POREĐENJE RAZVOJA OBNOVLJIVIH IZVORA ELEKTRIČNE ENERGIJE REGIONA JUGOISTOČNE EVROPE I POGODNO ODABRANIH EVROPSKIH DRŽAVA

COMPARISON OF THE DEVELOPMENT OF RENEWABLE ELECTRICAL ENERGY POWER SOURCES BETWEEN REGION OF SOUTH-EASTERN EUROPE AND CONVENIENTLY SELECTED EUROPEAN COUNTRIES

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Razvoj i uklapanje obnovljivih izvora električne energije (OIEE) u elektroenergetske sisteme evropskih država s jedne strane vođeni su odgovarajućim zakonskim propisima. S druge strane, dinamika primene OIEE i njihovog iskorišćenja, prevashodno zavisi od ekonomske snage država da ih podrže kroz odgovarajuće mehanizme. Otuda su uočljiva i veoma različita iskustva, primena i stepen rasta među evropskim državama. Ovaj rad prikazuje pregled trenutnog stanja i dosadašnjih trendova, za region jugoistočne Evrope i nekoliko pogodno odabranih evropskih zemalja, i to Nemačke, Velike Britanije, Danske i Portugala. Rad takođe pruža komparativnu analizu između njih, pri čemu je region jugoistočne Evrope posmatran kao jedna celina, iako se sastoji od jedanaest država koje su međusobno jako različite u pogledu iskorišćenja OIEE. Iz ovog poređenja i uočenih različitosti, izvedeni su odgovarajući zaključci o statusu trenutnog stanja, kao i mogućnostima i potrebama za preduzimanje daljih koraka u svakoj od njih sa ciljem daljeg kontinuiranog razvoja OIEE.

Ključne reči: obnovljiv; iskorišćenje; električna energija; razvoj; poređenje

Development and incorporation of renewable electrical energy power sources (REEPS) into electric power systems of the European countries is guided from the one hand by relevant legislative. On the other hand, dynamics of REEPSs application and consequently utilization is dominantly dependent on countries' economic strength to support it through appropriate mechanisms. Therefore, very different experiences, applications and growth rates are evident across European countries. This paper presents an overview of the present states and trends achieved so far, for the South-Eastern Europe region and several selected European countries, namely Germany, the United Kingdom, Denmark and Portugal. It also provides comparative analysis between them, whereas South-Eastern Europe region is observed as a whole, i.e. it is considered as one entity, although this region is comprised out of eleven countries, very different among themselves with respect to REEPS utilization. From this comparison and observed dissimilarities, appropriate conclusions were drawn, indicating plausibility of the present situation and possibilities and needs for the further steps to be taken in each of them with respect to further and continuous REEPS development.

Key words: renewables; utilization; electricity; development; comparison

1 Introduction

The historic 2015 Paris climate agreement has the objective of mitigating average global temperature increase to “well below 2°C” in the current century, in comparison with pre-industrial levels. Renewable electric energy power sources (REEPS), combined with continuously improving energy efficiency measures, constitute the basis of a viable climate solution.

The power sector is characterized by noticeable progress and evolution during the last decades, and the speed of progress is projected to be accelerated. In absolute terms, 167 gigawatts (GW) of

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REEPS capacity has been installed in the power sector in 2017 at a global level, reporting a significant increase of 8.3% over the previous year, underlining also a series of consecutive robust growth rates, amounting to 8% per year since 2010. Renewable power generation record a new historical high, representing an estimated quarter of total worldwide power generation. In addition and in line with the rapidly decreasing renewable energy capital costs, wind and solar power comprise the dominant technologies, reporting new additions of 94 GW in solar photovoltaics and 47 GW wind power, including 4 GW of offshore wind power [1]. A high and rapidly rising share of intermittent and variable renewable energy such as wind and solar power in electric power systems can have serious influences on the operation of conventional power units. Both renewable technologies are contingent on meteorological conditions, daily and seasonal fluctuations, and as a consequence, they cannot produce electricity “on demand” like conventional power units. Moreover, renewables have almost negligible marginal costs, denoting that they enter the system with priority (“for free”) whenever the primary resource (i.e., wind or sun) is available. These factors create a significant transformation of power systems, due to the requirements of flexibly dealing with the endogenous variations of renewables’ feed-in.

Historically, conventional power units have been designed as baseload power units (typically run throughout the year with the exception of their scheduled maintenance periods) to cope with electricity demand profiles characterized by relatively low fluctuations and variability, as well as typical and predictable daily, weekly and seasonal patterns. Power systems with high penetration of variable renewables are characterized by increased requirements for flexibility, which should be provided by swiftly dispatching conventional power units, including both thermal and renewables, being able to ramp up and down more frequently and more quickly, operate often at partial loads, and to start up and shut down with greater frequency. Not surprisingly, a large proportion of conventional power units cannot continue to operate as baseload capacity and must run with increased degrees of flexibility [2]. Furthermore, an increasing share of renewables decreases also the market profitability of conventional generation due to the so-called merit-order effect (economic dispatch). Moreover, it implies indirect impacts on conventional power units, on the ground that it raises the requirements for balancing services and congestion management in the power system.

Table 1 presents the evolution of negative marginal price values in the German power system for the period 2012-2017 [3]. More specifically, Germany faced 146 hours of negative prices (-26.47 €/MWh on average, while the lowest price reported was -83.06 €/MWh) on the day ahead market in 2017. It is also worth mentioning that in 2012, the average negative price value was -70.19 €/MWh on average, while the lowest price reported was -221.99 €/MWh. During all those periods, owners of power units paid to inject their electricity to the system, in order to avoid paying the relevant shut-down costs. However, frequent occurrences of negative wholesale prices provide also incentives and price-signals for potential investors and market participants to invest in highly flexible power sources (e.g., storage), as well as to adapt their production and/or consumption more flexibly to the variable renewable feed-in.

Table 1: Negative marginal price values in the German power system for the period 2012-2017

Year	2012	2013	2014	2015	2016	2017
Amount of hours with negative prices	56	64	64	126	97	146
Average negative price (€/MWh)	-70.19	-14.17	-15.55	-9	-17.81	-26.47
Lowest price (€/MWh)	-221.99	-100.03	-65.03	-79.94	-130.09	-83.06

Some key recent renewable energy cornerstones include [4]:

1. Denmark, 2 September 2015: The Western Danish power system operates without centralized power generation for the first time,
2. Spain, 28 February 2016: For the first time, wind power contributes in upward balancing reserves,
3. Portugal, 7-11 May 2016: Renewable energy, including conventional hydro, covers the equivalent of 100% of power demand for 107 consecutive hours,
4. Germany, 8 May 2016: Wind and solar PV meet the equivalent of approximately 75% of power demand,

5. Scotland, 14 August 2016: Daily wind power production surpassed demand, and
6. United Kingdom, 2016-2017: Wind power exceeds for two consecutive years the hard coal-fired electricity generation.

At present, Germany, the United Kingdom, Denmark, Spain and Portugal are the countries with in Europe that demonstrate day by day that managing power system with large shares of intermittent electricity generation is technically feasible. Indeed, in windy and/or sunny days, overall generation mix shares of 70% and more variable power production is already managed in those countries [5].

The objective of this paper is to present a detailed overview of the current situation and trends achieved so far, for the South-Eastern Europe region and several selected European countries, namely Germany, the United Kingdom, Denmark and Portugal. The following sections provide comparative analyses between them, whereas South-Eastern Europe region is treated and considered as one entity, although this region includes eleven countries, characterized by significant variation among them with respect to REEPS utilization. Main source for electricity data was ENTSO-E organization [6].

2 REEPS in electric power systems of SEE countries

The individual power systems of SEE countries vary to a significant extent among themselves with respect to the (electric) size, electricity demand, total installed power generation capacity, types of technology and fuels utilized in power units, and as a consequence in the resulting production mix as well. Fig. 1 depicts the power generation mix evolution, consumption and net exchange, while Fig. 2 portrays the total installed generation capacity evolution per technology type of the SEE region for the observed period (2008-2017).

Fig. 1 SEE region generation mix evolution, consumption and net exchange for the period 2008-2017

Fig. 2 SEE region total installed generation capacity evolution per technology type for the period 2008-2017

Total average production during the observed period was 271,300 GWh, reporting its minimum value in 2014 (260,600 GWh) and its maximum in 2010 (281,100 GWh), with noticeable downward trend. Thermal power units comprise the dominant technologies in the SEE region, with more than 39 GW of installed generation capacity, which contributes in the power mix with more than half in average over the studied period. This production can fluctuate to a significant extent, dependent on the existing hydrological conditions, fossil fuels prices' evolution, decommissioning of ageing power production fleet, and lately on the exposure on relatively low wholesale electricity prices (merit order effect). Its minimum value was observed in 2014, amounting to 126,000 GWh, while its maximum value, equal to 178,000 GWh, was recorded in 2008. Nuclear power units are installed in Bulgaria, Hungary, Romania and Slovenia, reporting a total capacity of 5.9 GW. Their production is generally stable with an average value of around 45,400 GWh/year, or 17% out of total regional production.

Another key aspect of SEE region is its relatively efficient utilization of available hydro potential, with a little less than 25 GW of total installed hydro power (around 30% out of total installed generation capacity). Large pumped-storage hydro power plants are installed only in Serbia and Bulgaria. Hydro power production represents on average 22% of total production, but is unpredictable and presents noticeable fluctuations from year to year, with a max-min span of even 28,400 GWh or 47% of average production. Minimum hydro power production occurred in 2011, 2012 and 2017 with almost the same generation levels of around 50,600 GWh, while the maximum was in 2010 (78,600 GWh).

Regarding the electricity demand, the average regional consumption was 279,500 GWh during the studied period. Maximal consumption of 287,900 GWh was recorded in 2008, while minimal consumption was recorded in 2014, amounting to 270,800 GWh (decrease of ~6% compared to 2008).

Net electricity exchanges (- for imports and + for exports) of SEE countries [7] are quite different among the countries, including significant net importers (Hungary, Greece and Croatia) and noticeable net exporters, namely Bulgaria, Romania and Bosnia and Herzegovina. SEE region in total is a net importer with imports of some 11,000 GWh/year in 10-years average, but with high volatility on a yearly basis, with maximum imports of 23,200 GWh in 2017 and minimum of 4,400 GWh in 2009.

Fig. 3 depicts renewables' generation mix evolution and percentage of consumption covering and Fig. 4 depicts renewables' installed generation capacity evolution per technology type, both for the 10-year studied period. An upward trend can be easily observed, with the growth rate to be accelerated between 2012 and 2014, while that pace has started to slow down during the remaining years (2015-2017) [8]. Nevertheless, REEPSS installed power capacity rose 8 times (from 1.6 GW to 12.9 GW) in the last ten years, in line with the production growth rate (from 3,300 GWh to 28,200 GWh). During 2017, REEPS accounted for some 15.6% of total installed generation capacity, 10.6% out of total regional production and covered 9.8% of regional consumption. With regard to the specific technology types, wind power plays the dominant role, followed by solar photovoltaics. Those two technologies account for 93% of renewables' installed generation capacity in 2017, with participation of 82% in renewable production in that year.

3 REEPS in electric power system of Germany

Fig. 5 depicts the generation mix evolution of Germany for the period 2008-2017. Germany's power system has faced significant changes during the last ten years, characterized by a rapid increase of renewables' penetration, and a drastic decrease in the nuclear power contribution, due to the intensive nuclear phase-out policy that has been adopted after Fukushima nuclear accident. It is also worth mentioning that electricity exports are in line with the renewables' capacity expansion, whose increasing penetration exerts downward pressure in the system's marginal prices (but lately with a serious plan for a phase-out of mandatory priority dispatch). More specifically, net electricity exports report an increase of around 146% between 2008 and 2017, from 22,500 GWh in 2008 to around 55,400 GWh in 2017, while renewables' power production is characterized by an increase of around 164% between 2008 and 2017, from 70,600 GWh in 2008 to around 186,400 GWh in 2017.

Total consumption is characterized by some variations in its evolution, reporting its peak in 2008, and then follows a generally decreasing trend with some fluctuations. Between 2008 and 2017, power consumption has decreased by around 5%.

Fig. 3 SEE region renewables' generation mix and percentage of consumption covering for the period 2008-2017

Fig. 4 SEE region renewables' installed evolution generation capacity evolution per technology type for the period 2008-2017

Fig. 5 Germany's generation mix evolution, consumption and net exchange for the period 2008-2017

Fig. 6 depicts Germany's total installed generation capacity evolution per technology type for the period 2008-2017. In parallel with the power mix trends, a skyrocketing increase in the renewable-based installed power capacity can be observed, from 32.4 GW in 2008 to around 106 GW in 2017. Nuclear phase-out policy is also clearly depicted in that Figure, on the grounds that nuclear capacity, from around 20 GW in 2008, equals around 9.5 GW in 2017 with a plan for a further decommissioning. Surprisingly, fossil fuel capacity reports an increase in its installed capacity, from around 72 GW in 2008 to 81.6 GW in 2017, highlighting the increasing share of natural gas-fired power units in the power mix. Lignite and hard coal capacity remain almost constant during the studied period.

Fig. 7 portrays the renewables generation mix evolution and percentage of consumption covering in Germany for the period 2008-2017. As can be observed in that figure, RES share in the power consumption covering accounts for 35% in 2017, beginning from around 12.4% in 2008, thus doubled in ten years. When considering total renewable net generation, including renewable hydro net generation, the corresponding share to the national electricity consumption equals 33.4% and 38.2% in 2016 and 2017, respectively. On the other hand, nuclear power production has lost a large part of its share in the power mix, since from 140,700 GWh in 2008, it amounts to 72,200 GWh in 2017, a decrease of

around 49%. Hydro power production remains almost constant, and relatively low, throughout the examined period, while fossil fuels maintain their share in the power mix reporting a reduction of around 13% between 2008 and 2017. Focusing on each specific renewable technology composition, wind and solar power comprise the dominant technologies, accounting for around 75% of the total renewables' production with 92% of the total renewables' installed power capacity in 2017 (Fig. 8).

Fig. 6 Germany's total installed power capacity evolution per technology type for the period 2008-17

Fig. 7 Germany's renewables' generation mix evolution and percentage of consumption covering for the period 2008-2017

Fig. 8 Germany's renewables' installed generation capacity evolution per technology type for the period 2008-2017

4 REEPS in electric power system of the United Kingdom

The main characteristic of the whole power system in the United Kingdom is the increasing share of renewables in energy mix, which along with the rising electricity imports, offset the decreasing share of fossil fuel-based electricity generation, as can be observed in Fig. 9, portraying the energy mix evolution in the United Kingdom for the period 2008-2017. More specifically, renewables account for a skyrocketing increase in their contribution in the energy mix, beginning from 1,100 GWh in 2008, rising to 12,500 GWh in 2012, and finally reaching to almost 72,000 GWh in 2017. Nuclear and hydroelectric energy generation remains almost constant during the studied period, with small fluctuations from year to year. The fossil fuel-based energy generation is characterized from a significant drop from 269,000 GWh in 2008, to 222,000 GWh in 2012, and finally to 167,000 GWh in 2017, namely a reduction of 38% between 2008 and 2017. This reduction is mainly attributed to the hard

coal-fired energy generation, while natural gas-fired energy generation keeps more or less the same levels in its corresponding share. Finally, electricity exchanges, namely electricity imports minus electricity exports, possess a noticeable share in the energy mix, reporting an average value of 18,500 GWh during the last 4 years (2014-2017). Electricity consumption is generally stable, without significant fluctuations, reporting an average value of 323,000 GWh during the period 2008-2017 and a standard deviation of around 11,000 GWh, or 3.5% of its average value.

Fig. 9 Generation mix, consumption and net exchange of the United Kingdom for the period 2008-17

With regard to the installed power capacity in the United Kingdom, the most noticeable aspect concerns the constantly growing capacity expansion of renewables, which from 1.4 GW in 2008, rise to almost 6 GW in 2012, and reach around 33.5 GW in 2017, as shown in Fig. 10, presenting the total installed power capacity evolution per technology type in the United Kingdom for the period 2008-2017. Hydro power capacity reports a small increase of around 13%, while nuclear and fossil fuel-based power capacity decreases by 15% and 20% correspondingly, between 2008 and 2017. Focusing on fossil fuel-based power capacity, this decrease is exclusive due to hard coal-fired units' decommissioning, while the capacity of natural gas-fired units increases during the same period.

Fig. 10 Total installed generation capacity evolution per technology type in the United Kingdom for the period 2008-2017

The importance of renewables-based electricity generation in the demand satisfaction is highlighted in Fig. 11, depicting the total electricity production from renewables and its percentage of total consumption in the United Kingdom for the period 2008-2017. It can be observed that although its share was almost negligible in 2008 (less than 1%), it has followed an upward orbit during the next years, approaching 10% in 2014, and amounting to 22.2% in 2017. When considering total renewable

net generation, including renewable hydro net generation, the corresponding share to the national electricity consumption equals 21.9 and 24.5% in 2016 and 2017, respectively. When examining the renewables' capacity additions composition, as shown in Fig. 12, it can be observed that wind power comprises the dominant technology, followed by solar power, which reports significant investments during the last 3 years, namely the period 2015-2017.

Fig. 11 Renewables' generation mix evolution and percentage of consumption covering in the United Kingdom for the period 2008-2017

Fig. 12 Renewables' installed generation capacity evolution per technology type in the United Kingdom for the period 2008-2017

5 REEPS in electric power system of Denmark

The Danish power system development share many common characteristics regarding its evolution with the British one. The main trend observed is the trade-off between fossil fuel-based electricity generation and renewables' energy contribution. Fig. 13 depicts the percentage of renewables' and fossil fuels' production to the total electricity consumption during the period 2009-2017. The decreasing share of fossil fuels is noticeable, since from satisfying around 73% of the total consumption in 2009, their share drops to around 60% in 2013, and finally amounts to the historic low of around 26% in 2017. This energy deficit is mainly covered from the growing utilization of renewables, whose share in the demand satisfaction starts from 26% in 2009, increases to 47% in 2014, and climbs to the historical high of 60% in 2017. When considering total renewable net generation, the corresponding share to the national electricity consumption equals 51.8% and 60.4% in 2016 and 2017, respectively (with the notion that hydro generation is almost negligible in Denmark). Note also that net imports' share in the total demand consumption is on average 17% during the last 3 years (2015-2017), highlighting the significant flexibility provided in the system by interconnections and electricity trading.

Fig. 14 presents the renewables' capacity expansion composition in Denmark for the period 2009-2016, where wind power constitutes the dominant technology with a share of 68% of the total renewables' installed capacity in 2017, and followed by biomass power with a share of 17%, solar power with 11%, and other renewables with 5%. Note also that during the last 3 years (2015-2017), the average utilization factor of biomass-fired units amounts to 38%, of wind turbines to 30%, and of solar units to 10%, indicating the dependence of the renewables' output to weather conditions and some of the advantages provided from dispatchable renewables such as biomass-fired units.

6 REEPS in electric power system of Portugal

Portugal comprises a country wherein the renewables along with hydroelectricity development has converted it into a net electricity exporter, while fossil fuel-based contribution, in terms of both capacity and generation, has maintained the same (or even higher in some cases, with the exception of oil-fired units facing massive decommissioning) levels. Fig. 15 depicts the generation mix evolution in the power system of Portugal for the period 2008-2017, where generation from renewables is provided

Fig. 13 Percentage of renewables' and fossil fuels' production to the total electricity consumption during the period 2009-2017

Fig. 14 Renewables' capacity expansion composition in Denmark for the period 2009-2017

as a share to the total power consumption in percentage terms (right axis). As can be also observed from that figure, renewables report a steady increase in their contribution, recording an increase of 112% from 2008 to 2017, namely from 7,300 GWh in 2008 (15% of the total power consumption) to 15,600 GWh in 2017 (31.5% of the total power consumption). When considering total renewable net generation, including renewable hydro net generation, the corresponding share to the national electricity consumption equals 63.1 and 42.7% in 2016 and 2017, respectively. This large variation is attributed to the high fluctuation characterizing hydro generation, since 2017 was a dry year. Hydroelectricity contribution is characterized by significant fluctuations during the studied period, since it reports an annual low of 6,500 GWh in 2012 and an annual high of 16,600 GWh in 2016. During those dry periods, fossil fuels are mainly responsible for bridging the gap between production and consumption, while during the last 2 years (2016-17) the country has been converted into a net electricity exporter.

Fig. 15 Generation mix evolution in the power system of Portugal for the period 2008-2017

Fig. 16 portrays the renewables and hydro installed capacity composition in Portugal during the period 2008-2017. Total renewables installed capacity has been developed from 2.7 GW in 2008 to 6.2 GW in 2017 (an increase of 129%), while the corresponding values for hydro units are 4.9 GW and 7.2 GW (an increase of 45%). The share of wind power to the total renewables' installed capacity amounts to 82% in 2017. Note also that during the last 2 years (2016-2017), the total average utiliza-

tion factor at an annual level equals 51% for biomass-fired units, 27% for wind turbines, 19.5% for hydro units, and 20% for solar units.

Fig. 16 Renewables and hydro installed capacity composition in Portugal during the period 2008-17

7 Comparative overview of REEPS in studied electric power systems

Comparison of REEPS capacity installation dynamics over the observed period of time, by country/entity, is depicted on the Fig. 17. From that figure, it is interesting to notice that Germany has the largest REEPS fleet in Europe with constant upward trend, while the United Kingdom has rapid increase starting from year 2015 onwards. Fig. 18 presents a comparison of each renewable technology type percentage share in total installed REEPS, by country/entity. From that figure it can be seen that wind participation is by far the largest among all, from 55% in Germany to 77% in Portugal and it is followed by biomass (and lately biogas) with participation range from 12% in Germany to 24% in the United Kingdom. Solar participates with shares ranging from 5% in Portugal to 26% in Germany, while all other renewable sources take only small portion (around 5%). SEE region sees an increase starting from year 2013, but with very modest trend so far [9].

Fig. 17 Evolution of RES installed generation capacities for the period 2008-2017

Fig. 18 Comparative percentage of installed RES generation capacities per technology type for year 2017

For the purpose of deeper insight into present state of REEPS, Table 2 (installed generation capacities) and Table 3 (power generation mix) provides a detailed info about overall installed generation capacities and generation mix, by technology type and by country, for the year 2017.

Table 2: Installed generation capacities for year 2017 [GW]

Country	Nuclear	Fossil	Hydro			RES without hydro					SUM Capacity
			total	non-renew.	renew.	total	Wind	Solar	Bio-mass	Other	
SEE region	5.883	39.359	24.685	2.891	21.794	12.910	6.729	5.212	0.685	0.284	82.837
Germany	9.509	81.577	10.615	6.282	4.333	105.708	55.072	42.020	7.250	1.366	208.229
UK	9.248	46.144	3.821	0	3.821	33.349	18.350	12.900	2.098	0.001	92.562
Denmark	0	7.609	0.006	0	0.006	8.124	5.497	0.908	1.349	0.370	15.784
Portugal	0	0	7.193	0	7.193	6.204	5.090	0.490	0.624	0	13.397

Table 3: Electricity production by technology type for year 2017 [GWh]

Country	Nuclear	Fossil	Hydro			RES without hydro					SUM production
			total	non-renew.	renew.	total	Wind	Solar	Biomass	Other	
SEE region	46,400	141,331	50,670	2,535	48,135	28,211	15,776	7,412	3,338	1,685	266,611
Germany	72,155	312,912	25,870	6,379	19,492	186,371	103,378	35,518	40,607	6,868	597,309
UK	65,620	167,314	7,509	0	7,509	71,904	43,970	10,450	17,416	68	312,347
Denmark	0	8,794	18	0	18	20,623	14,754	789	3,670	1,410	29,435
Portugal	0	31,566	7,339	1,802	5,537	15,639	11,973	853	2,813	0	54,544

8 Conclusions

A fundamental aspect of the energy revolution concerns the continuously increasing contribution of renewables in the electricity generation mix. Renewable electric energy power sources inject new features into the electric power systems, the successful integration of which is of utmost importance for their effective operation. Those include significant generation fluctuations with limited predictability, concentration in new remote areas without adequate existing transmission options, and almost negligible variable costs. The challenges that have yet to be addressed in order for the declared sustainability goals to be achieved include enhancement of decoupling of economic activity with the produced CO₂ emissions, adaptation of large and vertically integrated utilities to newly established business models, elimination of price distortion in power markets in order to send the appropriate price signals to markets participants and potential investors for the required investments, further reinforcement of the flexibility potential in the power generating fleet, further exploitation of electricity trading in the context of the pan-European internal energy market, as well as gradual decrease in the electricity bills paid by end consumers to become even more affordable.

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