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Research paper

Measuring the benefits of cross-border renewable auctions in Central and Eastern Europe — The theoretical case of Hungary

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ABSTRACT

Economic theory suggests that significant benefits can be realized, if two or more countries integrate their renewable support schemes and capitalize on the lowest cost renewable energy projects in merged markets. Hungary is one of the Central and Eastern European countries having a legal obligation to open their renewable auction schemes to other EU member states. This paper provides a model-based assessment of what such a cross-border cooperation could mean for Hungary and its neighbouring countries. Economic benefits are calculated and presented for the participating countries according to three pairwise cases for cooperation. Based on these outcomes, the paper concludes with the policy considerations and recommendations to shape the design of the opened auction scheme.

1. Introduction

Countries with renewable energy targets can increase the efficiency of their support schemes by cooperating with neighbouring countries. Supporting the cheapest source of renewable generation in a wider geographical area will in the end reduce the overall support levels. All EU countries have set renewable targets for 2020 and 2030, and, as economic theory suggests, these targets can be achieved at lower cost by opening the RES support schemes and cooperating. The Renewable Energy (RED I) Directive and the revised RES Directive (RED II) provide for various cooperation mechanisms (European Commission, 2009, 2018), including statistical transfer, joint projects and joint support schemes, and RED II set out non-obligatory indicative shares of opening national support schemes.

Despite the theoretical benefits, only limited number of such cases have arisen to date. In Europe the only joint support scheme was established by Norway and Sweden, along with some cases of statistical transfers (with Luxembourg, the Netherlands and Malta as offtaker, Denmark and Baltic states acting as host), and the mutual opening up of one German and one Danish PV auction between the two countries. In the state-aid decisions related to national RES-E support schemes, the European Commission imposed on some EU member states the obligation to open up their future support schemes to neighbouring countries as a remedy for any possible discrimination under articles 30 and 110 of the Treaty on the Functioning of the European Union (European Commission, 2012). Hungary is one of these countries, required to offer a share of its support budget to non-domestic RES-E projects in the validity period of its current support scheme from 2017 to 2026. The proposed amendment of RED II within the Fit for 55 package (European Commission, 2021) would require Member States to carry out a pilot cross-border cooperation project by the end of 2025 or contribute to projects under the Union renewable energy financing mechanism (European Commission, 2020). The aim of this analysis is twofold. Placing the Hungarian case into the focus of our assessment, we would like to collect and analyse the various pro and counter arguments for such a cooperation. Second, with the application of a quantitative, model-based assessment we wish to quantify the benefits of such a collaboration among countries with Hungary at the centre of the corresponding modelling.

The paper is structured into eight sections. After the introduction, Section 2 is a literature review on the renewable cooperation mechanisms. The subsequent sections cover the basic models of cross-border cooperation in the field of renewable auctions, the state of RES deployment and regulatory context, and the considerations for setting up cross-border auctions in Hungary. Section 6 details the modelling approach applied in the quantitative assessment followed by the detailed presentation of the outcome. Section 8 concludes with policy recommendations.

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List of abbreviations

aFRR	automatic Frequency Restoration Reserve
RES	Renewable energy sources
RES-E	Renewable electricity generation
RED	Renewable Energy Directive
TFEU	Treaty on the Functioning of the European Union
NREAP	National Renewable Energy Action Plan
MEKH	Hungarian Energy and Public Utility Regulatory Authority
FIP	Feed-in Premium

2. Literature review

Several studies have demonstrated that renewable energy targets of countries can be reached at substantially lower costs through ensuring a cost-effective distribution of renewable energy production across countries. Voogt and Uyterlinde (2006) proposed a tradable green certificate system to reach the 2010 renewable goals of EU-15 countries, showing that the last option needed to satisfy the overall EU RES-E target would equal 9.2 eurocent/kWh. Aune et al. (2012) have drawn attention to the possible gains from such a system in reaching the 2020 RES targets, although covering only the energy markets of 16 EU countries. They show theoretically that green certificate trading could ensure the effective distribution of RES generation and equalized production prices (cost plus green certificate price). Their modelling showed that in the 16 EU countries the total costs of target achievement could be 70% lower in case of a common certificate scheme with individual national targets, while in case of a common EU-wide commitment an additional 4% decrease could be realized. De Jager et al. (2011) find that RES cooperation between Member States is indispensable for the EU27 to achieve its renewable targets 2020. According to them a "pure" national RES target fulfilment would lead to an increase of costs and expenditures of 5% compared to a more intensive cooperation between MS's. Capros et al. (2011) compare the policy options of supporting domestic renewable investments and full RES trading through statistical transfers (resulting in equal marginal RES costs across the EU27) in their analysis of the impacts of various policies on achieving renewable and GHG targets, using the PRIMES model. According to their results, trading with renewables result in 15% lower compliance cost compared to the scenario without RES trading. Jägemann et al. (2013) compares long-term power sector decarbonization scenarios with a linear dynamic electricity system optimization model. Comparing the scenario with technology-specific RES-E targets (according to NREAPs) with a scenario with technology-neutral EU-wide target (besides existing GHG regulation), they found that reaching the 36% RES-E target by 2020 is 47% higher in terms of compliance cost in the technology-and country-specific case. Using a European electricity system optimization model, Unteutsch and Lindenberger (2014) show that achieving a European-wide 55% renewable electricity target additionally to the 40% GHG reduction target by 2030 would cost 41%–45% less than reaching targets through national support schemes without cooperation.

The academic literature on the broader category of renewable energy cooperation mechanisms is quite extensive. For instance, Klessmann et al. (2013) provides a comprehensive overview on the different design options and respective benefits and drawbacks of the cooperation mechanisms introduced by RED I. As mentioned above, these mechanisms are statistical transfers, joint projects and joint support schemes. They allow for member states to achieve their national RES target in cooperation with other countries within the EU and outside, requiring physical import in the latter case. The authors state that there are considerable benefits from cooperation among member states on meeting the renewable energy targets stemming from enhanced cost efficiency from tapping into cheaper RES potentials and the flexibility provision for member states in achieving their national targets.

Yet the adoption of said cooperation mechanisms has historically been limited to a few cases . Possible explanations (e.g. regulatory differences in support schemes, difficulty in the sharing of (in)direct costs and benefits, impact on domestic power prices, public acceptance, etc.) were already presented in Klessmann et al. (2013) and Jacobsen et al. (2014). Caldés et al. (2018) carried out an empirical analysis ranking the different drivers and barriers according to their respective relevance and found that much depends on whether the countries have already met or are having difficulties meeting their 2020 RES target and on whether they have experience using the Cooperation Mechanisms.

Klessmann et al. (2013) asserts that beyond the better utilization of RES potentials which is common to all cooperation mechanisms, the joint support scheme adds value by expanding RES markets and thus improving economies of scale for investors. Unfortunately, it is also the most complex mechanism to set up and requires an intensive coordination between the member states, e.g. approval by both national parliaments.

Busch (2017) emphasizes the importance of country level distribution effects and proposes a new mechanism for cross-border support of renewable electricity based on an improved allocation of the resulting benefits and costs.

Meus et al. (2019) compare via a stylized bi-level two-country competitive equilibrium model the efficiency of different renewable cooperation mechanisms (e.g. statistical transfers and joint support schemes) and assess the impact of national support instruments on these cooperation mechanisms. They find that statistical transfers are preferred over joint support schemes unless the latter is based on a joint feed-in premium which yields the most socially optimal outcome.

Concerning the choice of a support scheme for renewable energies, the auctioning of the financial support – and in particular the auctioning of a sliding feed-in premium – was recently adopted in several countries within Europe and worldwide. Empirical evidence indicates that auctions can indeed fulfil their main promise to improve cost-effectiveness and control of the renewable energy support compared to administrative tariff or premium setting (Gephart et al., 2017). Yet the actual performance of this support scheme is highly sensitive to its design elements. It is well established in the academic literature that an auction should be adapted specifically to the overall market context (e.g. technology to be supported, level of competition, etc.) in which it takes place. In accordance with the increasing dominance of auctions for supporting the uptake of renewables, also the academic literature on that has been growing rapidly. As a sort of stock tacking exercise, del Río and Kiefer (2023) provide a systematic and comprehensive review of the fast-growing literature on auctions for renewable energy. Moreover, they inform on lessons learned and propose a future research agenda. The list of recommendations includes at a methodological level that assessments of auctions with case studies should coexist with more quantitative assessments of the topic. In accordance with the above, this paper aims for combining both elements: a case study approach that includes a qualitative and a quantitative analysis.

Given the intricacies of both the cooperation and the support mechanism, cross-border cooperation requires however a dedicated consideration (see Section 5 for details). Overall, there appears to be a gap in the literature as regards the qualitative and quantitative assessment of cross-border auctions and their impact on reaching RES 2030 targets. This paper aims for contributing to fill that gap, at least in parts.

3. Basic models of cross-border cooperation in the field of renewable auctions

The opening of RES support schemes, and specifically of RES auctions, pick up pace in RED II. In a cross-border auction, partner countries conclude a cooperation agreement on the most important conditions for supporting renewable electricity in each other's country. They need to specify the laws related to the responsibilities and liabilities of the involved parties (e.g. authorities and investors), the method of allocating support costs and the statistical benefits among the partners to ensure EU RES targets are fulfilled.

Blücher et al. (2019) classifies cross border auctions into three categories according to the intensity of cooperation:

- Unilateral opening: a share of the support auctioned by the contributing country is offered for renewable projects developed in other countries.
- Multilateral model: partner countries both implement their own cross-border auctions and allow developers from the other country to participate.
- Joint auctions: participating countries agree on all elements of the auction design and determine a rule for allocating the statistical attribution of renewable generation.

Whereas in unilateral and multilateral cross-border auctions the cooperating countries rely on their own auction systems with some necessary modifications, the joint model is based on a new scheme set up jointly by participants, sometimes based on the scheme from one of the countries. This is usually accompanied by an agreement on shared support costs and distribution of statistical benefits. The higher the level of coordination, the higher the level of the administrative costs as well.

As regards the arguments for and against the opening of the support schemes, there are various factors to consider. The main objective of cross-border auctions is to increase the cost-effectiveness of renewable support for the participating countries. In the hosting country – where the investment takes place – additional financial support helps to develop a higher number of projects. Hosting member states can also gain from additional investment and job creation, lower import dependency, improved security of supply, and reduced air pollution and greenhouse gas emissions. However, higher RES deployment can increase grid connection and other system costs in their country, while reducing the availability of potential sites for later projects.

Member states providing the support (contributing countries) can benefit from the lower support costs relative to domestic RES investments due to access to better resources. Higher market values (higher electricity price) and/or lower cost of capital in the hosting country might also result in support cost reduction. Additionally, increased competition among a larger pool of participants (domestic and non-domestic project developers) should decrease bid prices. However, regulatory barriers and lack of social acceptance might result in extra costs which can decrease the gains from cooperation. Participating countries must conclude a cooperation agreement before getting engaged in cross-border auctions and agree on all relevant aspects of the cooperation and the auction design also entailing some extra administrative costs. Additionally, there is a lack of good practices available, as experience with cross-border auctions is very limited. (For more details see Blücher et al. (2019) and Ecofys and Eclareon (2018)).

4. State of RES-E deployment and regulatory context in Hungary

Hungary must open its renewable support scheme from 2017 to 2026 by offering a share of its RES support budget corresponding to the ratio of imported renewable electricity in total domestic electricity supply.

The total electricity supply in Hungary was 45.9 TWh in 2018, of which 14.3 TWh (31 percent) was imported. Nuclear energy makes up more than half of total domestic power generation followed by natural gas (24 percent) and lignite (15 percent).

4.1. Current state of RES-E deployment

Fig. 1 shows the evolution of renewable electricity generation (RES-E) in Hungary in the period 2004–2019. RES-E deployment was led by solid biomass (about 39%), followed by solar (30%) and wind (16%) and other sources (mainly renewable waste). RES reached 9.7 percent of gross electricity consumption in 2019. While wind development halted in 2011 due to regulatory restrictions, solar energy has boomed during recent auctions. The PV share in RES rose from 2% in 2014 to 30% in 2019 and is still growing. The official National Energy Strategy (2019) and the National Energy and Climate Plan of Hungary (2020) assigns a significant role to PV technology and foresee more dynamic growth in PV in the next decade. They envisage 6454 MW PV capacity by 2030 from 1,397 MW at the end of 2019 (MAVIR, 2019). Solid biomass is also expected to increase from 481 MW in 2019 to 796 MW (including renewable waste). Wind technology is practically banned by strict technical and siting conditions in Hungary (Kotek, 2016), therefore its 2030 capacity is planned to remain at around its 2019 level (329 MW) (EUROSTAT, 2019).

In 2017 Hungary's renewable support system transitioned from a feed-in tariff with administratively determined support levels to a competitive auction. Under the new support scheme (called METAR), only small power plants below 0.5 MW can apply for FIT and mandatory off-take of their generation (Governmental Decree 299/2017, Government of Hungary, 2017). Before this, from 2017, plants between 0.5 and 1 MW were eligible for a feed-in premium without competition. However, due to high demand, support for the small-size categories ceased in 2019. Installations from 0.3 MW can apply for support only if they take part in the organized RES auctions.

The first pilot renewable auction took place at the end of 2019 with two separate size categories (0.3–1 MW and 1–20 MW) eligible for a combined (annual) support budget of HUF 1 billion (∼EUR 2.8 million) for up to 66 GWh/year and 134 GWh/year production respectively. This pay-as-bid auction supported 193 GWh/year RES-E generation. The weighted average prices received in the auction were EUR 70 and EUR 61 per MWh for the two size categories, a much better outcome compared to the FIT administrative costs of more than EUR 100/MWh. Still, it was on the higher end compared to other EU countries. See Bartek-Lesi et al. (2020a) for more detailed information on the Hungarian auction design.

Since then, four other auctions have been organized. The second auction took place in Q4 of 2020 with similar conditions to the first but with a higher capacity limit of 50 MW for larger-sized plants, while the third auction was again announced with a 20 MW upper limit in Q2 of 2021. The weighted average winning prices decreased compared to the pilot auction, with 82 and 63 EUR/MWh in the second, and 76 and 58 EUR/MWh in the third auction for the two size categories, respectively. The volume awarded was 342 GWh/year in the second and 299.3 GWh/year in the third auction. The fourth auction, held at the end of 2021 was intended for power plants which have been in operation for

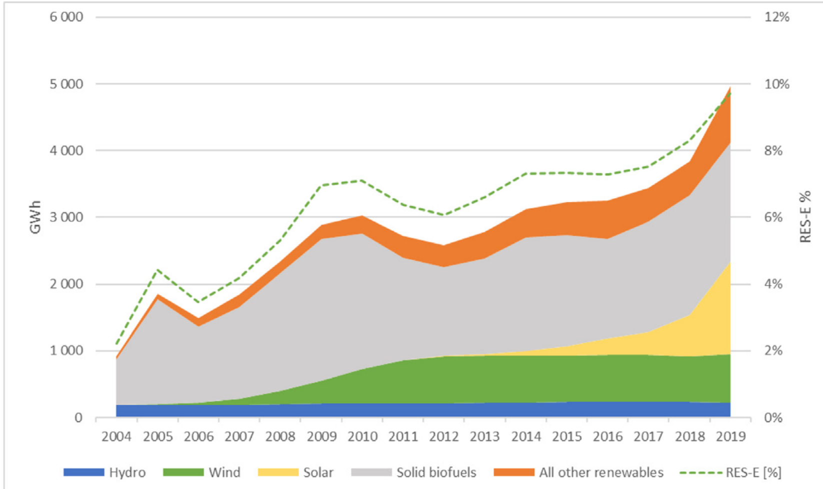

Fig. 1. Electricity generation from RES in Hungary in absolute (GWh) and relative terms (% - share of gross electricity consumption), 2004–2019. *Source:* REKK figure based on Shares database EUROSTAT (2019).

at least 20 years and needed major reconstruction. Plants could participate with at least 5 MW capacity in the lower and 20 MW in the larger size category. The auction was undersubscribed, and only half of the bidders (biomass plants and one hydro plant) were successful, all of which submitted the maximum bid price, around 140 EUR/MWh. In this auction, 876 GWh of annual production gained support. The latest auction, in March 2022, was also undersubscribed, with bids submitted for half of the advertised amount. Although new power plants were again eligible, the size categories were the same as in case of the fourth auction (5 – less than 20 MW and 20–50 MW), and the bidders were required to install storage capacity as well equivalent to at least 10% of the capacity of the RES-E plant to be built, to be made available as aFRR balancing capability. The weighted average prices achieved in the two size categories were 97 and 93 EUR/MWh, respectively. The amount of electricity awarded was 434.7 GWh per year (HEPURA, 2023)

4.2. Regulatory environment

The Renewable Energy (RED I) Directive and the revised RES Directive (RED II) of the European Union provide various mechanisms for RES cooperation, including statistical transfer, joint projects and joint support schemes. The Hungarian government is obliged to open its support scheme to other member states in compliance with the provisions laid down in its RES State Aid Decision of the European Commission (2017).

According to the decision, Hungary must offer a share of the financing allocated under its RES support scheme to non-domestic RES producers. The minimum share offered is calculated as the ratio of total renewable energy imports (based on RES-E in energy mix of neighbouring countries) to the annual domestic electricity supply in Hungary. This percentage will be updated annually based on previous values (or of the last year for which data are available). The Hungarian Energy and Public Utility Regulatory Authority (HEPURA) published the following percentages for the first four years of the support scheme period: 11.5% in 2017, 11.7% in 2018, 11.7% in 2019 and 13.7% in 2020 (HEPURA, 2020). Developers from neighbouring member states can apply for subsidies in Hungary only if an intergovernmental agreement has been signed previously by the two cooperating countries. According to the relevant ministerial decree, renewable electricity produced by installations outside of Hungary must be physically imported into the country (Ministerial Decree 62/2016 Government of Hungary, 2016).

Hungary regulated RES cooperation and provisions for its opening of the support scheme environment in the Governmental Decree 299/2017, Government of Hungary (2017), establishing that support for renewable installations located in foreign countries must be based on reciprocal governmental agreements. The decree also specifies that the terms and conditions applicable to developers in the partner country cannot be less stringent than the ones set for domestic bidders. The first two tenders conducted in 2019 and 2020 (ongoing) have not yet been opened for RES projects outside the Hungarian territory.

5. Considerations for setting up cross-border RES auctions for Hungary

5.1. Policy context

The overarching energy policy goal for Hungary is to increase its security of supply. In this respect, it would be beneficial to cooperate with countries that share physical connections, by maintaining or improving good diplomatic relations with neighbouring countries while ensuring the social acceptance of financing projects built outside of Hungary.

Hungary has strong geothermal potential, though investments are still limited. The shallow geothermal heat potential is estimated to be around 23 PJ/year, out of which 2.2 PJ/year is utilized for district heating, 2.8 PJ/year for agriculture and 2.6 PJ/year for balneology (Nádor et al., 2019). In power generation, Hungary has a mere 1.5 MW geothermal power capacity, and due to the low temperature of the shallow geothermal heat new capacities in the range of 3 to 10 MW failed to be realized due to economic reasons. Significant professional experience has been developed but only small-scale projects have been realized due to the high risks and associated costs. Solar irradiation is also relatively strong, but the availability of land for PV plants can become constrained with growing concerns over the use of greenfield (as opposed to brownfield) sites.

The timing of cooperation between partners is another important issue for the implementation of cross-border auctions. Even though annual support shares must be offered to non-domestic project developers for the period of 2017–2026, talks with potential partners have not yet been initiated. This is a slow process and on the other side developers need time to prepare for participating in the auctions of the partner member state.

Falling renewable technology costs would seem to support prolongment of cooperation, pushing the cooperation to the end of the commitment period (i.e. 2025, 2026), there are factors such as scarcity of area available for new projects, opposition of residents, and network congestion that increase costs over time for countries with higher renewable penetration. One example is onshore wind projects in Germany, where limited availability of suitable sites and the opposition of local residents lead to lower participation in the auctions and ultimately higher support levels (Sach et al., 2019). The other advantage for waiting to enter into a cooperation is to see how other countries proceed and learn from their practices.

One of the conditions set by the regulatory framework of the Government Decree is to ensure a level playing field for domestic and non-domestic projects. This, however, would be very difficult if not impossible to achieve because differences in cost levels are the justification for countries to enter into these agreements in the first place. Heterogeneous natural resources and policies help explain cost differentials and provide potential for harnessing cross-border auctions.

Different national regulatory, technological and market environments can strongly influence investment costs in the cooperating countries. Apart from the share of auctioned volumes offered to non-domestic bidders, the overall volume and frequency of auctions also affect the level of competition and the prices achievable. Hungary, for example, prefers promoting PV installations in its territory while inhibiting the development of wind projects. Thus, if the possibility to promote wind projects outside of the borders is not ruled out, a non-domestic wind project can submit lower bids than some Hungarian PV developers, resulting in lower overall support costs.

To keep administrative costs low, the Hungarian government can create unilateral openings, whereby Hungary would only participate as a contributing country (providing support) without requiring the cooperating partners (host countries) to open their support schemes for Hungarian projects (Governmental Decree 299/2017, Government of Hungary, 2017). However, within the reciprocal types of cooperation, a mutual opening would be preferred so that national auction rules can be applied with some small modifications rather than setting up much more complex joint auctions, making it administratively less demanding.

5.2. Partner selection

Since no negotiations with neighbouring countries have been initiated, an agreement is not expected before 2023. The EU neighbouring countries that would be considered as possible future partners include Slovakia, Austria, Slovenia, Croatia, and Romania.

When deciding about potential partners, the following features in Table 1 are also worth considering besides the cost savings.[1]

For the subsequent model-based analysis it was consequently decided to limit the assessment to 3 instead of all five of Hungary's neighbours, as Austria, Slovakia and Romania are representative countries in their RES utilization and policy in the region. Austria already deploys high RES levels and has ambitious targets to achieve 100% renewable electricity by 2030, while Romania has high resource potential in wind and solar. Slovakia has a generation portfolio and less ambitious targets in RES-E, similar to Hungary. In addition, it is only Romania and Hungary in the region having the obligation to open their RES support schemes.

[1] Please note that the table contains information available in 2021, at the time the modelling was carried out.

6. Approach used in modelling cross-border RES cooperation

This section aims to explain the approach taken within the modelling exercise dedicated to cross-border auctions between Hungary and selected neighbouring countries. The main tool is TU Wien's Green-X model, a specialized energy system model offering a sound coverage of support instruments for renewables as well as on the available resources and corresponding cost of individual RES technologies within Europe. Details on the applied model can be found at TU Wien (2021) and in Annex I

The modelling investigates how cross-border auctions may facilitate the achievement of 2030 RES targets laid down in National Energy and Climate Plans (NECPs) of the assessed EU member states. Geographically, Hungary is placed in the centre with all neighbouring countries serving as possible cooperation partners. As concluded at the end of the previous section, that list includes, apart from Hungary, Austria, Romania and Slovakia. Sector-wise, the analysis is constrained to the electricity sector since auctions play a predominant role in that sector for supporting the uptake of renewables. Moreover, cross-border cooperation by means of auctions appears, except for niches, hardly feasible for heat and for transport at present. Technology-wise, the approach taken can be classified as technology-neutral since all available RES technologies for electricity generation are considered. Modelling incorporates however practical hurdles that (currently) limit the uptake of RES technologies country-wise. In practical terms that implied for Hungary that a further uptake of wind power was permitted. At present, legal provisions in spatial planning and in permitting set a hurdle for that in Hungary. The economic assessment is limited to RES policy cost by means of support expenditures, representing the direct financial support that is paid to RES producers in a feed-in premium scheme on top of market revenues to make the investment viable. Any other costs or benefits related to the RES uptake are neglected in that brief analysis.

Two steps are taken to identify the most promising cooperation candidates:

- First the assumption is that all assessed countries form a joint region – a so-called "bubble" – where postulated national 2030 RES targets shall be met jointly. That implies that a regional policy approach would be agreed upon and implemented to allocate RES investments where economically most beneficial in future years. The continuation of current practices – where RES policies are designed and implemented to meet given national RES targets using only domestic resources – serves as reference case to the above. From a policy perspective this "bubble exercise" can be classified as unrealistic but it allows for identifying the most interesting cross-border collaboration partners for Hungary.
- In the next step, building on the lessons learnt from the "bubble exercise" under step two, three different subcases of bilateral RES cooperation between Hungary and a neighbouring country are analysed — the so-called "pairing cases". Neighbouring countries are selected to replicate distinct circumstances: one where Hungary acts as host (and Austria as off-taker), one as off-taker (Romania as host), and a third case tested with Slovakia, where it is unclear at the beginning how cross-border cooperation may affect future RES investments.

The whole assessment is undertaken for low and high demand scenarios shown in Fig. 1. This is acknowledging the uncertainty of future demand growth due to several factors: energy efficiency measures as well as economic stagnation may cause a decline in consumption for default electricity uses, or broad electrification and sector coupling will increase demand. In the low demand

Table 1
Factors influencing partner selection.

Characteristics	Description
Experience with auctions	Poland, Hungary and Slovenia are the three CEE countries that executed renewable auctions while Slovakia and Croatia are in the process of setting up their pilot auctions. Slovakia launched a competitive bidding process in February 2020 but the auction was cancelled due to COVID. Romania and Austria are still in the planning phase.
Opening obligation	From the selected countries, only Hungary and Romania have to open their support budgets to RES-E producers in other countries. Romania is transitioning from a green certificate system to a support scheme providing feed in premiums through auctions in 2021. No information is available yet on the planned auction design.
Capital cost level	Ecofys et al. (2017) found the weighted average cost of capital in Hungary to be 1%–2% higher than in neighbouring countries. PV project WACC is 7.3–8.75% compared to 4.5–6.0% in Slovakia, 7.3% in Romania 7.6% in Croatia. The DIACORE project put Austria at 6.5% in 2016 (Noothout et al., 2016).
Current level of support	Concerning the level of project costs and the required support level, auction prices are a better indicator of actual costs than Feed-in Tariffs since they are formed through a competitive process. As mentioned already, from among the countries in the region (besides Hungary), only Poland and Slovenia have implemented renewable auctions. In Slovenia, the average price offered by winning projects in the last auction was EUR 66/MWh, which is close to Hungarian auction prices. (IRENA, 2019) However, this is a one-sided FIP compared to the two-sided FIP offered in Hungary.
Wholesale electricity prices	Annual day-ahead wholesale electricity prices were lower in Germany, Austria and Slovakia than Hungary and about the same in Croatia, Romania and Slovenia (in 2018 and 2019).
Balancing cost/integration costs	According to ACER and CEER (2017), Slovenia has a similar balancing cost to Hungary (∼4 €/MWh) compared to Austria which is almost 3 €/MWh cheaper and Slovakia and Romania that are 2 €/MWh more expensive. In this respect Hungary could benefit from the lower Austrian balancing cost if the two country cooperates.
Distance from RES target	Romania and Croatia have already achieved a higher RES share in 2018 compared to their 2020 RES targets, and 2018 RES deployment in Austria was slightly below the targeted RES share for 2020. In contrast, Slovenia is furthest away. However, Croatia and Austria set very ambitious RES-E objectives for 2030, likely making it beneficial to pursue parts of their required renewable generation at lower costs abroad. The targets of Slovakia and Hungary are moderate, partially as an outcome of their ambitious nuclear energy policies. Countries with strong renewable resources that have already reached their goals might be more willing to participate in cross-border auctions.

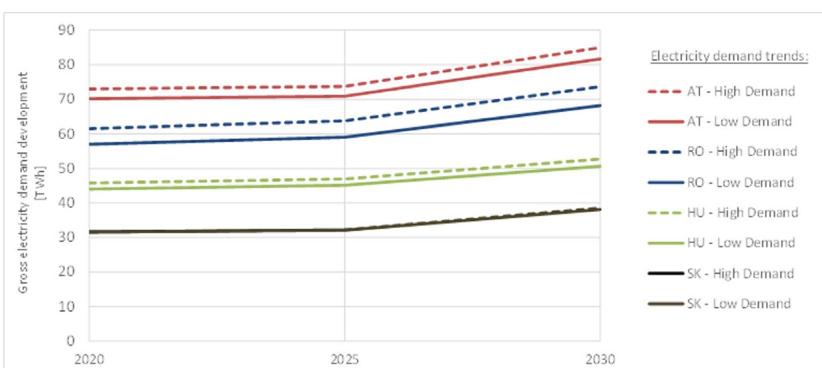

Fig. 2. Assumed gross electricity demand trends: Low Demand vs High Demand case.
Source: Own assessment based on E3M-Lab et al. (2016).

case, average yearly growth of gross electricity consumption is 1.1% for the whole region from 2015 to 2030, and for Hungary a slightly higher 1.4%. That leads to a gross electricity consumption of about 275 TWh by 2030 (compared to 233 TWh in 2015) for the whole region. The corresponding average yearly growth rate for the high demand case is 1.4% for the whole region and 1.6% for Hungary, leading to a regional gross electricity consumption in size of 287 TWh in 2030.

Electricity demand also affects the price developments in the wholesale electricity market, illustrated in Fig. 2. These outputs are taken from a recently completed electricity market study of a comparable geographical scope Szabó et al. (2020) (see Fig. 3).

7. Summary of results and findings

Building on the lessons learnt from the "bubble exercise" this section presents findings from the three pairings described above. Results of the preceding "bubble exercise" of regional RES cooperation involving all neighbouring countries of Hungary can be found in Bartek-Lesi et al. (2020b). First, Table 1 provides key results for the expected use of renewables in 2030 under both distinct policy cases (Cooperation vs Reference) combined with the two underlying demand trends (Low vs High Demand). Already a comparatively identical picture arises for the demand trends concerning the impact of RES cooperation on the allocation of RES investments.

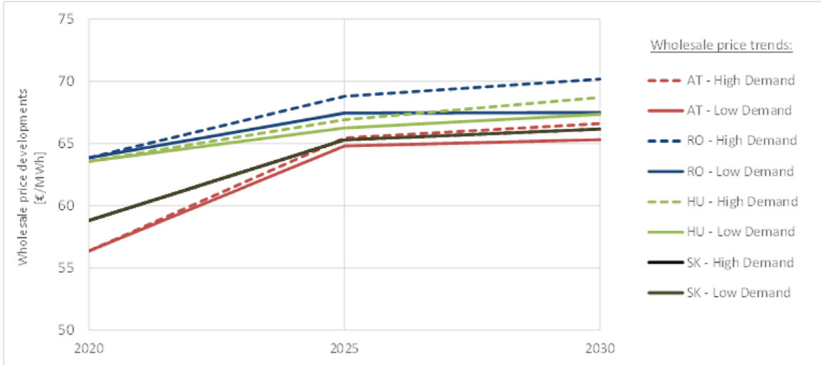

Fig. 3. Assumed wholesale price trends: Low Demand (left) vs High Demand case (right).
Source: Own assessment based on Szabó et al. (2020).

Table 2
Key results on 2030 RES-E deployment from the "pairing cases" (i.e. bilateral cross-border auctions between Hungary and selected neighbours).
Source: Own analyses (Green-X modelling).

Comparison of results: (Cross-border RES) Coooperation vs. Reference	Unit	Pairing cases								
		Hungary	Austria	Region	Hungary	Romania	Region	Hungary	Slovakia	Region
		HU	AT	Region	HU	RO	Region	HU	SK	Region
Targeted RES-E share 2030 (according to NECPs)		20,0%	92,0%		20,0%	49,4%		20,0%	27,3%	
Low Demand case (i.e. low demand growth due to limited economic growth and/or strong energy efficiency)										
Generation balance										
RES-E share 2030										
Reference	%	20,0%	92,0%	64,5%	20,0%	52,7%	65,9%	20,0%	27,3%	23,2%
Cooperation	%	21,1%	91,3%	64,5%	13,8%	53,0%	63,9%	19,5%	27,9%	23,2%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	1,0%	-0,7%	0,0%	-6,2%	0,2%	-2,0%	-0,5%	0,6%	0,0%
RES-E generation 2030										
Reference	TWh	10,13	75,20	85,33	10,13	35,96	46,09	10,13	10,52	20,66
Cooperation	TWh	10,66	74,63	85,29	7,51	37,18	44,68	9,89	10,76	20,66
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	0,53	-0,57	-0,04	-2,63	1,22	-1,41	-0,24	0,24	0,00
High Demand case (i.e. high demand growth due to strong sector coupling and enhanced electrification)										
Generation balance										
RES-E share 2030										
Reference	%	20,0%	92,0%	64,4%	20,0%	50,9%	67,3%	20,0%	27,3%	54,7%
Cooperation	%	22,1%	90,7%	64,4%	15,2%	52,9%	65,8%	19,9%	27,5%	23,1%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	2,1%	-1,3%	0,0%	-4,9%	2,0%	-1,5%	-0,1%	0,2%	-31,6%
RES-E generation 2030										
Reference	TWh	10,55	78,14	88,69	10,55	37,46	48,01	10,55	10,52	21,07
Cooperation	TWh	11,65	77,04	88,69	7,98	38,94	46,92	10,47	10,60	21,07
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	1,11	-1,11	0,00	-2,56	1,47	-1,09	-0,07	0,07	0,00
Evaluation: Cooperation characteristics		HU	AT		HU	RO		HU	SK	
Low Demand case										
High Demand case										

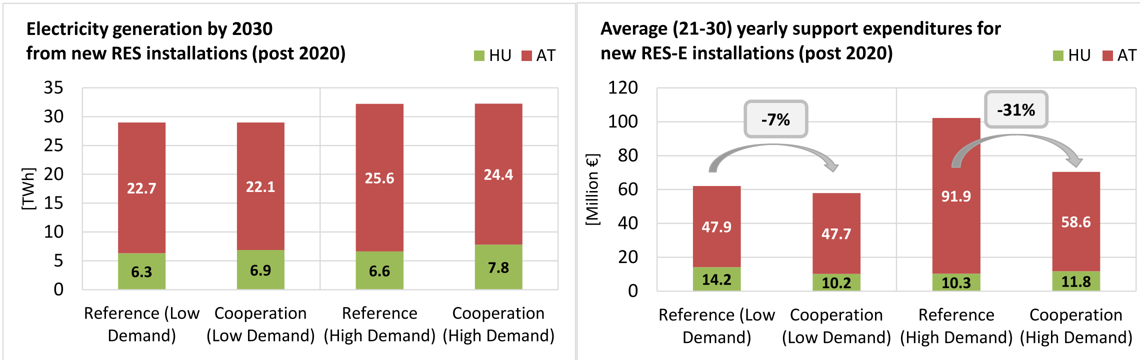

Fig. 4. Impacts of cross-border RES auctions between Hungary and Austria on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right).
Source: Own analyses (Green-X modelling).

7.1. Case 1: Cross-border RES auctions between Hungary and Austria: Hungary acting as host

As shown in Table 2, a bilateral RES cooperation between Hungary and Austria would make Hungary the host country and Austria the off-taker for parts of the planned RES uptake to 2030. Fig. 4 shows the impacts of this bilateral RES cooperation on the deployment of new RES installations in the electricity sector and the corresponding policy cost quantified as support expenditures.

Results show that only a minor part of RES-E is affected by cross-border RES cooperation and that the impact is stronger in a high demand scenario. In the Low Demand case 2030 RES-E generation from new installations increases from 6.3 to 6.9 TWh in Hungary and, consequently, RES-E generation from new plants decreases from 22.7 to 22.1 TWh in Austria. In the High Demand case the increase is double, 1.2 TWh.

When comparing the policy cost between the Cooperation and the Reference scenarios, cost savings triggered by RES cooperation can be identified, see Fig. 4 (right). Similar to RES-E deployment, savings are significantly higher under the High Demand case, together 31% compared to 7% in the Low Demand case. Cost savings are defined as the decline in average (2021–2030) yearly support expenditures dedicated to new RES (installed post 2020) compared to the Cooperation and the corresponding Reference scenario. A closer look at the distribution of costs among both countries indicates that Austria would benefit most from the assessed cross-border cooperation.

7.2. Case 2: Cross-border RES auctions between Hungary and Romania: Hungary acting as off-taker

Fig. 5 provides an overview of the impact of RES-E deployment on bilateral RES cooperation between Hungary and Romania. Implementing cross-border RES auctions for joint RES-E targets would lead to a strong reallocation of investments in renewables across the border. Because Romania's 2030 RES-E ambition is rather low, under Reference conditions 2030 RES-E deployment would already be above the targeted. This allows Romania to offer some of its RES-E surplus to Hungary, acting as off-taker under both assessed demand cases. Fig. 5 shows the impact of this bilateral RES cooperation, specifically on the deployment of new RES-E installations to 2030 (Fig. 5, left) and on the corresponding policy cost (Fig. 5, right).

As outlined above, the results reveal that the planned RES-E uptake for both countries is more strongly affected by cross-border RES cooperation than in the previous case:

In the Low Demand case 2030 RES-E generation from new installations declines in Hungary from 6.3 to 3.2 TWh, while RES-E generation from new plants in Romania only moves up slightly from 5.9 to 6.1 TWh. This implies that Romania can expect a strong surplus in RES-E generation compared to its low ambition 2030 Reference target.

Under the High Demand case a similar trend unfolds, but the changes in country-specific RES-E generation are smaller. As shown in Fig. 5 (left), domestic RES-E generation in Hungary is down to 2.3 TWh compared to 3.1 TWh (under Low Demand). As a consequence of the lower surplus in RES-E generation under Reference conditions there is a higher increase in RES-E generation in Romania. RES-E capacity increases by 1.2 TWh in the High Demand Cooperation scenario compared to just 0.2 MW in Low Demand Cooperation.

A comparison of policy costs between the Cooperation and the Reference scenarios reveals savings from cross-border RES cooperation. Aggregated together, these cost savings reach 87% in the Low Demand case and to 89% in the High Demand case. A closer look at the distribution of cost among both countries shows that Hungary would largely benefit from the cross-border cooperation. Romania would, in turn, face higher policy costs compared to its Reference but the Romanian economy may benefit from RES-related investments as well as the additional income for domestic RES-E producers.

7.3. Case 3: Cross-border RES auctions between Hungary and slovakia: negligible impacts on RES-E deployment accompanied by moderate savings in policy cost

Fig. 6 provides an overview of a bilateral RES cooperation between Hungary and Slovakia. Implementing cross-border RES auctions to jointly reach planned 2030 RES-E targets would cause only a negligible cross-border reallocation of investments into RES-E. There are, however, savings in policy costs as shown below in Fig. 6

According to the results, cross-border RES cooperation has a negligible effect on RES-E deployment in both countries:

In the Low Demand case 2030 RES-E generation from new installations declines from 6.3 to 6.1 TWh in Hungary. In turn, RES-E increases from 4.0 to 4.3 TWh in Slovakia.

Under the High Demand case the changes are significantly smaller in magnitude in 2030 as shown in Fig. 6 (right). The reallocation of RES-E deployment amounts to only 0.05 TWh, causing a negligible increase in Slovakia and a corresponding decline in Hungary.

A comparison of the impact on support expenditures between the Cooperation and the Reference scenarios shows that the cooperation brings only moderate savings. Aggregated together, cost savings amount to 6% in the Low Demand case and to 13% in the High Demand case. A closer look at the default cost distribution

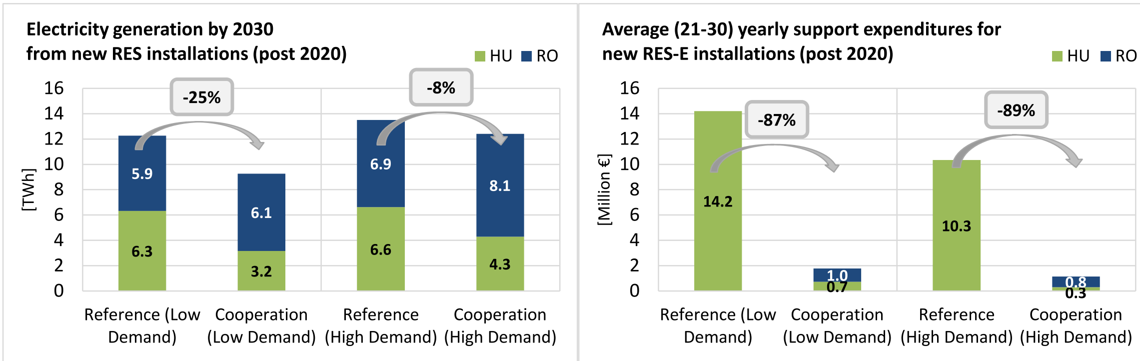

Fig. 5. Impacts of cross-border RES auctions between Hungary and Romania on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right).
Source: Own analyses (Green-X modelling).

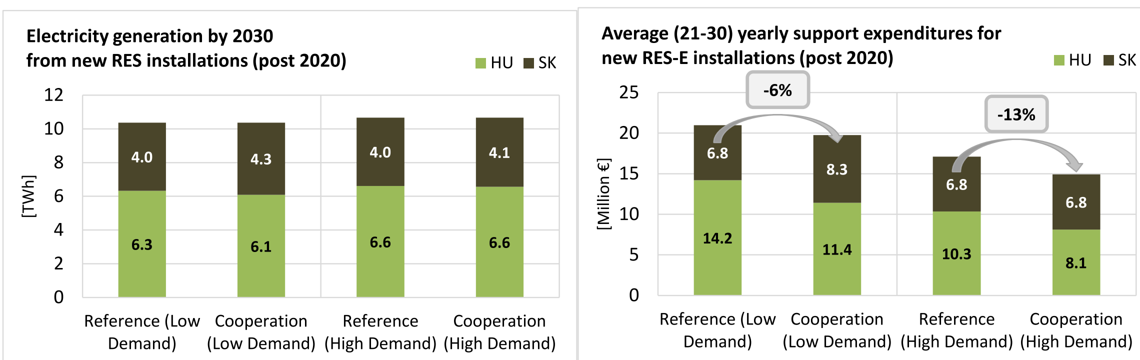

Fig. 6. Impacts of cross-border RES auctions between Hungary and Slovakia on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right).
Source: Own analyses (Green-X modelling)

among both countries indicates that Hungary would strongly benefit from the assessed partnership. For Slovakia, policy cost is not affected in the High Demand case and only slightly in the Low Demand case. This calls for additional measures or agreements between both countries to achieve a fair distribution of the overall benefits.

8. Conclusions

Establishing a well-functioning joint RES support scheme is a complex task, requiring an agreement between the cooperating countries on various design elements. Beyond the relatively straightforward economic benefits quantified in this article for Hungary and its selected neighbours, there are other elements that have to be agreed upon, such as the redistribution of costs and benefits, sharing of induced RES production to fulfil national targets, and the agreement on reference prices and exchange rates. Prevailing market conditions, such as balancing requirements and costs, the level of wholesale electricity prices, network constraints also influence the decisions on the scheme. The analysis of these aspects should be delivered in the near future, once Hungary and Romania start to fulfil their obligation of the opening requirement imposed on their RES support schemes, as these additional aspects can drive the negotiations in shaping the agreements between the cooperating partners. Due to resource constraints, this analysis is not part of the present study.

Selecting the right partner is also a multi-dimensional policy decision, where beyond the pure economic considerations, diplomatic relations, as well as technical issues (interconnection, net trade with the country) and additional obligations (e.g. obligation on opening up RES support scheme) play a crucial role.

Timing is also important for setting up cooperation schemes. If support cost reduction would continue in the future, delaying the joint auctions might be reasonable, but with increasing grid connection bottlenecks this could become a misguided strategy.

The modelling works performed indicate that cross-border RES cooperation between Hungary and its neighbours may lead to a reallocation of RES-E investments across national territories accompanied by some savings in terms of policy cost.

As the pairing case analysis has shown, Hungary's role as host or off-taker depends on the partner country chosen. With Austria, Hungary will become a host and both countries should benefit from the policy cooperation. In the case of Romania, its low policy ambition would make it the host, in turn, causing a significant decline to RES-E investments in Hungary. Yet aggregated cost savings between the two countries is higher in magnitude. A cross-border cooperation with Slovakia would cause negligible changes in RES-E deployment and moderate aggregate savings. Further agreements would be needed to result in a win-win situation for both participating countries.

The analysis prepared for this document can be seen as a first phase, which shows the economic potential of cross-border cooperation in the promotion and deployment of renewable energy. If cooperation were to be expanded from bilateral to multilateral, the economic benefits would likely increase further. This should be a future research direction, as in addition to the objectives of the Fit for 55 package for stronger renewable electricity, intensified cooperation will improve the economic efficiency of renewable energy deployment.

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CRediT authorship contribution statement

Mária Bartek-Lesi: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Gustav Resch:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **László Szabó:** Conceptualization, Writing – original draft, Writing – review & editing, Investigatio. **Lukas Liebmann:** Data Curation, Writing – original draft, Writing – review & editing. **Jasper Geipel:** Data Curation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request

Appendix. Brief characterization of the green-X model

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

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

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

Within the Green-X model, the allocation of biomass feedstock to feasible technologies and sectors is fully internalized into the overall calculation procedure. For each feedstock category, technology options (and their corresponding demands) are ranked based on the feasible revenue streams as available to a possible investor under the conditioned, scenario-specific energy policy framework that may change on a yearly basis. Recently, a module for intra-European trade of biomass feedstock has been added to Green-X that operates on the same principle as outlined above but at a European rather than at a purely national level. Thus, associated transport costs and GHG emissions reflect the outcomes of a detailed logistic model. Consequently, competition on biomass supply and demand arising within a country from the conditioned support incentives for heat and electricity as well as between countries can be reflected. In other words, the supporting framework at MS level may have a significant impact on the resulting bio-mass allocation and use as well as associated trade.

Please note that further details on the approach, assumptions as well as on the results of the analysis presented in this paper can be found in Bartek-Lesi et al. (2020b), serving as background report to this paper.

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