has a low effect on the wholesale prices. This means, that the proposed list of projects mainly serve RES integration objectives.

The new infrastructure elements can help to further reduce CO_2 emissions in the long run, through enhanced RES integration and trade opportunities. The full CO_2 reduction potential is realised rather at the end of the modelled period, by 2050, when more renewable capacity is available in the system.

Concerning the supply security dimension under the modelled scenarios, in most of the countries, no security of supply issues arises under the assumed market-based operation. Energy not supplied values are 0 among all scenarios in all countries and all modelled years. Very low missing reserve capacity values are present in only two countries (Albania and Ukraine). The analysed infrastructure extensions do not affect SoS indicators.

5 Implementation challenges and barriers to RES deployment and cross-border cooperation

5.1 Inventory of challenges

As a basis for the inventory of challenges, the first list of barriers was developed which was then updated, assessed and verified through stakeholder input. The barriers were categorized into five main groups (regulatory, financial, technical, political, socio-economic and environmental), and compiled through extensive desk research and reviewing literature from different entities. The final list of barriers is as follows:

Regulatory

1. Complexity and length of administrative procedures e.g. lack of information or involvement of a large number of entities in the permit procedures;
2. Lack of sufficient/insufficient integration of RES in spatial planning;
3. Design and approval of Power Purchase Agreements (PPAs)[40];
4. Lack of coordination of RES regulation between countries (e.g. support schemes, spatial planning, taxes, market access).

Financial

1. Lack of investment security for RES projects;
2. Fossil fuel energy subsidies and low energy tariffs that reduce the competitiveness of renewable energy;
3. Strict financing conditions for RES projects;
4. Funding gap for commercially non-viable cross-border interconnection.

Technical

1. Possible grid integration restrictions limit RES uptake;
2. Lack of technical capacity and know-how to accelerate the integration of RES in the region e.g., skills (technical, academic, planning and operational, entrepreneurial, policy, etc.);
3. Lack of comprehensive data;
4. Restricted exchange of data between countries;
5. Lack of long-term cross-border interconnector capacity products;
6. Uncertainties of assumptions underlying cost and benefit analyses of cross-border projects.

Political

1. Political instability affecting the creation of a transparent and reliable RES framework;
2. Prioritization of non-RES in the energy mix;
3. Uncertainty and complexity of designing the cooperation model;
4. Difficulties in defining adequate cost-benefit sharing mechanisms.

Socio-economic and environmental

1. Public acceptance in both off-taker and host countries;
2. Low public engagement and lack of public awareness on RES;
3. Environmental concerns, e.g. adverse effects on biodiversity.

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[40] This barrier was added by the stakeholders. It can refer to both, the PPA contracts with official authorities in the context of the support payments or PPA contracts with private companies. Problems probably arise mainly in those countries where official PPA contracts are not reliable or delayed.

Building on the verified list of barriers, a systematic format for the inventory of challenges was developed. In this format, the barriers are classified into five main categories and their severity is identified. The format facilitates an effortless comparison between the barriers facing different projects. Each barrier can be identified as irrelevant, low, moderate or high severity according to the evaluation carried out through the interviews and surveys. The table below shows the format of the inventory with the barriers and arbitrary projects.

Project Identifier:		**[N]**	**[M]**	**..**	**..**
Region:		**X-Y**	**-Z**	**..**	**..**
Regulatory	Complexity and length of administrative procedures				
	Lack of sufficient/insufficient integration of RES in spatial planning				
	Design and approval of Power Purchase Agreements (PPAs)				
	Lack of coordination of RES regulation between countries				
Financial	Lack of investment security for RES projects				
	Fossil fuel energy subsidies and low energy tariffs that reduce the competitiveness of renewable energy				
	Strict financing conditions for RES projects				
	Funding gap for commercially non-viable cross-border interconnection				
Technical	Possible grid integration restrictions that limit RES uptake				
	Lack of technical capacity and know-how to accelerate the integration of RES in the region				
	Lack of comprehensive data				
	Restricted exchange of data between countries				
	Lack of long-term cross-border interconnector capacity products				
	Uncertainties of assumptions underlying cost and benefit analyses of cross-border projects.				
Political	Political instability affecting the creation of a transparent and reliable RES framework				
	Prioritization of non-RES in the energy mix				
	Uncertainty and complexity of designing the cooperation model				
	Difficulties in defining adequate cost-benefit sharing mechanisms				
Socio-Economic & Environ-mental	Public acceptance in both off-taker and host countries				
	Low public engagement and lack of public awareness				
	Environmental concerns, e.g. adverse effects on biodiversity				

5.2 Survey

Survey sample size and respondents

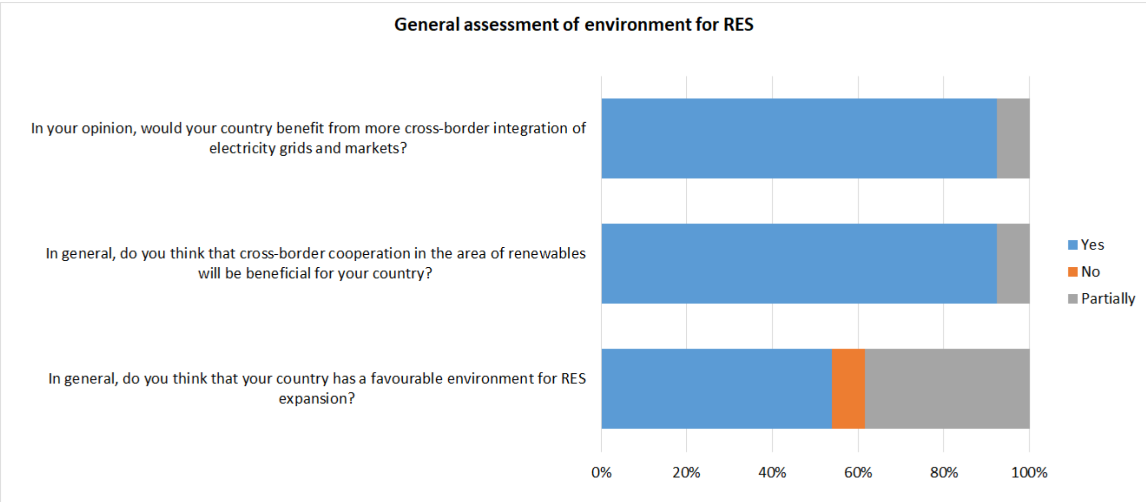
The survey and poll reached a total of 31 respondents (n=31)[41]. While this is a comparatively low sample size, the explanatory value of the results is increased given that the survey targeted and reached a highly specialized audience. However, a certain caveat as regards the validity of results remains. For a 95% confidence level, an adequate estimate of the margin of error is given by $1/\sqrt{N}$, where N is the number of respondents. The margin of error is thus 17.96%[42]. Due to the small number of respondents and a significant share of respondents representing multiple countries through either an NGO or an international organisation or body (EU, financial institution, etc.), it is not possible to derive country- or country-grouping-specific effects.

As for the types of respondents, it can be said that most respondents represent system operators (TSOs) or non-governmental organizations. Taken together, these two categories account for more than 50% of respondents which also means that they are proportionally overrepresented in the sample. Other types of respondents include national authorities, investors and financing institutions or energy utilities/project promoters. Specific challenges for certain investor groups such as small and medium companies can therefore not be assessed.

General framework for RES

As for the general assessment of the environment for RES deployment in their country, respondents' assessment was predominantly positive with more than 60% of respondents answering "yes" or "partially". Some 40% of respondents see room for improvement though when it comes to the framework conditions for RES expansion in general. When it comes to assessing the benefits of RES cross-border cooperation and cross-border integration of grids and markets, respondents are even more positive with shares higher than 90%. These rather high shares might be explained though by the types of stakeholders to which the survey was distributed which can in general be expected to have a positive attitude towards RES in general and cross-border RES cooperation in particular.

Figure 5.1 Results of the survey on a general assessment of environment for RES



Source: Survey done for this study.

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41 Numbers of respondents slightly vary across questions as a small number of respondents (<3) chose not to answer to certain questions. As some questions were only added during the survey, the sample size is smaller for these few questions.

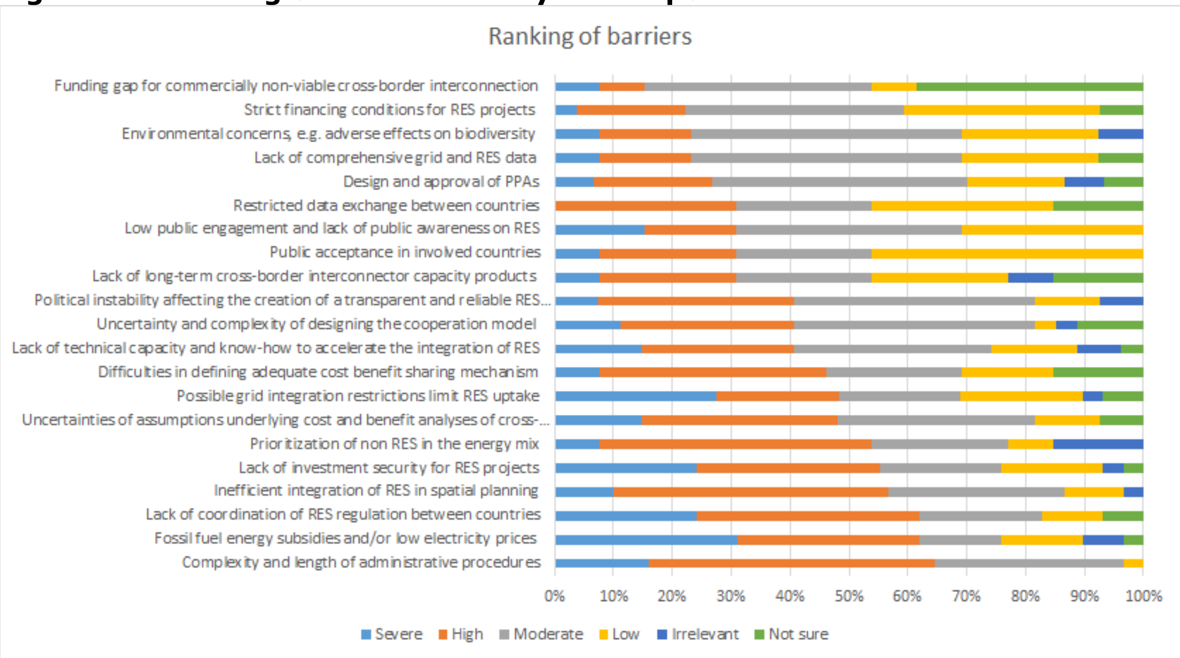
42 To put this into perspective, for a margin of error of only 10%, the survey would have needed to reach 100 respondents.

Ranking of barriers

Respondents were presented with a list of barriers, spread across five different categories, and asked to assess their importance. The below graph depicts a ranking of all barriers starting with those barriers ranked as most severe, irrespective of their sub-category. Three barriers were assessed as either high or severe obstacles to cross-border RES cooperation by more than 60% of respondents:

- Complexity and length of administrative procedures;
- Fossil fuel energy subsidies and/or low electricity prices;
- Lack of coordination of RES regulation between countries.

Figure 5.2 Ranking of the barriers by the respondents



Source: Survey done for this study.

Three additional barriers were ranked as being of either high or severe impact by more than 50% of respondents:

- Inefficient integration of RES in spatial planning;
- Prioritization of non RES in the energy mix;
- Lack of investment security for RES projects.

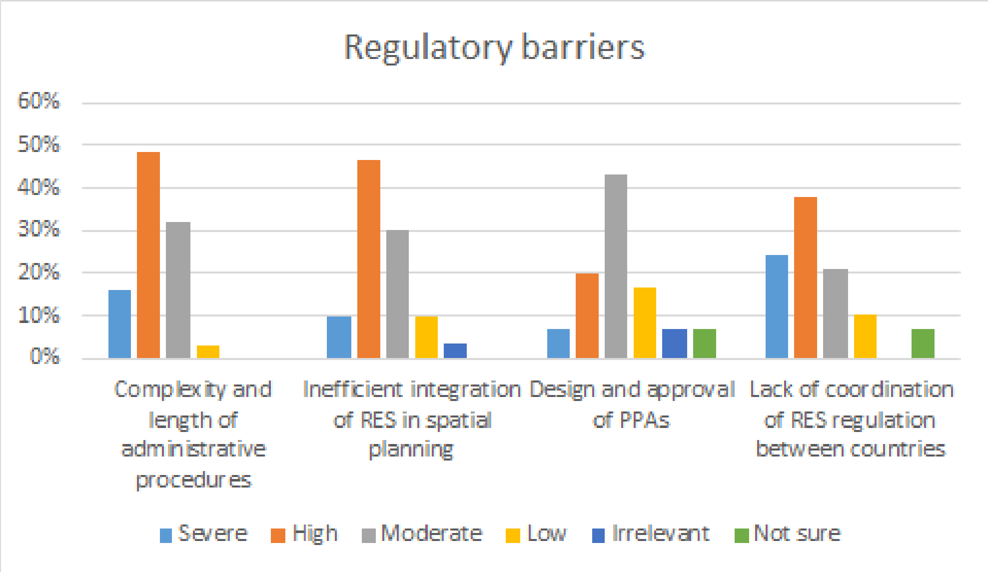
Findings across categories and countries

The following paragraphs discuss the survey results across categories and depict the most relevant results in graphs.

<u>*1 Regulatory barriers*</u>

The first category of barriers assessed in the survey are regulatory ones. Close to 65% of respondents rate complexity and length of administrative procedures as a severe or highly important barrier to cross-border RES cooperation. As for the lack of sufficient or inefficient integration of RES in spatial planning procedures, the picture is similar with more than 55% of respondents rating this as a severe or highly important barrier to cross-border RES cooperation. As for the design and approval of long-term Power Purchase Agreements (PPAs), the picture that emerges is less clear, even though in total the majority of respondents is of the opinion that their ramifications can represent an at least moderate barrier. An ambiguous answer was expected as PPA framework conditions and reliability differs substantially between CESEC countries. As expected for cross-border cooperation, the lack of coordinated regulation between countries is also perceived as a significant barrier with more than 60% of respondents answering that the issue is either of severe or high importance. All in all, regulatory barriers seem to be significant obstacles to efficient cross-border RES cooperation. This was also supported during the stakeholder interviews.

Figure 5.3 Importance of the different regulatory barriers



Source: Survey done for this study.

Summary of cross-country findings for regulatory barriers

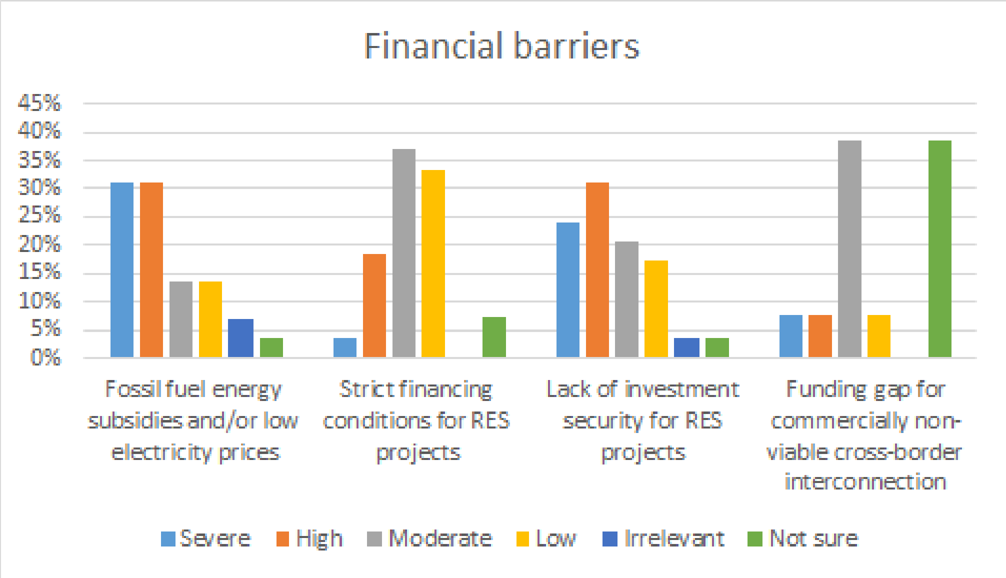
- When it comes to regulatory barriers of cross-border RES cooperation projects, the complexity and length of administrative procedures plays a significant role and is predominately assessed as either moderately or highly severe;
- The lack of integration of RES in countries' spatial planning is also predominately assessed as either moderately or highly severe;
- The lack of coordination or inefficient coordination of RES regulation between countries (e.g. support schemes, spatial planning, taxes, market access) is predominately assessed as either moderately or highly severe.

As for the design and approval of PPAs, the situation seems to differ across countries and no concrete picture emerges. This can be explained by the fact that the situation with regards to PPAs differs substantially between CESEC countries. In order to reach a stable RES expansion and enable cross-border cooperation, stable and reliable PPA contracts are however crucial in countries where these contracts form part of the support system.

2 Financial barriers

As for financial barriers, the most significant barrier emerging pertains to fossil fuel support in the form of energy subsidies and/or low electricity prices. In some countries of the CESEC region, electricity prices are kept below costs for electricity generation. Depending on the support system this can hinder substantially the expansion of renewable energies. Cumulatively, more than 60% of respondents assess these as a severe or highly important barrier. Strict financing conditions, on the contrary, are assessed as being of moderate or low importance by about 70% of all respondents. As for the other financial barriers, no clear picture is emerging with a larger degree of heterogeneity across countries. As for the funding gap for commercially non-viable cross-border interconnectors, the share of respondents who chose “not sure” was disproportionately high which suggests that the question was not clear enough or respondents did not feel in a position to judge.

Figure 5.4 Importance of the different financial barriers



Source: Survey done for this study.

Summary of cross-country findings for financial barriers

- The issue of fossil fuel energy subsidies and/or low fossil-fuel based electricity prices in countries is predominantly assessed as highly and severely important[43];
- Strict financing conditions for RES projects seem to play a smaller role and are predominately assessed as being of low or moderate importance;
- As for the lack of investment security for RES projects, the picture is more diverse across countries, with the distribution being slightly skewed towards the higher end of the tail.

3 Technical barriers

When it comes to technical barriers, results are heterogenous for the issue of grid integration restrictions limiting RES update, restricted data exchange between countries and lack of long-term cross-border interconnector capacity products. This suggests that situations across countries vary significantly. As for technical capacity and know-how as well as uncertainties of assumptions underlying cost and benefit analyses of cross-border projects, there is a concentration in the moderate and high range. Lack of comprehensive grid and RES data is predominantly assessed as moderately severe. It should be noted that for two questions the share of respondents choosing "not sure" was disproportionately high, which suggests that either the question was not sufficiently clear formulated or the respondents did not feel they possess the right knowledge to properly assess these questions.

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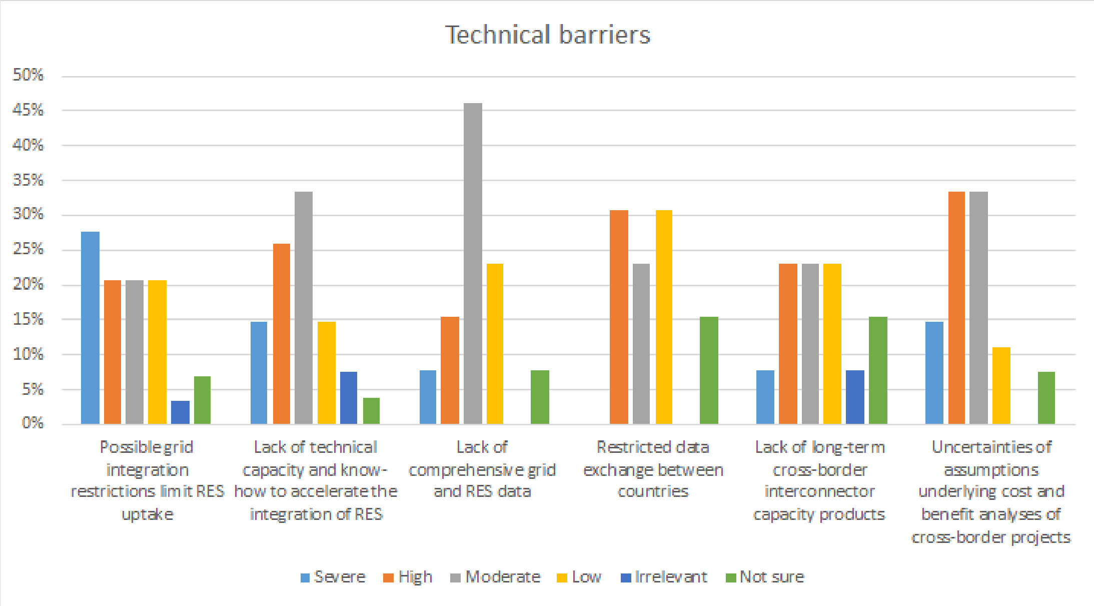
43 The issue at hand is comparatively lower retail prices for fossil based electricity in many of the concerned countries. Looking at the Energy Community Contracting Parties, direct subsidies to fossil fuel producers still exist in many countries and have a distorting effect, posing an obstacle to the energy transition.

Figure 5.5 Importance of the different technical barriers



Source: Survey done for this study.

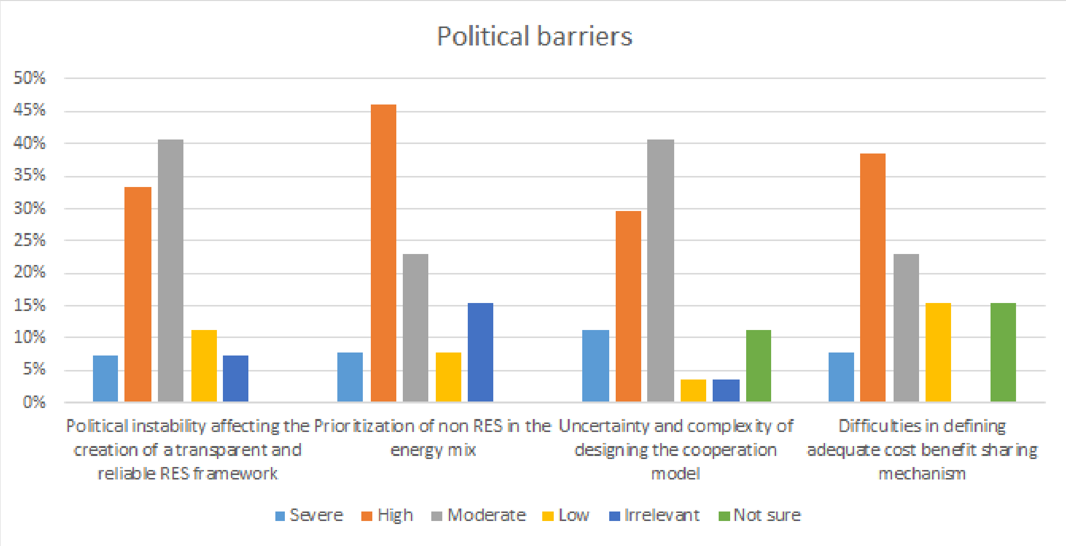
Summary of cross-country findings for technical barriers

- When it comes to possible grid integration restrictions limiting RES uptake, the results point towards a diverse situation across countries;
- As for the assessment of the lack of technical capacity and know-how to accelerate the integration of RES, the majority of respondents are concentrated in the moderate and high range;
- Lack of comprehensive grid and RES data is assessed as moderately severe, while there seem to be different situations across countries when it comes to data exchange between countries;
- When it comes to the lack of long-term cross-border interconnector capacity products, no coherent picture emerges;
- Uncertainties of assumptions underlying cost and benefit analyses of cross-border projects are predominantly assessed as moderately or highly severe.

4 Political barriers

In terms of political barriers, all identified barriers exhibit a concentration of respondents in the high and moderate severity segment, with the prioritization of non-RES in countries' energy mixes and difficulties in defining adequate cost-benefit sharing mechanisms being assessed as more severe than the other two barriers. Political instability is predominantly assessed as either highly or moderately severe, with most respondents rating it as moderately severe. Results are very similar for the uncertainty and complexity of designing the underlying cooperation model between countries. Again, two questions have a disproportionately high share of respondents having chosen "not sure" which might indicate that they were not sure how to answer the question either because it was not formulated clear enough or because they did not feel capable of judging the matter.

Figure 5.6 Importance of the different political barriers



Source: Survey done for this study.

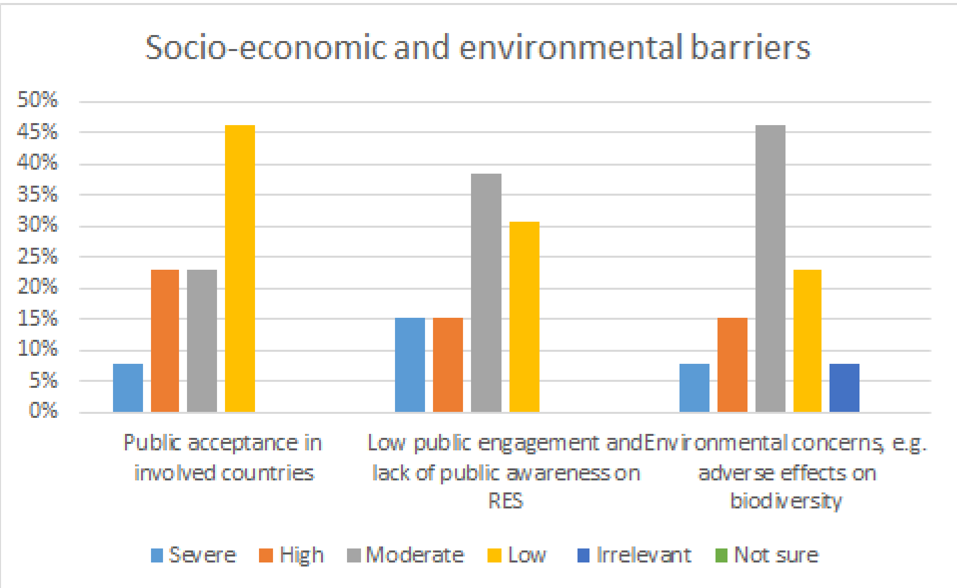
Summary of cross-country findings for political barriers

- As for political instability affecting the creation of a transparent and reliable RES framework, this is predominately assessed as moderately or highly severe;
- The prioritization of non-RES in the energy mix is mostly assessed as highly severe;
- Uncertainty and complexity of designing the cooperation model is predominantly assessed as moderately or highly severe.

5 Socio-economic and environmental barriers

The last category of barriers assessed were socio-economic and environmental ones. The picture that emerges here is that the majority of respondents ranked those challenges as being of either moderate or low significance.

Figure 5.7 Importance of the different socio-economic and environmental barriers



Source: Survey done for this study.

Summary of cross-country findings for socio-economic and environmental barriers:

- As for public acceptance in involved countries, this barrier is predominately assessed as being of low severity;
- Low public engagement and lack of public awareness on RES is predominately assessed as of either moderate or low severity;
- Environmental concerns, e.g. adverse effects on biodiversity, are predominately assessed as being of moderate severity.

5.3 Stakeholder interviews

To complement the survey results and add insights from practitioners, a total of eight stakeholders from six different countries (Bulgaria, Greece, Romania, Moldova, Republic of North Macedonia, Serbia) and two representatives from the Energy Community Secretariat were interviewed using semi-structured interviews. Interviewees were composed of four representatives from TSOs, two representatives of national Ministries in charge of cross-border infrastructure, two representatives from academia and two representatives from the Energy Community Secretariat.

On a high level, interviewees confirmed the survey results, even though there also seems to be considerable regional heterogeneity when it comes to assessing the impact of individual barriers. The interviews confirmed that local circumstances still differ considerably between countries and groups of countries, e.g. coal-dependent economies or smaller, import-dependent countries. Interviewees especially pointed out differences between the EU Member States and Energy Community Contracting Parties, particularly when it comes to regulatory frameworks. While interviewees confirmed that progress in that regard is being made, challenges persist and are perceived as detrimental to cross-border RES cooperation as sometimes differences between regulations are time-consuming to reconcile. Overall, interviewees were favourable to cross-border RES cooperation. Contracting parties acknowledged the positive effect of the EU regulatory system and available mechanisms for cooperation. Another issue that came up more than once was the importance of regulating entities being independent.

On the market side, stakeholders pointed out differences in maturity when it comes to the introduction of day-ahead wholesale markets which are not yet implemented in most Contracting Parties. Some interviewees mentioned the importance of the introduction and/or further development of market-based instruments, such as PPAs, as foreign investors are looking for those types of mechanisms. In some countries, there is still considerable state influence in the power system with large state-owned companies dominating the market. Fossil fuel subsidies remain an issue in some countries, but some interviewees also mentioned progress in this area with subsidies having been eliminated.

As for political challenges, stakeholders mentioned that a stable, long-term political vision is important for a successful energy transition. This does not only apply to cross-border topics but the deployment of renewables in general. Some interviewees also pointed out political instability as an issue as well as frequent changes in the leadership in charge of implementing the energy transition towards more renewables. Even though in most cases lower-ranking employees working in the administration are not affected by those types of changes, the effect can be severe as progress might be slowed down and projects put on hold or abandoned completely. On the other hand, leadership changes, for example, a more progressive government coming into power with a renewables agenda, can also have an accelerating effect and enable progress. Interviewees agreed that long-term strategies, frameworks and institutions have an important effect and help to instil trust. Some interviewees pointed out that it can be tiring for the administration when changes in direction occur frequently. Political conflicts in other unrelated areas, often also lead to tensions between countries when it comes to cross-border RES.

When it comes to socio-economic and environmental barriers, the picture that emerged from the interviews was more nuanced as compared to the survey. Public acceptance of RES remains an issue and needs to be carefully factored into the planning process of new projects. The general public is not aware of cross-border RES projects, but the issue also exists for renewables in general. Costs and benefits need to be communicated to the public and space for public involvement should be made. Examples of projects that had to be stopped because of poor public involvement processes and disregard of environmental considerations were mentioned.

Interviewees also pointed out that current cross-border infrastructure is not always used in an optimal way and that there is room for improvement. This should be considered when embarking on new projects.

5.4 Key Findings

1. In general, there is considerable consensus that cross-border cooperation is favourable and that countries will benefit from more cross-border integration of electricity grids and markets. Respondents are divided on the question, whether their country has a favourable environment for RES expansion with approximately half of the participants agreeing and the other half disagreeing or being of the opinion that the environment is only partially favourable.

2. The top three highest-ranked barriers to cross-border RES cooperation are complexity and length of administrative procedures, fossil fuel energy subsidies and/or low electricity prices and lack of coordination of RES regulation between countries.

3. Across countries, regulatory barriers to cross-border RES are assessed as the most severe (three barriers rated as either severe or highly important by more than 50%), closely followed by political barriers (four political barriers rated as either severe or highly important by more than 40% of respondents).

4. As for technical and financial barriers, the situation across countries seems more heterogeneous and for some of those barriers, there is no clear overarching tendency. This suggests that local circumstances continue to be diverse.

5. Compared to other types of barriers, socio-economic and environmental barriers are generally ranked lower in terms of severity, but the stakeholder interviews suggest that those types of challenges exist and need to be proactively addressed.

6 Conclusions and recommendations

This study investigated the different challenges and opportunities that the CESEC region faces, in terms of the potential of electricity generated from renewable energy sources and its cost-effective integration into the regional electricity system. More specifically, the analysis focused on the differences in cost and technology – and corresponding policy - implications in pair-wise combinations of three sets of scenarios, regarding: 1. the time horizon, 2. the RES targets and 3. the electricity interconnector infrastructure. More specifically, the two different time horizons considered in this study are the short term – 2030, and the long term – 2050. Second, the two sets of RES targets considered in this study are: a. the targets set out in the National Energy and Climate Plans (NECP), where defined - or alternative targets - which correspond to the scenario of reference contribution from RES in the electricity mix, and b. the targets underlying the Green Deal initiative, which correspond to the scenario of high contribution from RES. Finally, the two electricity infrastructure scenarios considered here are: a. no cross-border cooperation, whereby new capacity of RES technology is installed domestically, b. additional electricity infrastructure projects, as reflected in the planned projects in TYNDP, PECI and CESEC priority list, and c. infrastructure projects identified in addition to these latter projects. In scenarios b. and c., new capacity of RES technology is installed in regions with higher potential for power generation from RES technologies and neighbouring countries that rely on cross-border electricity trade. This study developed around the four questions below. This chapter first presents the main findings related to these questions and then provides a set of actionable recommendations:

1. What are the geographical locations of prime interest for RES development, with a cross-border dimension?[44]
2. What are the connecting infrastructure needs required to facilitate RES integration?
3. Which cross-border infrastructure projects can be identified as priority projects in enabling the integration of electricity from RES in the CESEC region?[45]
4. What are the technical, regulatory and market issues that create barriers to cross-border cooperation and hinder renewables deployment?[46]

6.1 Main conclusions

The CESEC region is promising in terms of potential electricity generation from RES technologies. More specifically, centralised and decentralised solar PV, as well as onshore wind are expected to make up the lion's share in the future electricity mix across the CESEC region. The most promising locations for the installation of offshore wind power technologies largely closely overlap with the locations for onshore wind. For this reason, while both technologies would benefit from similar wind conditions, the economics of onshore wind technology are relatively more attractive as long as land is available for its deployment. The optimal level of cost-effective hydropower capacity is almost reached by the current installed capacity, pointing to a decreasing dominance of this RES technology. The same holds true for other RES technologies.

Overall, electricity from RES is expected to reach shares of either 49% or 53.1% in the CESEC electricity mix by 2030, depending on whether the reference NECP or the Green Deal targets are implemented. By 2050, the difference between the two scenarios is much more pronounced: electricity from RES is expected to reach either 75-77% or 85-87% of the regional electricity mix, in the reference of the Green Deal scenarios, respectively.

These numbers obscure large differences between countries: while EU member states would need to double their currently installed capacity of RES, the Contracting Parties of

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[44] This question corresponds to the analysis presented in Chapter Three.
[45] Questions Two and Three correspond to the analysis presented in Chapter Four.
[46] This question corresponds to the analysis presented in Chapter Five.

the Energy Community (i.e. non-EU members of the CESEC region) would need to increase their installed capacity by more than a factor of four. Cross-border power trade and proactive cooperation in RES policy implementation has a large potential to contribute to the geographical smoothing of cost-effective electricity generation from RES: at the CESEC level, cost savings of 19% can be attributed to RES cooperation, facilitated by cross-border grid infrastructure. Albania, Bosnia and Herzegovina, Italy, Montenegro and Slovakia may offer promising RES potentials for export by 2030. In the long term to 2050, the picture partly changes: Bosnia and Herzegovina may again act as host country for the future RES uptake but other countries such as Greece, Moldova, Romania or Ukraine also join this group.

The figures presented above are discussed in more detail in the following paragraphs.

1. What are the geographical locations of prime interest for RES development, with a cross-border dimension?

The following areas at or close to borders with other CESEC countries are identified as having the highest potential for cost-effective installations, PV, onshore and offshore wind[47] capacities:

A. (AT-IT): Cross-border region at the Western part of Austria and the North-East of Italy – with strong dominance of storage hydropower in mountainous parts, complemented by photovoltaics.
B. (AT-SI): Cross-border region at the Southern part of Austria and the North of Slovenia – offering a balanced mix of wind, photovoltaics and hydropower.
C. (AT-HU-SK): Cross-border region at the North-Eastern part of Austria, the South of Slovakia and the North-Western part of Hungary – with wind available at several hotspots at favourable conditions (despite not used equally in all three countries involved), combined with run-of-river hydropower and photovoltaics.
D. (UA): Western part of Ukraine, close to the Slovakian and Hungarian border – with favourable wind conditions, waiting to be exploited at large scale and complemented by some photovoltaics in mainly rural areas.
E. (BG-MD-RO-MD): Black sea region involving the Southern part of Ukraine and Moldova as well as the Eastern coast areas of Bulgaria and Romania – with wind generally available at favourable conditions, waiting to be exploited at large scale, complemented by photovoltaics and minor small-scale hydropower developments.
F. (RS): Northern part of Serbia at the border to Hungary and Romania – with promising wind potentials, complemented by photovoltaics.
G. (RO-RS): South(-East)ern border region of Romania, combined with the Serbian border region Borska oblast – offering a balanced mix of hydropower and photovoltaics, complemented by some wind developments at best available sites.
H. (BA-HR-RS): Cross-border region involving the Southern part of Croatia, Bosnia & Herzegovina and the Serbian province Zlatiborska oblast – offering a balanced mix of wind, photovoltaics and (mainly existing) hydropower.
I. (AL): Albanian region Shkoder at the border to Montenegro – providing a balanced mix of wind and photovoltaics, complemented by (mainly existing) hydropower.
J. (IT): Provinces at the Eastern stretch of Italy, directly at or close to the Adriatic coast and in close distance to Albania – with favourable wind sites still waiting to be exploited and room for a strong uptake of photovoltaics.
K. (AL-BG-EL): Cross-border region involving Southern provinces of Bulgaria, regions in the North of Greece and the Eastern stretch of Albania – offering favourable potentials for photovoltaics and (mainly existing) hydropower, complemented by wind at certain hotspots.

[47] It is important to note that most promising locations for onshore and offshore wind installations largely overlap concerning grid integration. Coupled with the much lower technology cost of onshore wind, this suggests that offshore wind is a farther 3rd most attractive RES technology option for the time being.

2. What are the connecting infrastructure needs required to facilitate RES integration?

To answer this question, we first need to understand the main challenges that an increased contribution of electricity from RES would bring about to the existing electricity system – i.e. in the absence of further reinforcement and development of the electricity infrastructure. These are the challenges that the infrastructure needs identified in this study aim to address and are the sources of potential bottlenecks in the electricity infrastructure. The main challenges refer to the increased commercial congestion of the power grid, the evolution of electricity prices and their volatility, as well as the risk of disruption in security of electricity supply. In addition to these challenges, this study also calculated the potential of infrastructure projects to enable the reduction of CO2 emissions, due to helping to integrate the increased share of electricity from RES in the power system.

Overall, **the electricity infrastructure projects that are currently planned**[48] in CESEC countries are suitable to support the **market integration of the RES projects** identified in this study. Additional infrastructure projects would mainly contribute to this aim in the period after 2040. The following paragraphs discuss how the identified infrastructure projects impact individual aspects of the electricity market.

Under a coherent and homogenous regulatory framework across CESEC countries, currently planned projects also help the **integration of RES generation on balancing markets**. Furthermore, already planned infrastructure projects, apart from positively affecting the security of supply of the countries concerned, also **contribute to the integration of RES on the reserve market**. At the same time, they have a **significant contribution to reducing the curtailment of RES** power output. Curtailment – primarily of solar power generation, but also of wind power – reaches significant levels in 2040 and by 2050 almost all CESEC countries are affected by this phenomenon. However, despite the strong contribution of planned projects in reducing the need for curtailment, this phenomenon persists even after the planned projects become operational, albeit at a much smaller scale.

In terms of their **effect on commercial congestion**, planned infrastructure projects are not only sufficient but necessary to avoid critical levels of commercial congestion that would occur by 2050, at many borders. Currently, the Balkan region is the most prone to commercial congestion, but this situation is addressed with the planned projects. However, even after the completion of the planned projects, commercial congestion is expected to occur in the Italy-Austria-Slovenia region.

One important point to consider is that the issues of commercial congestion and RES integration are expected to occur in separate geographical areas and are thus expected to be addressed by different infrastructure projects. In other words, those lines which play an important role in RES integration are not necessarily those which reduce commercial congestion the most.

The planned projects are also **critical in addressing transmission grid bottlenecks**, especially in the regions of Western Balkans and Austria and neighbouring countries. While some congestion occurs on internal lines, the vast majority is expected to affect cross-border interconnectors.

2040 is a key year for both the accelerated deployment of RES and the contribution of planned infrastructure projects to all aspects of the electricity market discussed above. This contribution is stronger if the share of RES is already high. Due to their contribution

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[48] These projects refer to the infrastructure development projects available in the draft ENTSO-E TYNDP 2020, the projects submitted for the Project of Energy Community Interest (PECI) evaluation, including the PECI and PMI projects, the CESEC electricity action plan and the Network Development plan of the Energy Community.

to the integration of RES, planned infrastructure projects **contribute to CO_2 emissions reduction**, but this effect is more visible closer to 2050.

It is important to note that the discussion above is based on the analysis results of all planned infrastructure projects taken together. The assessment of individual projects was beyond the scope of this study. However, these projects are very heterogenous, particularly in terms of cost and contribution to overall objectives. In other words, some projects make up a small share of the overall costs but provide a much larger share of aggregate benefits.

3. Which cross-border infrastructure projects can be identified as priority projects in enabling the integration of electricity from RES in the CESEC region?

The CESEC region would face significant commercial congestion issues and RES integration bottlenecks if the already planned (TYNDP, PECI and CESEC priority list) grid infrastructure projects would not be realised. With the existing grid topology, congestions would occur at the West Balkan region, while with the realisation of the planned projects remaining congestions would be centred at the borders of Italy, Austria and Slovenia. Without the planned extensions, there are significant congestions in the system, reaching a critical level by 2050 at many borders.

For this reason, priority should be given to projects that would enable the integration of electricity from RES across the largest number of the scenarios discussed above, as well as at the earliest time. The list below provides a ranking of these projects, according to these two main criteria. Information on the countries they connect and the earliest year they are expected to contribute to RES integration is provided in brackets:

- Prati – Steinach (AT – IT, 2030)*[49]
- Reschenpass Interconnector Project* (AT – IT, 2030)
- Lienz-Venetto region (AT – IT, 2030)
- Albania-Greece capacity extension* (AL – EL, 2040)
- CSE4* (BG – EL, 2040)
- Black Sea Corridor (BG – RO, 2040)
- Refurbishment of the 400k V Meliti - Bitola interconnector (EL – MK, 2040)
- Mid Continental East corridor (RO – RS, 2040)
- HU-RO (2040)
- Romania-Moldova interconnector (Vulcanesti-Chisnau) (MD – RO, 2040)
- Suceava-Balti new interconnector (MD – RO, 2040)
- Mid Continental East corridor (RO – RS, 2040)
- Transbalkan Corridor (ME – RS, 2040)
- Albania-Kosovo capacity extension* (AL – XK, 2040)
- New interconnector UA_E-RO (UA_E-RO, 2040)
- New interconnector UA_W-SK (UA_W-SK, 2040)
- South Balkan Corridor* (AL – MK, 2040)
- Obersielach-Podlog (AT – SI, 2040)
- Pannonian Corridor (HU – RS, 2040)
- Slovenia-Hungary/Croatia interconnection* (HU – SI, 2040)
- Upgrading of existing 220 kV line between HR and BA to 400 kV (BA – HR, 2050)
- CSE1 New (BA – HR, 2050)
- New 400 kV interconnection line between Serbia and Croatia (HR – RS, 2050)

There are important economic gains associated with the planned infrastructure projects, compared to only the projects already under construction. These differences stem mainly from a most cost-efficient reallocation of RES installation in areas with higher RES potential. Cost savings can reach up to 23% and 38% between the two infrastructure

[49] Interconnector projects marked with " * " are already under construction.

scenarios,[50] depending on the type of support scheme in place. In turn, due to the rapid decrease of costs of RES technologies – both achieved and further expected – new RES installations will require significantly less financial support, compared to the RES installations already in place. When looking at individual types of policy support schemes, the absolute costs associated with targeted, technology-specific incentives for RES uptake are approximately 40% lower than the costs associated with a RE technology-agnostic, policy umbrella approach.[51]

4. What are the technical, regulatory and market issues that create barriers to cross-border cooperation and hinder renewables deployment?

One picture that emerges from surveys and expert interviews is that there is a wide array of barriers ahead of meeting the Green Deal RES targets cost-effectively. More importantly, the set of national barriers is heterogenous across countries, however, a set of common concerns emerges: across countries, political and regulatory barriers to cross-border RES are assessed as the most severe. These are followed by technical and financial barriers and, lastly, socio-economic and environmental barriers.[52]

Overall, most identified (inter)national experts consider that cross-border cooperation projects are beneficial for their respective countries, with approximately half of respondents considering that their countries have a high potential for RES expansion, while the remaining respondents consider the RES potential in their countries as partially favourable. These complementary results point to the high potential for cross-border cooperation in the CESEC region, as the number of countries with relatively high RES potential RES is similar to the number of countries that would benefit from imports of cost-effective RE power generation.

When it comes to **regulatory barriers** of cross-border RES cooperation projects, the complexity and length of administrative procedures plays a significant role and is predominately assessed as either highly or moderately severe. The lack of integration of RES in countries' spatial planning is also predominately assessed as either highly or moderately severe. The lack of coordination or inefficient coordination of RES regulation between countries (e.g. support schemes, spatial planning, taxes, market access) is predominately assessed as either highly or moderately severe. As for the design and approval of PPAs, the situation seems to differ across countries and no concrete picture emerges.

With regard to **political barriers**, the prioritization of non-RES in the energy mix is mostly assessed as highly severe. Political instability affecting the creation of a transparent and reliable RES framework is predominately assessed as moderately or highly severe. Uncertainty and complexity of designing the cooperation model is predominantly assessed as moderately severe. When it comes to difficulties in defining an adequate cost benefit sharing mechanism, no clear picture emerges.

As for **financial barriers**, the situation across countries seems more heterogenous. The issue of fossil fuel energy subsidies or low electricity prices in countries are predominantly assessed as very highly and highly severe. Strict financing conditions for RES projects seem to play a smaller role and are predominately assessed as being of low or moderate importance. As for the lack of investment security for RES projects, the

50 This number is calculated based on the RES ambitions states in the National Energy and Climate plans, i.e. 33.6%, instead of the Green Deal target of 40%. The cost refers to the average yearly support expenditure for post-2020 RES installations, for the 2021-2030 period.

51 Examples of targeted versus umbrella policy instruments are auctions for feed-in-premiums and technology-neutral quotas with certificate trading, respectively.

52 It is important to keep in mind that this ranking refers to the type of barriers within individual countries and does not offer information for comparison across countries. For example, a low severity ranking of environmental barriers can only be understood as lower than other type of barriers within a specific country, not lower compared to the severity of environmental barriers in other countries.

picture is diverse across countries, with a smaller concentration in the high and moderate segments.

Similar to financial barriers, the assessment of **technical barriers** also varies considerably between countries. When it comes to possible grid integration restrictions limiting RES uptake, the results point towards a diverse situation across countries, with some countries already facing full capacity use of the cross-border grid infrastructure. The lack of functional power exchanges was also identified as a particularly important barrier to RES integration, especially in the Energy Community countries. The assessment of the lack of technical capacity and know-how to accelerate the integration of RES does not provide a coherent picture across countries. Lack of comprehensive grid and RES data is assessed as moderately severe, while there seem to be different situations across countries when it comes to data exchange between countries. Uncertainties of assumptions underlying cost and benefit analyses of cross-border projects are predominantly assessed as moderately severe.

Compared to other types of barriers, **socio-economic and environmental barriers** are generally ranked lower in terms of severity. This assessment varies significantly between countries, with particularly new hydropower projects facing strong opposition on environmental grounds, in several countries. Overall, environmental concerns, e.g. adverse effects on biodiversity, are predominately assessed as being of moderate severity. Low public engagement and lack of public awareness on RES is predominately assessed as of either moderate or low severity. As for public acceptance in involved countries, this barrier is predominately assessed as being of low severity.

6.2 Recommendations

Based on the main findings summarised above, we formulate a series of actionable recommendations to facilitate the cost-effective uptake of RES in the CESEC region, in line with the Green Deal.

1. 2040 is marked by a series of challenges: the uptake of RES is expected to accelerate and the power grid stability faces serious concerns of curtailment and bottlenecks. However, already planned infrastructure projects seem suitable to address these challenges. **We recommend ensuring that they will be realised on schedule.**

2. There are several site locations in the CESEC region with high potential for offshore wind installations. However, these locations are very close to the coastline. This, coupled with the much lower technology cost for onshore wind, make the latter technology a much more promising option, under current assumptions of technology costs and their developments. In other words, onshore and offshore wind compete for similar site locations – and onshore wind emerges as a winner, due to its much lower technology cost. **We recommend an in-depth investigation of the trade-offs between on-land site locations for onshore wind and the relatively higher technology cost of offshore wind, in order to understand under which condition the latter could become economically attractive.**

3. The results presented here are based on a holistic approach to RES deployment and necessary cross-border grid infrastructure. This contrasts with the fragmented approach that is usually used in reality.[53] Lack of coordination raises uncertainty in the results of all aspects discussed in this study. **We recommend prioritising those projects which particularly benefit from an integrated implementation related to design and techno-economic feasibility.**

4. Different infrastructure projects address different concerns. Projects that contribute the most to reducing commercial congestion are not necessarily the

[53] This situation is heterogenous across countries.

same projects that contribute the most the RES integration. **We recommend updating the existing decision frameworks (notably, the TEN-E Regulation) to reflect the new climate ambitions and the ensuing challenges to the development of the appropriate electricity infrastructure. In particular, we recommend prioritising projects which, under the new targets for electricity from RES in the CESEC region, exhibit the highest- and earliest aggregate benefits.**

5. There are systematic differences between EU and Energy Community countries, particularly in terms of current RES shares, institutional and regulatory frameworks and maturity of different electricity markets. In particular, the development of products of electricity markets that are already established in mature and liberalised markets – such as power purchase agreements (PPA) - require well-functioning and liquid wholesale (especially forward) electricity markets. Furthermore, these conditions, reflected in less market concentration and increased competition, are required for the coupling of different electricity markets. **We recommend an in-depth analysis of the differences of regional and national electricity markets, with respect to regulatory frameworks and market maturity. Subsequently, we recommend that the development of customised approaches to address these barriers pay close attention to these systemic market differences.**

6. Overall, the identified barriers to RES development and associated infrastructure needs paint a regionally fragmented picture. At the same time, the main study results assume an institutional framework that is relatively homogenous. **We recommend that regulatory barriers are addressed at group level and political barriers are addressed at the country level.**

7. The strong regional heterogeneity of technical and institutional aspects suggests there is a large scope for learning from historical best practices. **We recommend identifying the role of key enablers of previous and current projects and implementing capacity building and exchange and cooperation mechanisms, in order to address financial barriers.**

8. Socio-economic and environmental barriers are ranked as lower severity, relative to other types of barriers – particularly regulatory and political barriers. However, new hydropower projects face strong opposition from environmental civil society, on environmental grounds, in several countries. **We recommend a rigorous and transparent involvement of the civil society in the development decisions of RES projects, to address environmental barriers.**

9. A noteworthy point is that some of the CESEC areas with the highest potential for cost-effective RES installation are located close to borders with non-CESEC – but EU – countries. More specifically, the North-Western part of Ukraine – at the border with Poland – and the North-Eastern part of Austria and the North-Western part of Slovakia, situated close to the Germany and Czech Republic, respectively, show particularly high potential for cost-effective installations of onshore wind. **We recommend considering exceptionally promising areas for RES development situated at the border with CESEC countries, for further analysis.**

10. One important area that is gaining ground especially in Western European countries is that of coupling of the energy sectors: the electricity, heating and transportation sectors. This issue was beyond the scope of this study. However, the rationale of sector coupling is that it is building on synergies between sectors to address different – technical, environmental, economic – challenges. **We recommend extending the analysis of the electricity system in the CESEC region to an energy sector-wide analysis, to understand how sector coupling could support the cost-effective integration of RES, in the CESEC region.**

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Annex 1: Key literature and data sources

Below key literature and data sources used within this study are summarised. It is clustered in accordance with the respective parts of the study.

Key relevance for identifying potentials for RES integration in the CESEC region:

Databases:

- TU Wien's own Green-X database, containing verified assumptions on technology-specific RES potentials and related costs by CESEC country, including financing cost (WACC) will serve as a starting point and solid basis for this assessment;
- The IRENA database, specifically concerning solar and wind potentials (IRENA et al., 2017), building on GIS-based assessments for both key supply options, and for biomass where the forthcoming IRENA study "Renewable Energy Prospects for CESEC" contains data on sustainable biomass options for the CESEC region. In general, special attention will be paid to the data for and presentation of biomass feedstocks, including consideration of sustainability, and their usability in the various energy sectors, with special attention to the power sector;
- The ENSPRESO database of JRC: an open data for the whole EU-27, comprising a comprehensive transparent and coherent database of wind, solar, biomass and hydropower energy potentials cited as Ruiz et al. (2019);
- The LOCATE - Territories and Low-Carbon Economy (Schremmer et al., 2018): One objective of this project was the provision of an overview on the regional (NUTS-3) potential for generating and distributing renewable energy across Europe, broken down into wind power, solar power (thermal, photovoltaic and concentrated), hydroelectric power, tidal power, geothermal energy, biomass and the renewable part of waste;
- The RiverWatch Database of planned hydropower plants outside protected areas in the SEE region cited as RiverWatch (2021).

Reports/Studies useed in the literature review of RES potentials in CESEC countries of Chapter 3.1:

Hydropower

- DLR, 2006
- ECN, 2004
- HPD, 2012
- IRENA et al., 2017
- JRC, 2020
- Neubarth, 2018
- RiverWatch, 2021
- Schremmer et al., 2018

Bioenergy (incl. liquid and solid biomass, biogas, biowaste)

- DLR, 2006
- Heaps et al., 2009
- IRENA et al., 2017
- Ruiz et al., 2019
- Schremmer et al., 2018

Geothermal electricity generation

- DLR, 2006

- IRENA et al., 2017

Photovoltaics (PV)

- DLR, 2006
- IRENA et al., 2017
- Schremmer et al., 2018

Wind energy (onshore)

- DLR, 2006
- ECN, 2010
- IRENA et al., 2017
- Schremmer et al., 2018

Key relevance for identifying connecting infrastructure needs to ensure RES integration:

- Agora and EMBER (2021) *The European Power Sector in 2020;* https://ember-climate.org/wp-content/uploads/2021/01/Report-European-Power-Sector-in-2020.pdf;
- ENTSO-E (January 2020) *3rd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects*, draft version; https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/Cost%20Benefit%20Analysis/200128_3rd_CBA_Guideline_Draft.pdf;
- ENTSO-E (divers) *ENTSO-E Transparency Platform*; https://transparency.entsoe.eu/;
- ENTSO-E (divers) *ENTSO-E ten-year network development plan;* https://tyndp.entsoe.eu/;
- European Commission (2020) *Impact assessment, Stepping up Europe's 2030 climate ambition, Investing in a climate-neutral future for the benefit of our people;* https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/impact_en.pdf;
- European Commission (divers) *Projects of common interest – Interactive map*; https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html;
- European Community (divers) *PLIMA: Infrastructure Transparency Platform*, https://energy-community.org/regionalinitiatives/infrastructure/PLIMA.html;
- European Union (September 2017) *Memorandum of Understanding complementing the Central and South-Eastern Connectivity (CESEC) initiative with a Joint approach on electricity market, energy efficiency and renewable deployment*, [Task 2]; https://ec.europa.eu/energy/sites/ener/files/2017_mou_on_cesec_extension_signed.pdf;
- REKK (2020) *latest reference scenario: Updated (mainly by consumption and fuel/EUA prices) version of the Assessment for the identification of candidate Projects of Energy Community Interest (PECI) and candidate Projects for Mutual Interest (PMI), Final Report*, 05.06.2020; https://www.energy-community.org/regionalinitiatives/infrastructure/selection.html.

Key relevance for identifying implementation challenges and barriers to RES deployment and cross border cooperation:

- Agora Energiewende (2018) *A Clean-Energy Transition in Southeast Europe: Challenges, Options and Policy Priorities*; https://www.agora-energiewende.de/en/publications/a-clean-energy-transition-in-southeast-europe/;

- ETC/CME (2020) *Cross-border regional cooperation for deployment of renewable energy*; https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-6-2020-cross-border-regional-cooperation-for-deployment-of-renewable-energy-sources;
- Fraunhofer ISI (divers) *Scale-Up Renewable Energy for Power Generation in the Western Balkan Countries*;
- Fraunhofer ISI & TU Wien (2016-2020) *RES-Observer: Technical Assistance in Monitoring and Analysis of Renewable Energy Data for the Period 2016-2020;*
- Friedrich-Ebert-Stiftung (2018) *Energy Transition in South East and Eastern Europe, South Caucasus and Central Asia Challenges, Opportunities and Best Practices on Renewable Energy and Energy Efficiency*; http://library.fes.de/pdf-files/id-moe/14922.pdf;
- IRENA (2020) *Renewable Energy Prospects for Central and South-Eastern Europe Energy Connectivity (CESEC);* https://www.irena.org/publications/2020/Oct/Renewable-Energy-Prospects-for-Central-and-South-Eastern-Europe-Energy-Connectivity-CESEC;
- IRENA (2019) *Renewable Energy Market Analysis – South Eastern Europe* https://www.irena.org/publications/2019/Dec/RE-Market-Analysis-Southeast-Europe;
- IRENA et al. (2017) *Cost-competitive renewable power generation: Potential across South East Europe*; https://www.irena.org/publications/2017/Jan/Cost-competitive-renewable-power-generation-Potential-across-South-East-Europe;
- Joanneum Research (2016), *Policy and regulatory barriers to renewable energy deployment in South East Europe;* https://www.irena.org/-/media/Files/IRENA/Agency/Events/2016/Jan/18/Joanneum-Research-Policy-and-regulatory-barriers-to-renewable-energy-deployment-in-South-East-Europe.pdf;
- MUSTEC (2018), *Analysis of the barriers to the use of the cooperation mechanisms for renewable energy in the EU*; https://mustec.eu/sites/default/files/reports/MUSTEC%20D4.1_Barriers%20for%20cooperation%20mechanisms.pdf.

Annex 2: Approach and assumptions of the GIS-based analysis for wind energy (on- and offshore) and solar PV

The approach taken to estimate the potential for wind energy and solar PV comprised the following steps:

1. As a starting point, a **GIS-based processing of weather data** was conducted: Comprehensive meteorological datasets on time-series of wind, solar irradiation, temperature etc. for past weather years were processed by use of the open-source GIS software QGIS[54] under a detailed geographical resolution (100m times 100m), serving as a basis for identifying unconstrained resource potentials across the whole CESEC region:
    - For wind on- and offshore the meteorological data involves the historical record of the years 1995 to 2019, stemming from satellite observations and involving reanalysis done at an hourly level at a grid layer of 6 km times 6 km at a height of 150m above ground. The dataset is named COSMO-REA6 and was provided by Deutscher Wetterdienst (DWD);[55]
    - For solar PV accurate meteorological data is provided by the Joint Research Centre of the European Commission at a platform named PVGIS.[56] In this GIS-based analysis average solar irradiance at an inclined surface for the historic record 2005 to 2015 was used to analyse the PV potential.

2. As the next step within the GIS-based assessment, **spatial constraints were incorporated** that stem from competing land use, such as nature protection (e.g. by excluding Natura 2000 protected areas), urban, agriculture, military use or other purposes that limit the suitability for renewable power production and related grid deployment. Data sources for the land use were the CORINE land cover database as of 2021 and, in the case CORINE data was not applicable the GlobeLand database57 as of 2021:
    - For onshore wind that involved excluding nature protection areas, the built environment, military sites, etc. The potential was then further restricted by limiting wind power use in dependence of the underlying land category (i.e. to 40% in the case of agricultural areas or e.g. to 10% in the case of forestry land). Additionally, distance rules were applied, limiting wind deployment at sites closer than 1.2 km to occupied buildings and to respect distances to railways, motorways (250 m);
    - For offshore wind military zones, nature protection areas and major shipping routes were excluded, and distances to tourism areas were respected (5 km to the shore). The remaining area available for offshore wind development was however huge, leading to technical potentials far above that what could be integrated into the power system. Thus, for estimating realisable technical potentials only the best sites were considered by country, i.e. generally that limited deployment to approx. 1% of available sites;
    - For decentral solar PV systems, typically roof-top or facade-integrated, the assumption was taken that on average 3.5% of artificial land appears suitable for installing those systems. For estimating the potential of central (free-land) PV systems the assumption was taken that 1% of current cropland and 0.25% of artificial land would be dedicated to that purpose.

3. **For calculating the potentials** in terms of installed capacities and electricity generation **state-of-the-art technology was considered**.

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54 Accessible at https://www.qgis.org/de/site/.

55 For details see https://www.dwd.de/DE/klimaumwelt/klimaueberwachung/reanalyse/reanalyse_node.html.

56 The dataset on solar radiation named PVGIS Climate Monitoring Satellite Application Facility (CM SAF) was used in this study, accessible at https://ec.europa.eu/jrc/en/PVGIS/downloads/CMSAF.

57 Accessible at https://observer.globe.gov/do-globe-observer/land-cover/science.

- That involved in the case of onshore wind to apply a power curve of a typical 5 MW wind turbine (Nordex N163-4.95) and to approximate the area needed for one turbine (0.54 km^2). For offshore wind, an 8 MW wind turbine (Vestas V164/8000) with a hub height of 150 m and a rotor diameter of 164 m served for that purpose.[58] As the threshold for wind power development sites with low wind speeds, leading to full load hours below 1600 h/a even at optimal conditions (i.e. high (85%) wind park efficiency) were finally excluded;
- For analysing the potentials of solar PV, it was not necessary to specify a certain module or developer. Estimating the performance ratio (85%) and the average efficiency (15%) of the PV system served for that purpose.

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[58] Selected wind turbines for the GIS-based analysis of applicable on- and offshore potentials can be classified as state-of-the-art from todays (2021) perspective. Larger turbines, as possibly applicable in future years, and specficially higher hub heights would lead to an increase of the technical potentials identified within this study.

Annex 3: Recap on 2030 RES targets

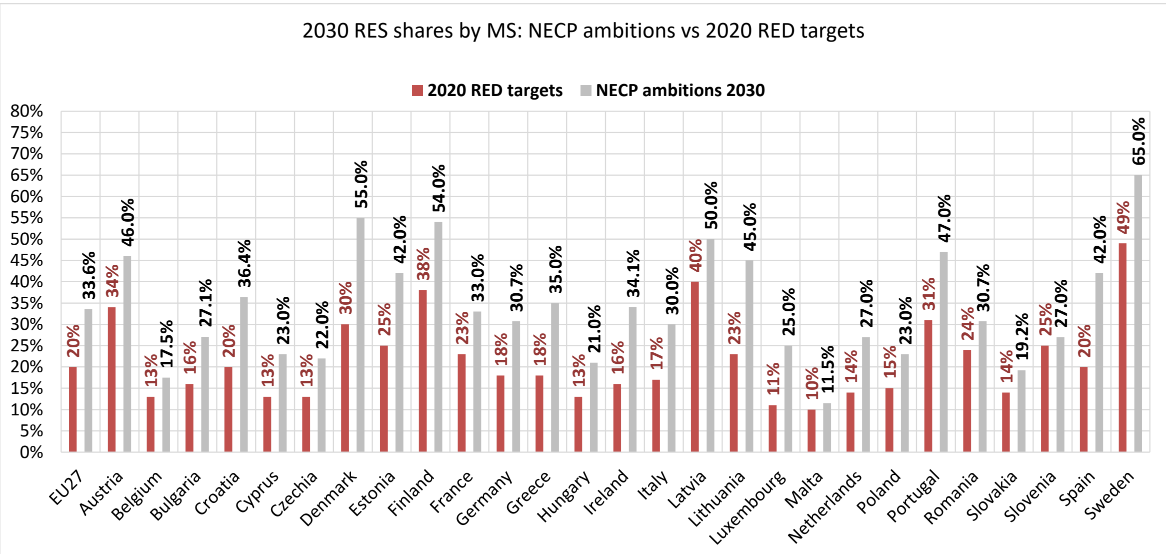
This Annex provides a recap on 2030 RES targets defined at EU level since those were an important input for the power sector modelling done within this study, specifically for the underlying scenario definition (cf. section 2.3) for the identification of highest-potential renewable energy zones.

Please note that the underlying model-based analysis of 2030 RES targets, done by use of TU Wien's Green- X model, was undertaken in the course of the ongoing Horizon 2020 project AURES II[59]. Further details on that topic and the underlying analysis are provided in a recently compiled policy brief on "Modelling of European / Cross-Border RES auctions" (Resch et al., 2021).

The role of RES in National Energy and Climate Plans

Throughout the last years, EU Member States have agreed upon 2030 energy and climate targets. In the field of renewables, the current framework implies at EU level an increase of the RES share from 20% by 2020, as set by the original Renewable Energy Directive (RED) (Directive 2009/28/EC), to (at least) 32% by 2030, in accordance with the recast of the RED (Directive 2018/2001).

Figure A3.1 2020 RED targets vs. 2030 RES shares by EU Member State according to NECPs (Target Scenario)



Source: NECP and own analysis.

To facilitate this energy transition, EU Member States had to provide National Energy and Climate Plans (NECPs) by the end of 2019, indicating how to contribute to the overall 2030 EU energy and climate targets. Thus, Member States have to increase their RES shares (well) above their 2020 RED targets to contribute to the overall EU RES target of (at least) 32% by 2030, and they are aware of that: Summing up the nationally planned RES shares (and where reported demand projections) for 2030 leads to an EU RES share of approx. 33.6%. The RES ambition however differs to a large extent across Member States: at the lower end, Member States like Malta, Slovenia, Belgium and Slovakia plan for increasing their RES share until 2030 less than 6 percentage points compared to their 2020 RED RES target, which is less than half of the RES share increase imposed at EU level during the same period in time. At the upper end, Denmark, Lithuania, Spain and Ireland aim for increasing their RES share until 2030 by more than 18 percentage points which is well above the EU RES share increase (12 percentage points) agreed upon.

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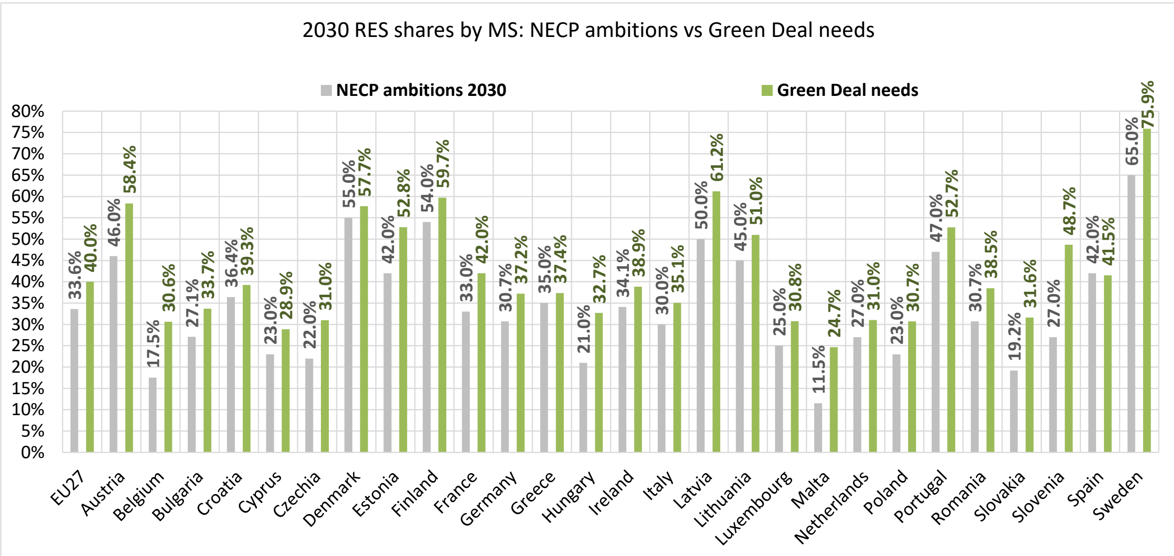
59 For details see www.aures2project.eu.

The necessary increase of the RES ambition in accordance with the European Green Deal

The EU Green Deal and the corresponding increase in the 2030 climate ambition (approximately 55% instead of 40% GHG reduction) raises the need for a stronger uptake of renewables. Within the underlying model-based analysis the assumption was taken that the EU 2030 RES target would consequently be increased from (at least) 32% to (at least) 40%. Subsequently, a fair effort sharing across Member States was calculated, expressing national contributions for the EU RES target in accordance with an approach for doing so as described in the EU Governance Directive[60] (Regulation 2018/1999), cf. Figure A3.2. Except for Spain where national planning shows a higher RES ambition, this implies in general a strong increase of the RES ambition in the forthcoming decade. Following that approach would imply the highest increases of the 2030 RES share (above 10 percentage points) for Slovenia, Malta, Belgium, Austria, Slovenia, Latvia, Hungary, Sweden and Slovakia, whereas a comparatively small increase (below 3 percentage points) would result for Greece, Denmark and Croatia.

Figure A3.2 2030 RES shares by EU Member State according to NECP planning (Target Scenario) vs Green Deal needs



Source: NCEP and own analysis.

Implications for the electricity sector and the uptake of renewables at EU level

This section aims for analysing the implications arising from the above discussed 2030 RES targets, defined as overall RES share in gross final energy demand, on the electricity sector. Here via modelling light has been shed on the necessary uptake of renewables in the electricity sector and the feasibility of that. Derived least-cost pathways of RES deployment provide, on the one hand, insights on the planned RES uptake within the electricity sector in accordance with NECP planning as well as on likelihood of that. On the other hand, modelling also allows for identifying the needs arising from the Green Deal for a stronger increase of RES overall, and, a focal point within this study, on the contribution of RES electricity to that.

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[60] The question arose how to distribute the increased overall RES effort at EU level across individual Member States. Annex II of the EU Governance Directive introduces for that purpose a methodology for establishing benchmarks concerning the national contributions for the RES share in gross final energy consumption in the 2030 context at EU level. This approach follows an integrated concept taking into account the differences in economic development, the potential for cost-effective RES deployment and the interconnection level in the European Network of Transmission System Operators for Electricity (ENTSO-E) across the EU and its Member States, respectively.

A distinct approach is followed while conceptualising the RES uptake in the electricity sector in the underlying scenarios:

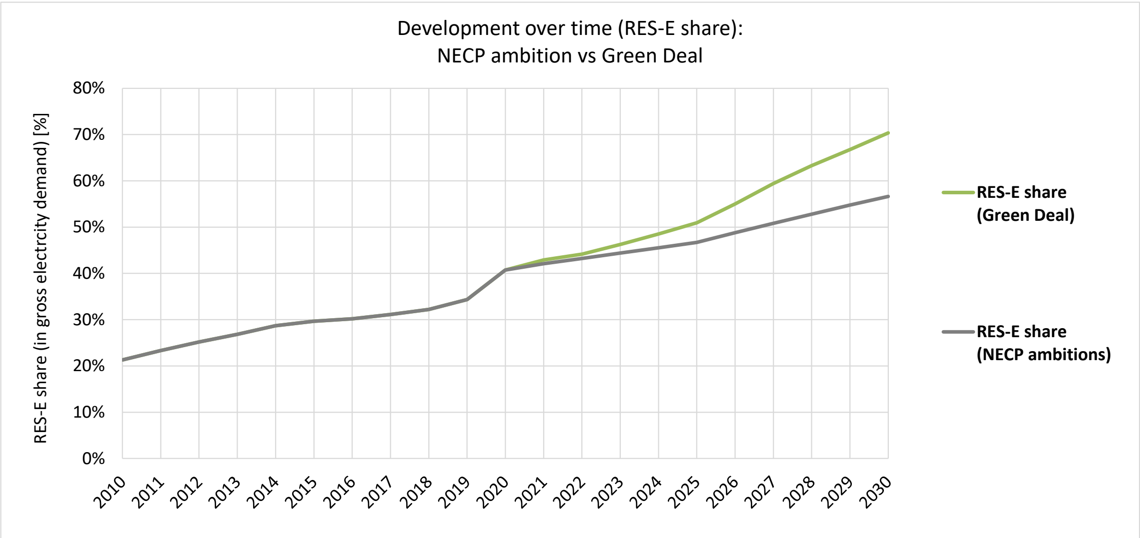
- From the NECP perspective the deployment of RES-electricity (RES-E) is modelled in accordance with planning;
- From the Green Deal perspective, a cross-sectoral least-cost allocation of RES deployment is derived by the applied (Green-X) model endogenously.

Figure A3.3 and Figure A3.4 illustrate the proclaimed uptake of RES in the electricity sector at EU level. More precisely, Figure A3.3 shows the development of the RES-E share at EU level over time according to distinct scenarios (with RES cooperation), reflecting, on the one hand, the NECP ambition in corresponding planning and, on the other hand, the Green Deal needs. Figure A3.4 provides a graphical illustration of the development of electricity generation from RES at EU level under NECP planning over time, indicating the required uptake of new RES installations within this decade (up to 2030). Table A3.1complements the above by taking a closer look at 2030, listing 2030 EU RES and RES-E shares for all scenarios assessed.

Key results derived from this analysis are:

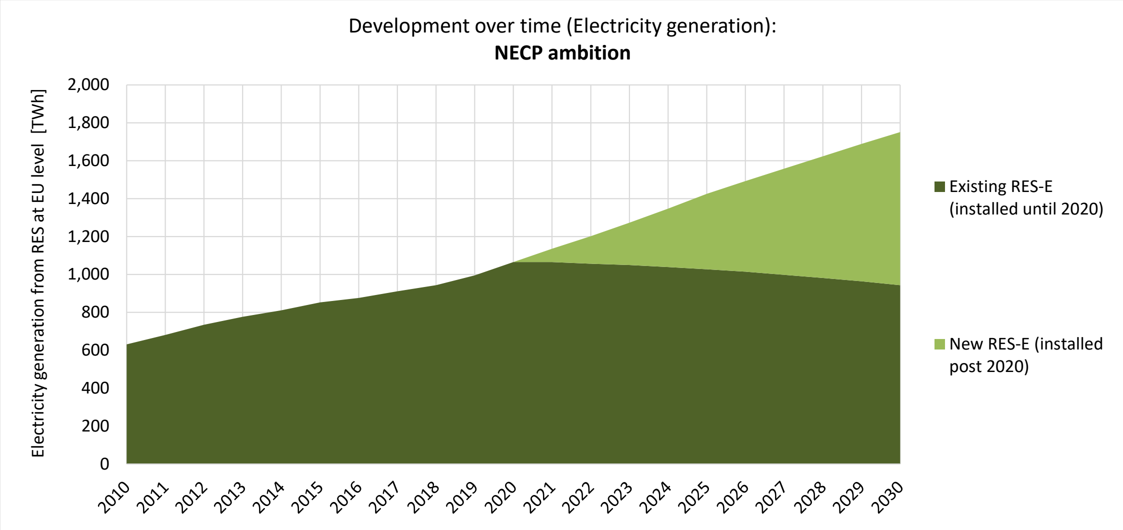
- At EU level one can see a moderate RES uptake in the electricity sector if NECP planning is considered
  (56.9-57.0% RES-E share 2030), and
- a strong increase of RES deployment in the electricity sector if the Green Deal perspective is followed
  (ranging from 64.7 to 70.3% by 2030);
- New RES installations within this decade (up to 2030) have to provide by 2030 slightly less than half of the total electricity generation from RES (i.e. 46% of total) under NECP planning. The required contribution of new installations has to increase to 57% of the total RES-E volumes considering Green Deal needs.

Figure A3.3 Development of the RES-E share at EU level over time (NECP ambition (RefRES scenarios) vs Green Deal (HighRES scenarios) – according to scenarios with RES cooperation)



Source: Green-X modelling.

Figure A3.4 Electricity generation from RES at EU level over time (NECP ambition (RefRES scenario) – according to the scenario with RES cooperation)



Source: Green-X modelling.

Table A3.1 2030 share of RES & RES-E at EU level: NECP ambitions (RefRES scenarios) vs. modelled deployment of Green Deal needs (HighRES scenarios).

RES & RES-E shares 2030 at EU level: NECP ambitions vs modelled deployment of Green Deal needs		RES	RES-E
NECP ambitions	%	**33.6%**	**56.7%**
(NECP) L.c. scenario WITHOUT Coop	%	33.0%	57.0%
(NECP) L.c. scenario WITH Coop	%	**33.6%**	**56.9%**
Green Deal needs	%	**40.0%**	
(Green Deal) L.c. scenario WITHOUT Coop	%	37.8%	64.7%
(Green Deal) L.c. scenario WITH Coop	%	**40.2%**	**70.3%**

Source: Green-X modelling.

In summary, the EU Green Deal and the corresponding increase in the 2030 climate ambition will require a significantly stronger RES uptake at short notice, specifically but not exclusively in the electricity sector – this is getting apparent from the analysis discussed above. Such an uptake appears feasible from a policy and market perspective but requires dedicated policy action to be taken well in time. Intensifying cross-border cooperation appears as an essential element in this respect.

Annex 4: List of identified promising cross-border RES zones in the CESEC region

This Annex provides a detailed list of identified promising cross-border RES zones in the CESEC region, in accordance with the mapping exercise described in section 3.2 and specifically Figure 3.30.

Cross-border RES zone:	A
Location:	Cross-border region at the Western part of Austria and the North-East of Italy
RES characterics:	Strong dominance of storage hydropower in mountainous parts, complemented by photovoltaics

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	18	11377	8823	20218
Maximum	18	11489	9872	21375
Average	18	11443	9404	20865

List of NUTS3** regions covered:

Name	NUTS3 ID
Oberkärnten	AT212
Pinzgau-Pongau	AT322
Tiroler Oberland	AT334
Tiroler Unterland	AT335
Brescia	ITC47
Bolzano-Bozen	ITH10
Trento	ITH20
Verona	ITH31
Udine	ITH42

Cross-border RES zone:	B
Location:	Cross-border region at the Southern part of Austria and the North of Slovenia
RES characterics:	Balanced mix of wind, hydropower and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	118	655	2642	3562
Maximum	2974	659	3830	7463
Average	1004	658	3329	4991

List of NUTS3** regions covered:

Name	NUTS3 ID
Oststeiermark	AT224
West- und Südsteiermark	AT225
Pomurska	SI031
Podravska	SI032

Cross-border RES zone:	C
Location:	Cross-border region at the North-Eastern part of Austria, the South of Slovakia and the North-Western part of Hungary
RES characterics:	Wind is available at several hotspots at favourable conditions (despite not used equally in all three countries involved), combined with run-of-river hydropower and photovoltaics (in urban and rural areas).

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	6519	3361	13543	23423
Maximum	14513	3465	22062	39825
Average	9785	3419	18059	31263

List of NUTS3** regions covered:

Name	NUTS3 ID
Nordburgenland	AT112
Mostviertel-Eisenwurzen	AT121
Waldviertel	AT124
Weinviertel	AT125
Wiener Umland/Nordteil	AT126
Wiener Umland/Südteil	AT127
Wien	AT130
Innviertel	AT311
Linz-Wels	AT312
Mühlviertel	AT313
Győr-Moson-Sopron	HU221
Bratislavský kraj	SK010
Trnavský kraj	SK021
Nitriansky kraj	SK023

Cross-border RES zone:	D
Location:	Western part of Ukraine, close to the Slovakian and Hungarian border
RES characterics:	Wind is available in this region at favourable conditions, waiting to be exploited at large scale and complemented by some photovoltaics in mainly rural areas.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	20513	0	1692	22526
Maximum	28025	0	2017	30042
Average	22973	0	1865	24838

List of NUTS3** regions covered:

Name	NUTS3 ID
L'viv	UKR.14_1
Volyn	UKR.25_1

Cross-border RES zone: E

Location: Black sea region involving the Southern part of Ukraine and Moldova as well as the Eastern coast areas of Bulgaria and Romania

RES characterics: Wind is generally available in this region at favourable conditions, waiting to be exploited at large scale. Furthermore, this is complemented by photovoltaics and minor small-scale hydro developments.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	8642	41	6392	16121
Maximum	24079	46	7993	31158
Average	16139	43	7352	23535

List of NUTS3** regions covered:

Name	NUTS3 ID
Varna	BG331
Dobrich	BG332
Shumen	BG333
Burgas	BG341
Brăila	RO221
Constanţa	RO223
Galaţi	RO224
Tulcea	RO225
Cahul	MDA.6_1
Cantemir	MDA.8_1

Cross-border RES zone: F

Location: The Northern part of Serbia at the border to Hungary and Romania

RES characterics: Wind offers promising potentials in this area, complemented by photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	3161	0	568	3993
Maximum	7460	0	1069	8275
Average	5386	0	821	6207

List of NUTS3** regions covered:

Name	NUTS3 ID
Južnobanatska oblast	RS122
Severnobanatska oblast	RS124
Severnobačka oblast	RS125
Srednjobanatska oblast	RS126

Cross-border RES zone: G

Location: The South(-East)ern border region of Romania, combined with the Serbian border region Borska oblast.

RES characterics: Hydropower and photovoltaics are the major renewable sources available in this area, complemented by comparatively

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	154	4454	2170	6999
Maximum	271	4823	2731	7578
Average	209	4593	2534	7335

List of NUTS3** regions covered:

Name	NUTS3 ID
Dolj	RO411
Mehedinţi	RO413
Olt	RO414
Vâlcea	RO415
Borska oblast	RS221

Cross-border RES zone: H

Location: Cross-border region involving the Southern part of Croatia, Bosnia & Herzegovina and the Serbian province Zlatiborska

RES characterics: Balanced mix of wind, hydropower and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	2691	2429	2740	8037
Maximum	6888	2452	3914	13112
Average	4730	2445	3321	10496

List of NUTS3** regions covered:

Name	NUTS3 ID
Ličko-senjska županija	HR032
Zadarska županija	HR033
Splitsko-dalmatinska županija	HR035
Federacija Bosna i Hercegovina	BIH.2_1
Repuplika Srpska	BIH.3_1
Zlatiborska oblast	RS211

Cross-border RES zone: I

Location: The Albanian region Shkoder at the border to Montenegro.

RES characterics: This region offers promising potentials for hydropower, complemented by wind and photovoltaics.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	10	1501	278	1807
Maximum	178	1510	290	1969
Average	103	1506	285	1894

List of NUTS3** regions covered:

Name	NUTS3 ID
Shkodër	AL015

Cross-border RES zone: **J**

Location: Provinces at the Eastern stretch of Italy, directly at or close to the Adriatic coast and in close distance to Albania.

RES characterics: This region offers favourable potentials for wind, complemented by photovoltaics and a comparatively negligible amount of small-scale hydropower.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	23083	115	14078	37967
Maximum	29074	115	14942	43337
Average	26592	115	14510	41217

List of NUTS3** regions covered:

Name	NUTS3 ID
Taranto	ITF43
Brindisi	ITF44
Lecce	ITF45
Foggia	ITF46
Bari	ITF47
Barletta-Andria-Trani	ITF48
Potenza	ITF51

Cross-border RES zone: **K**

Location: Cross-border region involving Southern provinces of Bulgaria, regions in the North of Greece and the Eastern stretch of Albania.

RES characterics: This region offers favourable potentials for photovoltaics and hydropower, complemented by wind at limited hotspots.

Cumulative installed capacities (in MW) of key RES technologies by 2050 according to modelling*

Technology:	Wind	Hydropower	Photovoltaics	Key RES total
Minimum	305	3622	8096	12186
Maximum	499	3785	10530	14673
Average	353	3702	9503	13559

List of NUTS3* regions covered:

Name	NUTS3 ID
Stara Zagora	BG344
Blagoevgrad	BG413
Plovdiv	BG421
Haskovo	BG422
Pazardzhik	BG423
Evros	EL511
Drama	EL514
Thessaloniki	EL522
Kilkis	EL523
Pella	EL524

*Remark on installed capacities:
Tables show ranges for cumulative installed capacities of key RES technologies by 2050, stemming from the four RES scenarios analysed in this study (i.e. RefRES and HighRES
**Remarks on the list of regions:
- For countries where no NUTS3 coding was applicable, an alternative regional clustering was applied
- Coal regions are marked in grey

Annex 5: Main input assumptions for power system modelling

Data and information updates of both the electricity market model (EPMM) and the network model have been carried out. DG ENER provided February 2021 a dataset on draft final results of the forthcoming PRIMES reference scenario. This reference scenario does not reflect the latest EU policy (e.g. targets such as 55% GHG emission reduction are not reflected), so after careful consideration, it was decided not to include them in the modelling. Data used for assumptions on energy demand and installed capacity are based on the values of the REKK Reference scenario. These values already include information on coal phase-out plans, therefore better reflect increased ambitions. For cross-border capacities, the information received from the Commission[61] regarding all infrastructure investments and plans were incorporated.

Activities conducted include the following areas:

1. Updating the power generation capacity forecasts in the EPMM model covering the CESEC region. This includes the review of recent studies covering fully or partially the CESEC region power sector developments in the forthcoming years with an outlook until 2030;
2. Checking and updating the model data on the existing cross-border capacities as well as the planned new capacities in the region;
3. Cross-checking the data on the electricity demand forecasts for the CESEC countries;
4. Collecting information on the fuel prices and their forecasts for the 2030 period and beyond in the region, including natural gas, coal and lignite;
5. Collecting the same information for EU ETS allowance prices.

Five main sources of information were used for this update. These include the following studies and assessments:

1. IRENA REMAP study: Renewable energy prospects for central and South-Eastern Europe energy connectivity, 2020 (IRENA, 2020);
2. Kantor, E3M: A carbon pricing design for the Energy Community – Final Report, 2021 (Kantor et al., 2021);
3. EUCO EU32325 scenario: Technical Note Results of the EUCO3232.5 scenario on Member States (EC, 2019) and Impact Assessment of the 55% target, 17.9.2020 SWD(2020) 176 final (EC, 2020a);
4. REKK latest reference scenario: Updated (mainly by consumption and fuel/EUA prices) version of the Assessment for the identification of candidate Projects of Energy Community Interest (PECI) and candidate Projects for Mutual Interest (PMI), Final Report, 05.06.2020;
5. ENTSOs Scenarios: TYNDP 2020 Scenario Report, National Trends scenario (ENTSO-E, 2020).

In addition to the data gathering and updating process, the team further elaborated the methodology part, focusing on the treatment of the household side PV installations and the handling of regional data derived on the RES deployment in the network and economic models.

These developments are introduced in more detail in the following sections.

Overview of the recent studies covering the CESEC region

This section describes the most recent studies covering the CESEC region (fully or partially in their geographical coverage), cf. the Table below. These studies have overlapping information on various factors (capacity development, price assumptions).

61 On 7th June 2021.

These are described briefly in this section. Following this review, the most adequate data is used in the reference scenario.

One important recent study assessing the potential development of the CESEC region is the **IRENA REMAP study**. It has a modelling horizon up till 2030 and it has two analysed scenarios, a reference and the REMAP scenarios with higher RES uptake. The study has a detailed data publication (e.g. on installed capacities, NTC developments and prices for 2015 and 2030). It applies a rather conservative CO_2 price assumption (i.e. 25€/tCO_2 in 2030), and in the case of some countries, it uses rather outdated information on the installed capacities. The following table summarises the used information sources in the study on a country basis.

Table A5.1 Information source used for the IRENA REMAP Reference scenario

Country	Sources for Reference Case
AL	IRENA based on WBIF (forthcoming)
AT	IRENA analysis based on E3MLab *et al.* (2016)
BA	IRENA based on WBIF (forthcoming)
BG	IRENA analysis based on E3MLab *et al.* (2016)
HR	IRENA analysis based on E3MLab *et al.* (2016)
GR	IRENA analysis based on E3MLab *et al.* (2016)
HU	IRENA analysis based on E3MLab *et al.* (2016)
IT	Draft Integrated National Energy and Climate Plan (Government of Italy, 2018)
MK	IRENA based on WBIF (forthcoming)
MD	IRENA analysis based on Renewable readiness assessment for Republic of Moldova (IRENA, 2019e) and *Energy strategy of the Republic of Moldova to the year 2030* (Government of the Republic of Moldova, 2012)
ME	IRENA based on WBIF (forthcoming)
RO	IRENA analysis based on E3MLab *et al.* (2016)
RS	IRENA based on WBIF (forthcoming)
SK	IRENA analysis based on E3MLab *et al.* (2016) and Slovak proposal for an Integrated National Energy and Climate Plan (Slovak Ministry of the Economy, 2018)
SI	IRENA analysis based on E3MLab *et al.* (2016)
UA	IRENA analysis based on *Energy strategy of Ukraine for the period up to 2035* (Government of Ukraine, 2017), Diachuk *et al.* (2017) and consultations with State Agency for Energy Efficiency of Ukraine
XK	IRENA based on WBIF (forthcoming)
CY	IRENA (2015b)

Source: IRENA REAMP, CESEC.

The next important study partially covering the CESEC region is the **EUCO 3232.5 scenario** (EC, 2019). The former reflects the policies and targets included in the Clean Energy Package, namely for 2030 a share of at least 32% renewable energy in the EU energy mix, an improvement in energy efficiency of at least 32.5% at EU level, and reduction of domestic emissions of greenhouse gas by at least 40%. The EU3232.5 assessment covers only EU Member States, which means a partial coverage of the CESEC region. Its modelling horizon is up till 2030. There is an outlook up till 2050 as well, but this outlook is not publicly available. If this information will be made available for the consortia, it can be taken into account in the scenario set-up. The study models the 40% GHG reduction target, and consequently applies a rather low carbon price (28€/tCO_2 in 2030). The 2020 Impact Assessment already takes the 55% GHG target in its focus, and models an EU wide perspective. However, rather aggregated data is available for the modelled 7 scenarios. It gives a varying carbon price for the modelled 7 scenarios, ranging from 32 to 65 €/tCO_2. Since the carbon price assumption is a key driver of the power market development, the assumed carbon value pathway in this assessment will be agreed upon with the EC services.

The **Kantor – E3M study (2021)** models the Energy Community countries plus Bulgaria, Romania and Greece to assess the impacts of a possible future carbon pricing scheme on the region. It applies a country-specific lignite and gas price range for the region and a medium level CO_2 price path (32 €/tCO_2 in 2030 and 80€/tCO_2 in 2040) in the reference scenario. It provides detailed capacity expansion pathways in its assessed five scenarios. (Kantor et al., 2021)

The **ENTSOs TYNDP** study assesses three scenarios for the future development of the EU power and gas sector:

1. National trends (reference case);
2. Distributed Energy;
3. Global Ambitions.

Its modelling horizon is up till 2040 with an outlook till 2050. Detailed country input data is available, and the whole ENTSO-E region is covered. However, it still applies the 40% GHG reduction target for 2030 and applies uniform fuels prices for the whole region.

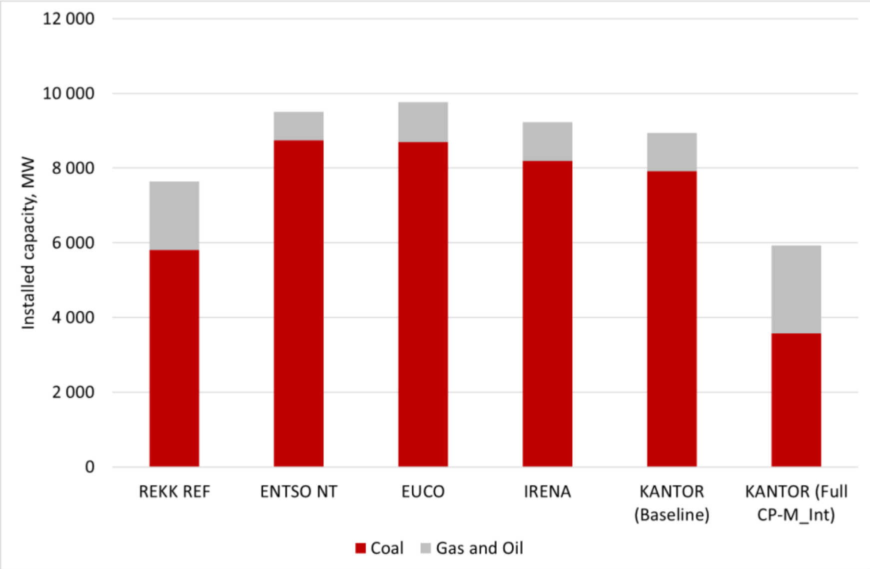
The latest **REKK Reference scenario** (2020) is an updated - mainly by consumption and fuel/EUA prices - version of the one used in the Assessment for the identification of candidate Projects of Energy Community Interest (PECI) and candidate Projects for Mutual Interest (PMI), Final Report, (05.06.2020). The EPMM model was also used in the project Support to the evaluation of Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure, carried out for the Commission in 2020. The REKK reference scenario applies recent information from various studies, where conventional capacities are aligned according to the latest available national sources. New gas-based capacities are modelled, determined by the economic feasibility of their development. RES capacities are based on the latest Green-X modelling for the Energy Community countries, and the EUCO3232.5 scenario for the EU countries. Fuel prices are based on various sources (coal price by ARA prices of the latest IEA WEO (2020)), lignite is based ENTSO-E, while the gas price is based on REKK own modelling. Important to note that it reflects already the 55% GHG target pathway, applying a middle range of the EU 2020 Impact Assessment for 2030 (44 €/tCO_2).

Generation prospects

There are sizeable differences in the assumed capacity development in the various studies for the region. This not only concerns the RES capacities (which is not assessed in this section), but also the conventional capacities (coal, gas and nuclear). The purpose of this comparison is to identify the most suitable basis for the modelling in the crucial variables (capacity development, demand, prices) and to identify the level of uncertainties in assumptions. To indicate this difference the following graphs show the conventional capacities for various grouping of the CESEC countries.

The first figure, Figure A5.1 shows the capacities for the West-Balkan 6 countries (WB6) for 2030 for six studies/scenarios.

Figure A5.1 Installed capacities in the WB6 region, 2030

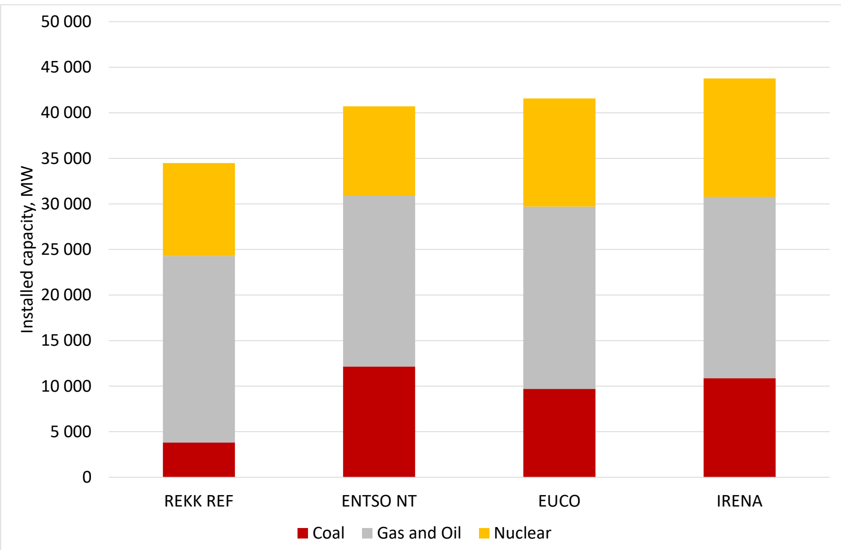


Source: IRENA (2020), Kantor et al. (2021), EC (2020a), ENTSOs (2020), Agora et al. (2021), REKK (2021).

As the graph illustrates the REKK reference scenario and the Kantor Full CP-M scenario have the lowest level of installed conventional capacities. This development is most likely driven by the higher carbon pricing assumption and the inclusion of coal phase-out plans, which reflects the 55% GHG reduction target scenario, in contrast to the other studies built around the 40% GHG reduction assumption for 2030.

A similar pattern is observed for the CESEC EU countries, where the REKK scenario results in the lowest level of installed conventional capacities. This low level of fossil capacity is mainly due to the REKK scenario setup: it already reflects the already announced coal phase-out plans of various EU Member States, as well as the highest carbon pricing schemes assumed amongst the assessed studies. The REKK model does not use forced retirement of additional fossil capacities (so they remain in the system till the end of their economic lifetime), only the ones announced in the phase-out plans. Other factors, such as the assumed fossil fuel prices and the uptake of RES generation also impact the power capacity mix, but to a lesser extent.

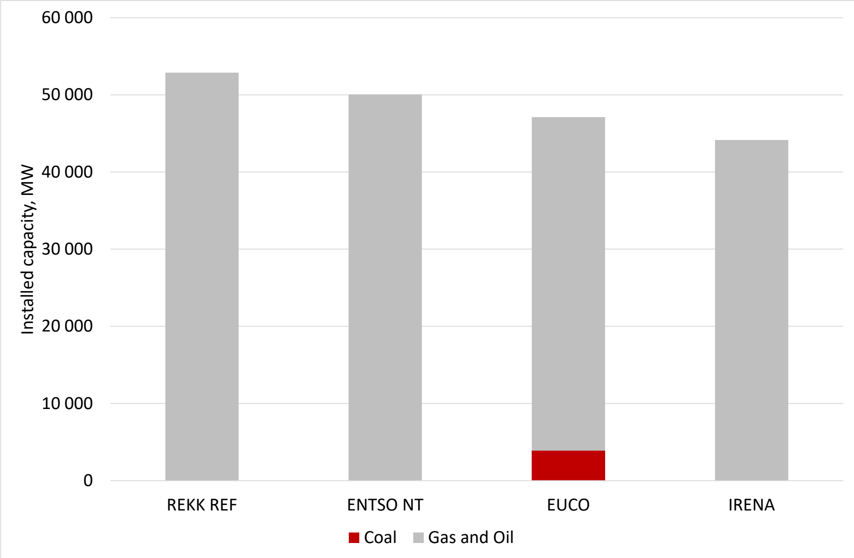
Figure A5.2 Installed capacities in the CESEC EU Member States except Italy, 2030



Source: IRENA (2020), Kantor et al. (2021), EC (2020a), ENTSOs (2020), Agora et al. (2021), REKK (2021).

For Italy, as can be seen in Figure A5.3, a more balanced picture is presented, where gas-based capacities vary between 45 to 52 thousand MWs, according to the projections.

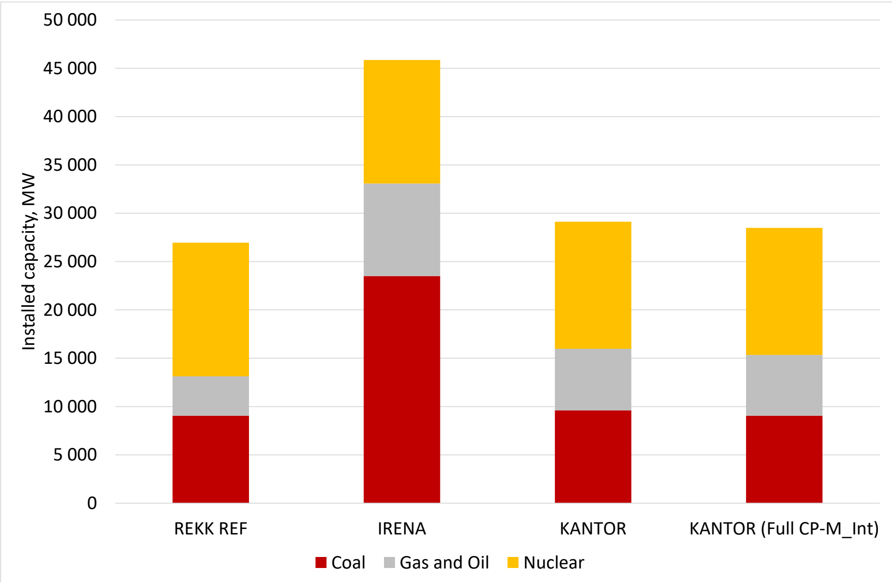
Figure A5.3 Installed capacities in Italy, 2030



Source: IRENA (2020), Kantor et al. (2021), EC (2020a), ENTSOs (2020), Agora et al. (2021), REKK (2021).

Ukraine, as can be seen in Figure **A5.4**, needs special attention with its large power market size, where the concentration of coal and nuclear capacities is the highest. Here three projections come to a close estimation of future capacities in fossil and nuclear-based generation (REKK, Kantor and ENTSOs), while the IRENA scenario is an outlier with a 50% higher capacity level than the other three studies.

Figure A5.4 Installed capacity in Ukraine, 2030



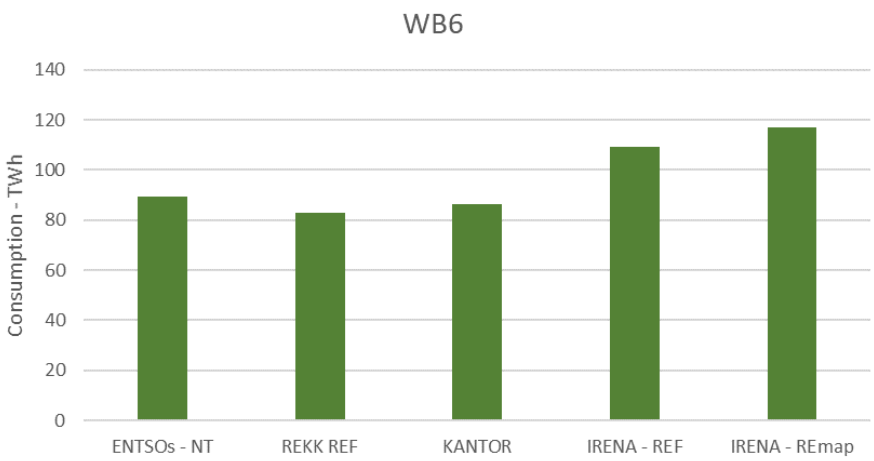
Source: IRENA (2020), Kantor et al. (2021), EC (2020a), ENTSOs (2020), Agora et al. (2021), REKK (2021).

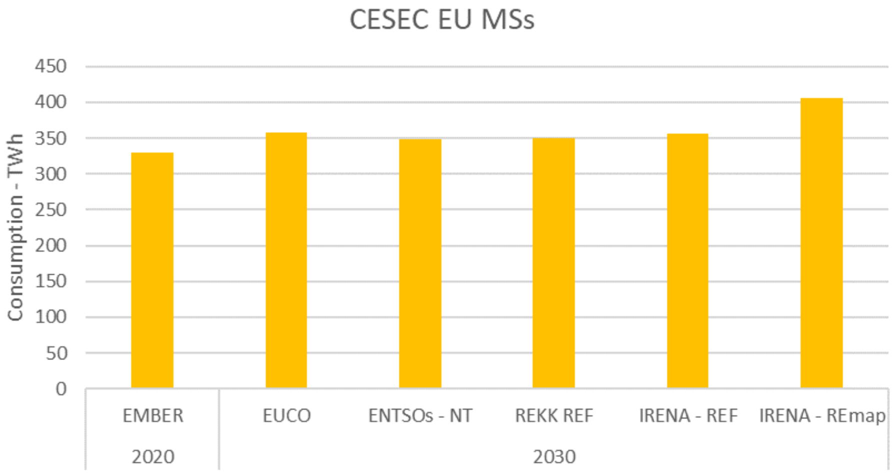
Based on this comparative assessment, the proposed REKK Reference scenario seems to be in line with the other studies concerning the assumed conventional capacity development, with a somewhat more updated view on coal phase-out plans, that is in line with the new increased emission reduction targets. There are some differences amongst the compared studies, which could serve as a basis for indicating the uncertainty levels. One main difference detected is the assumption on the level of coal phase-out, where most studies did not use the recent decisions of the CESEC countries on their timing, and many of the studies have applied a rather lower level of carbon pricing compared to the REKK assumption (see details on Figure A5.9). These important drivers have to be reflected in the current modelling in order to build a reference scenario that closely reflects the EC vision of the decarbonisation pathway and the derived targets. Due to its bottom-up approach – meaning the dataset on capacities is built up from individual units also considering their technical lifetime, the model gives a reasonable picture of the possible future development of the conventional capacities. The above-presented values for 2030 are a starting point, as the model is capable to include endogenously further fossil capacities on the long term if the decision seems to be economically viable. Extending with the different modelled RES uptakes by the Green-X model, the models provide realistic power sector scenarios for the CESEC region. In the final scenarios, there is more natural gas capacity at the end of the modelled period (2040-2050) in the Reference RES cases compared to the High RES cases.

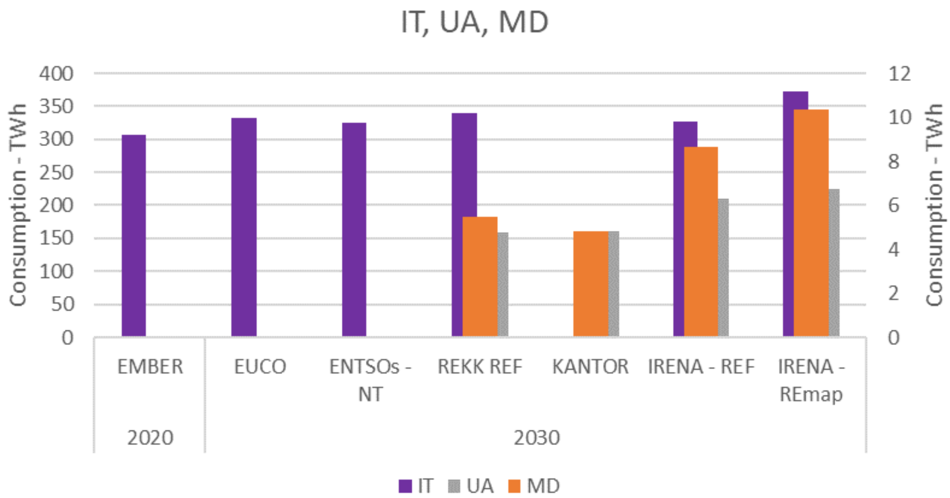
Demand overview

Demand assumptions were also analysed for all five above mentioned sources. Not all of them cover the whole CESEC region, so comparisons were made for the different country groups separately in light of data availability. The IRENA study covers the entire CESEC region. It includes two scenarios, the Reference and the REmap. Explicit gross electricity consumption data is not provided in the study, however, from total renewable power generation and RES-E shares the values can be calculated. These calculations lead to different consumption levels for the two scenarios. The Kantor study covers the Energy Community Contracting Parties (WB6, GE, MD, UA) and three EU Member States: Bulgaria, Greece and Romania. The graphs below, Figure A5.5, are included for gross electricity consumption (load and losses) for each country, data is estimated based on these figures. In the EUCO3232.5 scenario, gross electricity consumption is also not stated explicitly but can be calculated from gross electricity generation (in GWh) and net imports (in ktoe). The forecast covers only EU Member States. The ENTSOs TYNDP 2020 forecast includes all ENTSO-E members, meaning only three countries are not covered from the CESEC region: Kosovo, Moldova and Ukraine. The document includes 3 scenarios, here the central scenario, the National Trends is presented. The REKK reference scenario includes the latest available information based on data received in the PECI assessment, data from final NECPs and local partners. Finally, the latest available data for 2020 is also indicated where available to see the plausibility of the forecasts. The source is the study of EMBER and Agora Energiewende, published in 2021 January (Agora et al., 2021), which only covers EU Member States.

Figure A5.5 Gross electricity consumption by country groups within the CESEC region







Source: IRENA (2020), Kantor et al. (2021), EC (2020a), ENTSOs (2020), Agora et al. (2021), REKK (2021).

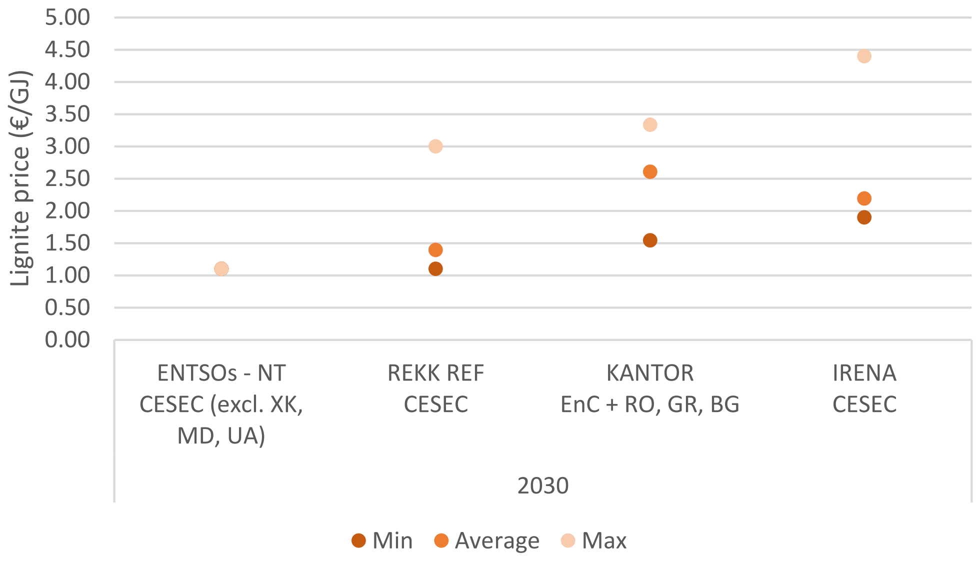
As it is stated above, only the REKK Reference scenario and the IRENA study includes data for all CESEC countries. The latter seems to be a bit of an outlier as for many countries the IRENA REMAP study includes a much higher consumption pathway compared to the other sources. This is also indicated by comparing 2020 actual data (Agora et al., 2021) with the assumed consumption levels in 2030. For consistency and in light of the 2020 actual data the REKK Reference demand pathways are used in this assessment.

Fuel price assumptions

Fuel price assumptions of the different sources were also compared. The country coverage is the same as for consumption, and thus minimum, maximum and average values are compared when the set of countries differs among sources.

Most sources provide lignite price assumptions at individual country levels, as can be seen in Figure A5.6. The studies from IRENA, Kantor and REKK include relatively high price ranges, with around 2-2.5 €/GJ difference between the smallest and highest prices. The ENTSOs TYNDP scenarios assume one common lignite price for all countries, and the EUCO scenario does not provide lignite price assumptions. The lignite price assumptions used in the Kantor study are in between assumptions made in the other sources, and includes a rather sophisticated approach that takes into account domestic production costs, Therefore the Kantor study lignite price assumptions are used as reference assumption in this project.

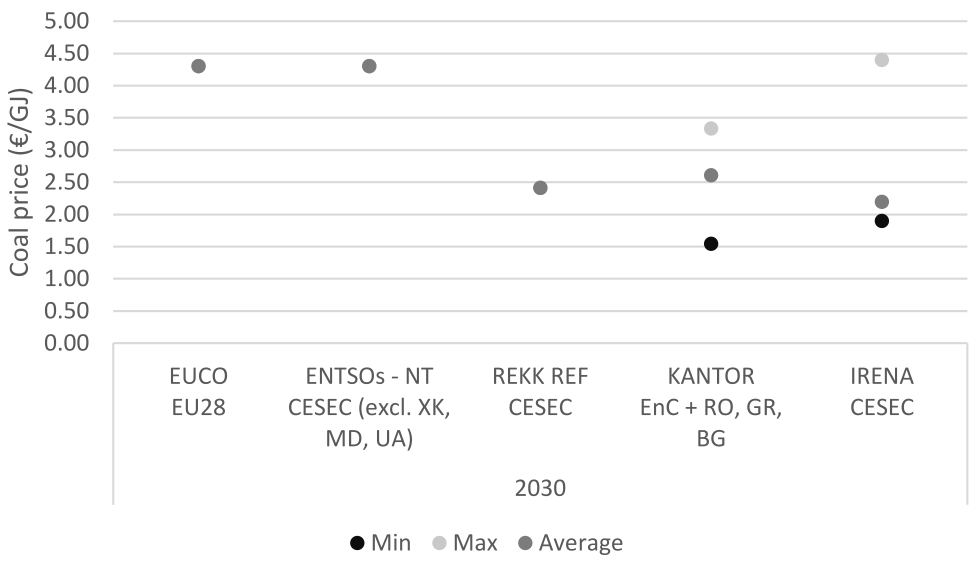
Figure A5.6 Lignite price assumptions for 2030 for the CESEC region



Source: ENTSOs (2020), REKK (2021), Kantor et al. (2021), IRENA (2020).

Coal price assumptions in the IRENA and Kantor study are in the same range for the modelled countries, see Figure A5.7. This might be the right approach for own coal production, while for countries – at least partly – importing coal an international benchmark might be a realistic estimation. As in the CESEC region coal extraction is in place in several countries, it is difficult to determine country by country which coal/lignite price assumption is the most suitable one – e.g. to use the country-specific information or the international coal price or use country-specific information, as many times these prices could be distorted. The approach to be taken is to use country-specific lignite prices, where this information is available, and use international benchmark prices in the other countries and for coal prices. The Kantor study values are a good starting point in this respect. These values are cross-checked with the EnC Secretariat to ensure higher reliability, as national sources could be more distorted sources of information (also coal subsidies distort these prices in the short term).

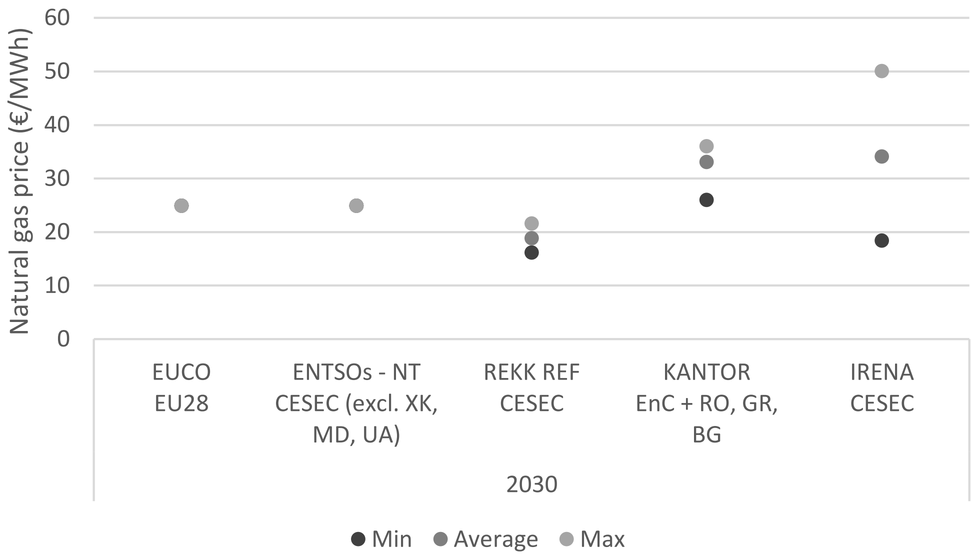
Figure A5.7 Coal price assumptions for 2030 for the CESEC region



Source: ENTSOs (2020), REKK (2021), Kantor et al. (2021), IRENA (2020), EC (2020a).

For natural gas prices, as can be seen in the below Figure A5.8, the ENTSO and the EUCO scenarios assume one common value, while the other three sources differentiate at least between country groups. Here the most sophisticated approach is taken by the REKK scenario, where the forecast for natural gas prices is carried out with REKK's European Gas Market Model (EGMM), which provides separate natural gas prices for each country and each year. Therefore, for consistency and to include the most detailed source these natural gas prices are used as inputs for the modelling.

Figure A5.8 Natural gas price assumptions for 2030 for the CESEC region

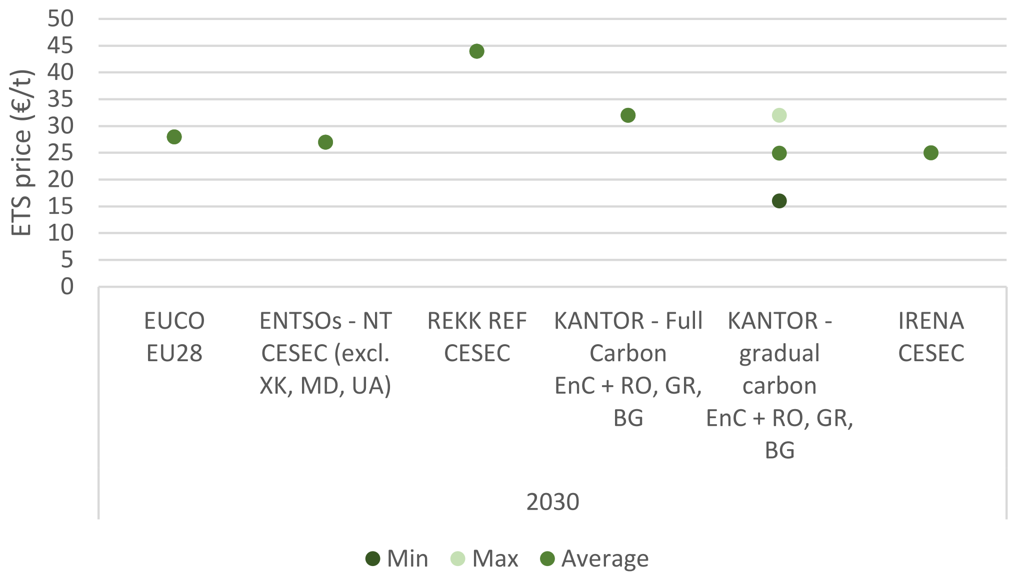


Source: ENTSOs (2020), REKK (2021), Kantor et al. (2021), IRENA (2020), EC (2020a).

Finally, carbon price assumptions are summarised in Figure A5.9. All sources except the Kantor study assume one common carbon price for every country in 2030, assuming all of them have joined the EU ETS scheme by then. The Kantor study includes two scenarios, one of which (the gradual carbon scenario) includes different carbon prices by country, based on the unequal possibilities among countries to respond to carbon pricing. The EUCO3232.5 scenario, the ENTSOs National Trend scenario and the IRENA study do not take into account the Green Deal and the latest developments regarding 2030 emission reduction targets, as these analyses were carried out before the latest EU Impact Assessment was published in 2020 September[62]. Consequently, these studies have lower carbon price assumptions. The Kantor study uses the results of the Impact Assessment, however, the applied values come from the assessment's Baseline scenario, where the 55% reduction target is not met. In the REKK reference scenario, the applied assumption is the value from the MIX scenario, in which the target is met. Therefore, the carbon price assumptions from the MIX scenario are used in the modelling, that reflects a combination of regulatory-based (REG scenario of the Impact Assessment) and carbon-pricing based (CPRICE scenario of the Impact Assessment) achievement of 55% GHG reduction, meaning the underlying assumption is expanding carbon pricing and moderately increasing the ambition of policies. An EU ETS entry year of 2030 is assumed for all WB6 countries, and 2035 for Ukraine and Moldova. The assessment assumes no carbon border adjustment mechanism (CBAM) before the entry year[63]. For Ukraine, the already applied carbon taxation is modelled with the respective scheme in place.

[62] https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/impact_en.pdf.
[63] Details of the foreseen CBAM were published after the modelling had already been carried out.

Figure A5.9 Carbon price assumptions for 2030 for the CESEC region



Source: ENTSOs (2020), REKK (2021), Kantor et al. (2021), IRENA (2020), EC (2020a).

Transmission capacities

In this subsection, the main aim is to present the relevant input data about net transfer capacities (NTCs), which was used by EPMM for the initial runs. The results from the initial runs in turn were the input to the TGM model to calculate flow-based parameters and determine final NTCs. These final NTCs were then inputs to the EPMM for the exact market assessments. The cross-border infrastructures included in the EPMM are presented separately when assessing the present and planned infrastructures. In the extended grid scenario, the initial NTCs is identical to the figures applied in the planned infrastructure scenario while the final NTCs are based on the outcome of the analyses using the TGM model.

It is important to note that EPMM is a European wide model covering most of the European countries. As the focus of this report is the CESEC countries only, those NTCs and cross-border infrastructure development input data are presented, which are directly associated with at least one country of the CESEC region. However, it is important to note, that the same assumptions for new cross-border infrastructure were applied for all modelled countries.

Assumptions on cross-border infrastructure

The main assumption of the existing grid scenario is that only those infrastructures will be completed, which are currently under construction, in addition to those cross-border lines currently in operation. This means that no major extension of the grid is considered.

Table A5.2 shows the assumed initial NTC values for the CESEC countries. The values are based on ENTSO-E TYNDPs, PCI technical documents and other national sources. For all modelled time periods the same NTC value was used within a year, so the shown capacities can be considered as yearly average values.

Table A5.2 Existing NTCs of CESEC countries in 2020, model input data

Origin and destination country		NTC, MW		Origin and destination country		NTC, MW	
From	*To*	*A->B*	*B->A*	*From*	*To*	*A->B*	*B->A*
AL	**EL**	220	220	**HU**	**RO**	619	438
AT	**CH**	823	685	**HU**	**RS**	892	885
AT	**CZ**	696	644	**HU**	**SK**	848	1048
AT	**HU**	602	691	**HU**	**UA_W**	405	473
AT	**IT**	207	90	**IT**	**EL**	450	450
AT	**SI**	770	842	**IT**	**SI**	570	466
AT	**DE**	4410	4410	**IT**	**ME**	540	540
BA	**HR**	715	745	**XK**	**ME**	270	270
BA	**ME**	387	450	**XK**	**RS**	292	292
BA	**RS**	482	463	**XK**	**MK**	135	262
BG	**EL**	516	459	**XK**	**AL**	190	199
BG	**MK**	225	90	**MD**	**UA_E**	1080	720
BG	**RO**	371	341	**ME**	**AL**	316	300
BG	**RS**	300	255	**MK**	**EL**	296	300
BY	**UA_E**	810	810	**MK**	**RS**	406	487
CH	**IT**	2222	1549	**PL**	**SK**	611	556
CZ	**SK**	1791	1080	**RO**	**UA_W**	96	199
FR	**IT**	2131	917	**RS**	**ME**	289	315
GR	**TR**	189	69	**RS**	**RO**	475	523
HR	**HU**	900	1080	**SK**	**UA_W**	540	540
HR	**RS**	449	462	**TR**	**BG**	270	630
HR	**SI**	1289	1333				

Source: REKK's own estimation based on ENTSO-E data, PCI technical documents and other national sources.

In addition to existing grid capacities, data on grid extension projects under construction in the CESEC region is assumed to become part of the future grid capacity. Table A5.3 includes the names, technical characteristics and commissioning dates of these grid extension projects. It is important to note that the commissioning date shows the first year in which a given project was modelled not the actual date of commission[64]. Data on grid extensions is based on the ENTSOs TYNDP 2020, which is the most recent available data source about planned cross-border infrastructures. In the TYNDP, ENTSO-E tracks the status of all investments, so only those are considered which are labelled as "under construction". Also, the CESEC priority project list was used to determine the actual status of the investment.

The table shows that there are currently nine projects under construction, all of them are to be completed by 2025[65]. It is important to note that the NTCs presented in the table, are additional capacities on top of the currently existing ones, so they should be added to the values of Table A5.2, after their completion.

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64 If a project was completed for example in 11.2020, than the highlighted commissioning date will be 2021 because of the yearly setup of the EPMM model. Those projects are included in the table where first modelled year is later than 2020.

65 Some of them already completed but first modelled for 2021.

Table A5.3 Planned cross-border infrastructure projects which are already under construction, model input

Project name	From (A)	To (B)	First year of operation (in model)	NTC A to B (MW)	NTC B to A (MW)
Albania-Greece capacity extension	AL	EL	2021	150	150
Albania - Kosovo	AL	XK	2021	150	150
New Slovakia-Hungary interconnector*	SK	HU	2021	1300	800
Slovenia-Hungary/Croatia interconnection	SI	HU	2022	1200	1200
CSE4	BG	GR	2023	930	600
Prati(IT)-Steinach(AT)	AT	IT	2023	90	90
Reschenpass Interconnector Project	AT	IT	2023	300	300
South Balkan Corridor	MK	AL	2023	500	500
Black Sea Corridor	BG	RO	2024	600	600

Source: ENTSO-E TYNDP 2020.
*Already came online in 2021.

Assumptions on cross-border infrastructure in planned infrastructure scenario

In the planned infrastructure scenario a large extension of the existing European grid is assumed. For this reason, all cross-border infrastructure projects currently planned by European countries were included. Table A5.4 summarises those planned interconnectors for the CESEC countries on top of the ones already shown under the existing grid scenario. The presented data is generally based on the draft ENTSO-E TYNDP 2020, supplemented with the projects submitted for Project of Energy Community Interest (PECI) evaluation including the PECI and PMI projects, the CESEC electricity action plan and the Network Development Plan of the Energy Community as well.

Table A5.4 Proposed future cross-border infrastructure projects, model input

Project name	From (A)	To (B)	First year of operation	NTC A to B (MW)	NTC B to A (MW)
Refurbishment of an interconnector UA- SK	UA_W	SK	2023	474	616
Mid Continental East corridor	RO	RS	2023	844	600
Romania-Moldova interconnector (Vulcanesti-Chisnau)	RO	MD	2024	500	500
Mid Continental East corridor	RO	HU	2025	617	335
Italy – Montenegro	IT	ME	2026	600	600
Transbalkan Corridor	RS	BA	2026	700	850
Transbalkan Corridor	RS	ME	2026	500	20
Lienz-Venetto region	AT	IT	2027	500	500
New interconnector UA-RO	UA_E	RO	2029	1000	1000

Project name	From (A)	To (B)	First year of operation	NTC A to B (MW)	NTC B to A (MW)
Suceava-Balti new interconnector	RO	MD	2029	500	500
CSE1 New	HR	BA	2030	644	298
Extension of interconector SK-UA	UA_W	SK	2030	26	41
HU-RO	RO	HU	2030	1117	685
Upgrading of existing 220 kV line HR-BA to 400 kV	BA	HR	2033	500	500
Obersielach - Podlog	SI	AT	2034	500	500
New 400 kV interconnection line RS-HR	RS	HR	2035	600	600
Crete-North Greece-North Macedonia-Bulgaria Interconnector	EL	MK	2036	2000	2000
Crete-North Greece-North Macedonia-Bulgaria Interconnector	MK	BG	2036	2000	2000
Pannonian Corridor	HU	RS	2036	500	500
Refurbishment of 400kV Meliti(GR)-Bitola(MK) interconnector	EL	MK	2036	500	500

Source: ENTSO-E TYNDP 2020 & PECI submissions & CESEC electricity action plan & Energy Community Network Development Plan.

Altogether there are 20 new projects which are proposed but not yet under construction in the region, with commission dates ranging from 2023 to 2036.

Subsequent sections inform on objective, approach and planned activities concerning modelling and complementary analyses in further detail. This thus demonstrates how the scenario modelling contributes to achieving the overall study objectives and how all that fits together.

Annex 6: Detailed results of EPMM modelling

Table A6.1 Wholesale prices in the different scenarios in 2030

2030	Wholesale price, €/MWh							
	REF RES				High RES			
	Coop		No_Coop		Coop		No_Coop	
	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid
AL	72.4	68.2	67.6	62.3	68.9	65.4	64.1	59.4
AT	51.8	51.6	51.4	49.7	50.8	50.9	50.6	50.7
BA	67.2	59.8	67.7	57.2	66.7	60.1	67.8	57.0
BG	57.5	56.7	52.1	54.6	59.4	58.6	53.6	54.6
EL	52.9	52.6	50.5	51.1	52.8	52.8	51.6	51.9
HR	61.4	59.6	57.2	56.9	63.3	60.1	58.4	56.6
HU	61.4	59.3	57.2	56.6	63.3	60.0	58.4	56.5
IT	55.8	55.4	56.4	54.1	55.4	54.7	56.3	55.9
XK	68.8	64.5	65.8	60.3	68.5	64.6	64.2	59.4
MD	33.3	35.1	33.2	35.0	33.7	36.7	33.4	36.1
ME	66.2	60.3	64.1	57.2	65.4	60.2	63.8	57.9
MK	72.8	68.4	67.7	62.9	69.5	66.0	64.2	59.5
RO	59.2	59.0	52.7	56.3	59.1	59.5	52.7	55.4
RS	65.8	59.8	63.8	57.2	65.3	60.1	63.0	56.9
SI	61.4	59.3	57.2	56.6	63.3	60.0	58.4	56.5
SK	59.3	59.1	56.0	55.2	59.1	59.1	57.6	56.4
UA_E	33.3	35.1	33.2	35.0	33.7	36.7	33.4	36.4
UA_W	61.4	59.1	57.2	55.3	63.3	59.1	58.4	56.4
CESEC weighted average price	55.7	54.7	54.5	53.0	55.5	54.6	54.4	53.8

Source: EPMM modelling results.

Table A6.2 Wholesale prices in the different scenarios in 2050

2050	Wholesale price, €/MWh							
	REF RES				High RES			
	Coop		No_Coop		Coop		No_Coop	
	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid
AL	355.8	83.8	315.9	61.0	236.1	60.4	171.2	63.1
AT	74.0	70.8	71.7	52.1	53.4	54.0	58.0	57.6
BA	269.7	80.1	350.9	62.0	179.7	62.3	191.1	63.9
BG	104.6	80.1	124.9	59.7	55.2	58.2	70.0	61.4
EL	106.6	79.0	125.5	55.5	51.9	54.9	80.2	61.5
HR	67.9	76.7	64.5	59.7	57.1	59.6	51.0	56.7
HU	74.6	77.0	72.3	59.2	60.6	58.1	54.7	56.3
IT	70.5	70.1	68.8	58.8	61.6	60.0	62.9	62.0
XK	351.7	85.8	315.9	61.9	232.0	61.2	171.1	63.7
MD	61.7	69.8	62.4	58.4	59.5	56.6	62.4	60.3
ME	336.7	79.5	306.3	59.2	188.9	59.7	164.8	59.5
MK	357.4	80.2	316.8	59.8	239.1	58.3	172.1	61.6
RO	134.8	79.5	163.3	58.2	39.8	56.3	58.4	57.3
RS	329.7	80.6	301.7	60.4	210.3	59.9	162.3	59.1
SI	67.7	69.8	64.3	57.4	57.0	56.7	48.1	52.4
SK	72.9	68.9	70.9	56.9	59.1	56.0	54.1	54.4
UA_E	61.7	65.0	62.4	57.9	59.5	58.8	62.4	61.6
UA_W	73.8	68.9	72.6	56.9	61.4	56.0	59.6	54.4

2050	Wholesale price, €/MWh							
	REF RES				High RES			
	Coop		No_Coop		Coop		No_Coop	
	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid
CESEC weighted average price	100.3	72.2	101.6	58.0	72.4	58.5	72.7	60.4

Source: EPMM modelling results.

Table A6.3 CO2 emission of electricity generation in the CESEC region, 2030

2030	CO2 emission, kt							
	REF RES				High RES			
	Coop		No_Coop		Coop		No_Coop	
	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid
AL	0	0	0	0	0	0	0	0
AT	4 914	4 882	4 891	4 448	4 215	4 271	4 223	4 257
BA	5 300	1 380	5 865	977	5 115	2 268	5 752	1 491
BG	6 564	6 769	5 607	6 332	4 920	5 085	4 256	4 523
EL	10 359	10 186	8 669	8 227	8 994	8 821	7 802	7 721
HR	4 139	3 851	3 662	3 474	3 299	2 852	2 685	2 496
HU	5 260	4 807	4 393	4 197	4 706	4 192	3 747	3 460
IT	31 721	30 407	37 330	25 673	28 291	27 187	34 421	32 726
XK	2 647	2 523	2 198	2 205	2 414	2 236	2 009	2 020
MD	10 086	10 537	10 075	10 446	9 940	10 597	9 919	10 290
ME	752	246	724	205	774	263	732	254
MK	1 023	956	989	910	1 000	958	979	930
RO	10 134	9 682	8 728	9 396	10 469	9 640	8 342	8 988
RS	9 212	3 472	8 900	3 059	8 643	4 354	7 954	3 590
SI	4 493	3 682	3 709	3 067	5 124	4 150	4 375	3 634
SK	3 187	3 173	3 029	2 874	2 191	2 154	2 037	2 006
UA_E	30 424	43 061	30 446	39 763	28 288	40 174	28 458	38 354
UA_W	0	0	0	0	0	0	0	0
CESEC	140 215	139 612	139 215	125 254	128 382	129 203	127 692	126 739

Source: EPMM modelling results.

Table A6.4 CO2 emission of electricity generation in the CESEC region, 2050

2050	CO2 emission, kt							
	REF RES				High RES			
	Coop		No_Coop		Coop		No_Coop	
	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid	2020Grid	PCIgrid
AL	0	0	0	0	0	0	0	0
AT	7 122	7 520	6 637	3 340	1 889	1 816	2 039	2 014
BA	3 177	982	4 332	51	1 829	51	2 820	280
BG	8 276	9 290	9 199	5 920	4 366	5 562	5 757	6 505
EL	6 312	7 527	6 759	4 614	3 815	5 212	6 341	7 476
HR	6 727	6 907	5 959	4 360	4 558	4 166	2 255	3 580
HU	6 041	6 367	5 962	4 640	4 741	4 844	4 322	4 986
IT	33 024	31 279	29 441	16 518	20 096	17 511	21 634	19 133
XK	960	703	924	504	865	509	793	500
MD	893	1 557	905	852	831	950	980	1 152
ME	991	254	889	19	512	35	503	46
MK	743	437	703	234	675	199	582	208
RO	1 380	1 387	1 459	837	393	729	741	898
RS	4 076	1 823	3 633	824	3 159	912	2 815	880
SI	2 244	2 423	1 964	1 054	1 247	1 324	603	814
SK	4 895	4 783	4 788	3 208	5 332	4 591	4 207	4 023
UA_E	34 741	36 291	35 264	28 733	27 272	26 665	32 763	31 176
UA_W	0	0	0	0	0	0	0	0
CESEC	121 604	119 530	118 819	75 709	81 581	75 075	89 153	83 671

Source: EPMM modelling results.

Table A6.6 Reserve capacities by technology in the CESEC region, 2030

	2030	REF RES				High RES			
		Coop		No_Coop		Coop		No_Coop	
		2020 Grid	PCIgrid	2020 Grid	PCIgrid	2020 Grid	PCIgrid	2020 Grid	PCIgrid
Reserve market - up, average GWh	Coal	314	207	319	218	305	242	314	246
	Natural gas	2 070	2 196	2 293	2 322	2 039	2 167	2 240	2 291
	Hydro	1 779	1 734	1 622	1 746	1 890	1 822	1 830	1 827
	Other RES	0	0	0	0	0	0	0	0
	Storage/DSM	1 241	1 262	1 079	1 256	1 296	1 308	1 227	1 251
	Missing reserve	19	19	19	17	17	17	17	17
	Total (incl nuclear)	5 533	5 533	5 445	5 679	5 679	5 679	5 752	5 752
Reserve market	Coal	407	421	399	390	413	433	407	412
	Natural gas	1 974	1 940	1 776	1 704	1 718	1 685	1 660	1 662
	Hydro	422	407	425	429	445	423	455	422
	Other RES	1 817	1 832	1 967	2 169	2 148	2 155	2 255	2 257
	Storage/DSM	327	346	315	366	334	362	334	359

	Missing reserve	25	25	25	26	26	26	26	26
	Total (incl nucl)	4 972	4 972	4 907	5 084	5 084	5 084	5 138	5 138

Source: EPMM modelling results.

Table A6.6 Reserve capacities by technology in the CESEC region, 2050

	2050	REF RES				High RES			
		Coop		No_Coop		Coop		No_Coop	
		2020 Grid	PCIgrid	2020 Grid	PCIgrid	2020 Grid	PCIgrid	2020 Grid	PCIgrid
Reserve market - up,	Coal	47	37	44	6	23	7	31	14
	Natural gas	3 042	2 947	3 276	3 484	3 395	3 415	3 606	3 582
	Hydro	2 691	2 790	2 700	3 113	3 148	3 133	2 945	2 953
	Other RES	0	0	0	0	0	0	0	0
	Storage/DSM	3 803	3 848	3 867	3 945	3 976	3 987	3 917	3 953
	Missing reserve	1	1	1	1	1	1	1	1
	Total (incl nuclear)	9 713	9 713	9 968	10 589	10 589	10 589	10 551	10 551
Reserve market - down,	Coal	20	6	21	0	13	0	15	0
	Natural gas	1 021	1 033	1 017	558	584	557	773	763
	Hydro	260	246	285	203	203	210	235	239
	Other RES	6 310	6 325	6 413	7 634	7 612	7 632	7 278	7 297
	Storage/DSM	537	538	600	406	390	403	467	469
	Missing reserve	44	44	43	51	51	51	45	45
	Total (incl nucl)	8 192	8 192	8 379	8 854	8 854	8 854	8 814	8 814

Source: EPMM modelling results.

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