OPTIGRID project

Deliverable 4.2 - Development of Case Study C - Market splitting scenarios in MIBEL

July 2021

Project Name: OPTIGRID	Document Number: D4.2	Revision: V17	Date: 2021-07-16
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Revisions in this document: V17 - first version draft for customer approval / comment (2021-07-16)			

*Project PTDC/EEI-EEE/31711/2017 submitted under the call for tenders (AAC) No. 02 / SAICT / 2017, and funded by national funds through the budget of the Foundation for Science and Technology (FCT).

Executive Summary

The work presented in this deliverable was developed by R&D NESTER and LNEG as part of the R&D activities of the project OPTIGRID - *Methodology for the dynamic line rating analysis and optimal management of power networks*.

This report presents the deliverable 4.2, which consists of the definition of the last case-study of the project: *Case Study C - Market splitting scenarios in MIBEL.* As well as a brief explanation of the other two Case Studies defined in the deliverable 4.1.

The list and location of the tie-lines responsible for the energy flow between Portugal and Spain are presented. The monthly nominal power capacity of each tie-line is quantified, using the limits from the Portuguese and Spanish Transmission System Operators (TSOs), *Rede Eléctrica Nacional* (REN) and *Rede Eléctrica de España* (REE), respectively.

Market splitting is analysed in Case-study C. Thus, it is presented a brief description about how market splitting works as well as some statistical information from 2016 to 2020.

Based on the available capacity of the tie-lines, taking in consideration the possible flexibility of the Portuguese limits using a Dynamic Line Rating (DLR) approach, the maximum available capacity for DLR is presented. This maximum value takes in consideration that the REE limits are not exceeded.

The amount of interchange capacity available in the Iberian market has reduced the market split below 5% of the total of hours during the year under analysis in this project (2019). The research work expected to be performed within the Case Study C, based on the available capacity for DLR related to the tie-lines from Portugal and Spain, will try to quantify the amount of reduction in the market split occurrences in the Iberian electricity market.

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1. Introduction

The present deliverable was developed by R&D NESTER with the collaboration of LNEG as part of the OPTIGRID project R&D activities *Task 4 - Development of RES Case Studies*. This report presents the deliverable 4.2, which mainly focus on the definition of the last case-study of the project: *Case Study C - Market splitting occurrence in MIBEL due to congestion in interconnections.*

This deliverable revisit the main details of Case Studies A and B defined in the deliverable 4.1 [1], namely, the motivation beyond the scope of each Case Study as well as some specifications and data of the RNT gathered for the regions under study.

This case study is related to the occurrence of market splitting scenarios in the Iberian electricity market (MIBEL) that is expected to be reduced through the use of OPTIGRID tools thus contributing to a more sustainable and energy-efficient economy. Concretely, the competitiveness of MIBEL is highly dependent on available thermal capacity in transmission tie-lines connecting the Portuguese and Spanish power systems. In addition, the market splitting occurrence has a significant influence on electricity market prices with a negative impact for the end-user customers.

Therefore, the last case-study of this project consists in the study of the congestion verified in interconnection lines between Portugal and Spain. These lines are illustrated in Figure 1.

The System Operator can take advantage from using the meteorological variables from the operational wind and solar forecast tools, such as wind speed and direction, solar irradiation and ambient temperature, to predict the dynamic line rating capacity of overhead power lines.

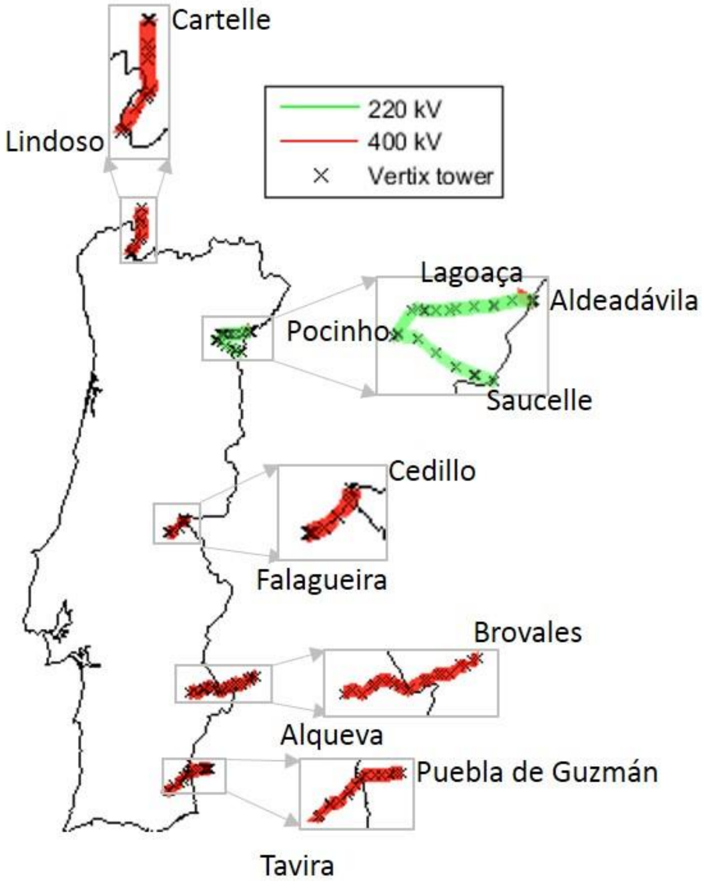


Figure 1 - Portugal and Spain interconnection lines location [2].

This deliverable also presents the hours in which occurred market splitting in the Iberian Electricity Market and the evolution of the number of hours in which the market split occurred throughout 2017 until 2019.

For confidentiality reasons, only non-confidential information are presented in this report. Nevertheless, within the scope of this project, all the data needed to apply (and validate) the mathematical models under development were obtained.

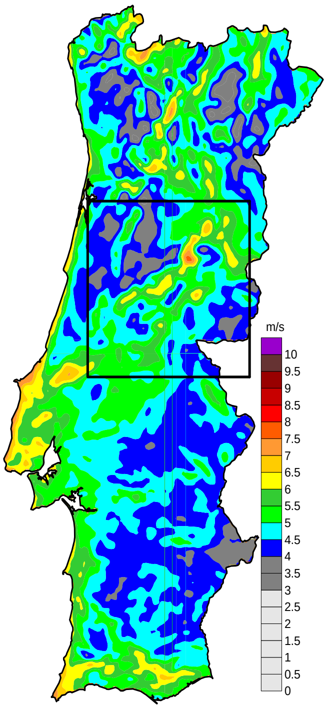
2. Development of RES Case Studies

In this deliverable, the last Case Study of the project will be defined, namely scenarios in Iberian Electricity Market with market splitting, as well as the description of the previously defined study cases in D4.1 of the OPTIGRID project.

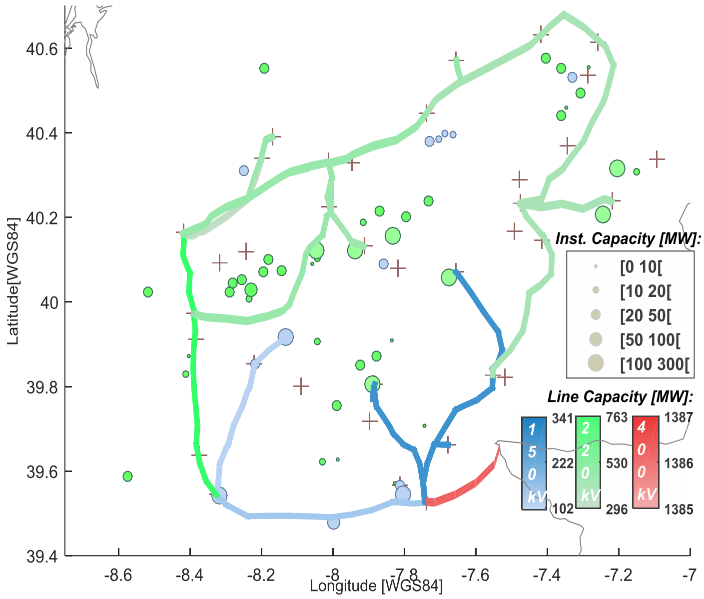
2.1. Case Study A & B – Regions predominantly with wind and PV distributed generation

The first Case Study defined is situated in the centre of Portugal, named *Pinhal Interior* region, illustrated in Figure 2. The location was selected due to its excellent orographic conditions and resource availability.

The transmission lines heat loss is directly related with the wind conditions at each time due to the effect of convective heat transfer (cooling effect). This wind effect is relevant on the thermal balance of overhead conductors, improving their transmission capacity in periods of high wind power generation. Therefore, this Case Study was selected to assess the dynamic line rating impact in a region with a high penetration of wind generation.



a)

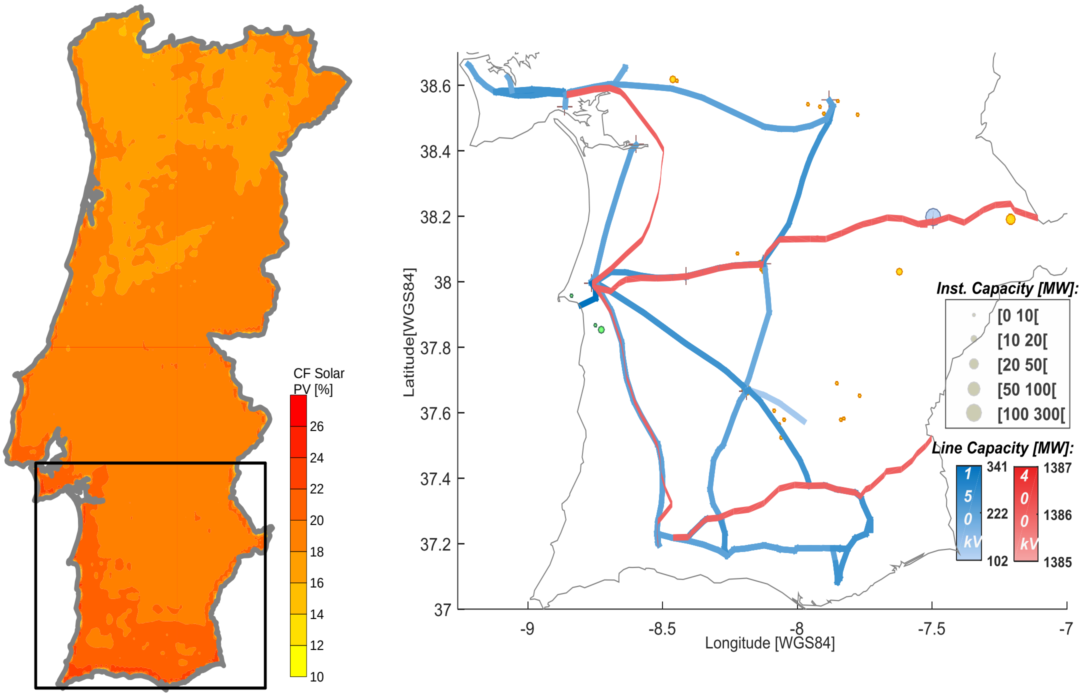


b)

Figure 2 - Case Study A region and nominal capacity of the RES generation [2].

Figure 2 illustrates the location and nominal capacity of the Renewable Energy Sources (RES) generation of the Case Study A - blue circles represent hydro generation and green circles represent wind generation. The symbol "+" represents the substations. The blue, green and red lines represent the line capacity during the winter for 150 kV, 220 kV, and 400 kV, respectively.

The second selected Case Study aims to assess the DLR impact in a region with very high solar potential and limited grid capacity. The extreme environmental conditions expected in this region in some periods of the year, may originate a real transmission capacity lower than the one established by the DLR methodology, illustrated in Figure 3.



a) *b)*

Figure 3 - Case Study B region and nominal capacity of the RES generation [2].

Figure 3 depicts the Case Study B region under analysis and characterizes the grid and the installed RES power capacity - blue circles represent hydro generation, yellow circles represent solar generation and green circles represent wind generation. The symbol "+" represents the substations. The blue, green and red lines represent the line capacity during the winter for 150 kV, 220 kV, and 400 kV, respectively.

2.2. Case Study C – Market splitting scenarios in MIBEL

This Case Study is related to the occurrence of market splitting scenarios in MIBEL that can be reduced using the tools to be developed in the OPTIGRID project. In 2018, 5.2% of the time MIBEL operated under market splitting, leading to a less cost-effective use of generation units. Therefore, the constant activation of market splitting mechanisms constitutes a great Case Study to apply DLR to assess the potential of such techniques in reducing the numbers of hours with market splitting.

2.2.1. Characterization of the interconnection between the electric systems of Portugal and Spain

For a proper operation of the electrical system is essential to strengthen international interconnections. Having more electricity capacity to exchange with neighbouring countries provides greater security of supply and increases efficiency between neighbouring systems and a better integration of renewable energy. In Figure 4 [3] is presented the approximate location of the lines, as well as the names of the substations that connect to the lines in Spain. The red colour means a voltage level of 400kV and the green colour 220kV. It is possible to observe that the interconnection lines are mostly in the north region of Portugal, especially in the International Douro region.

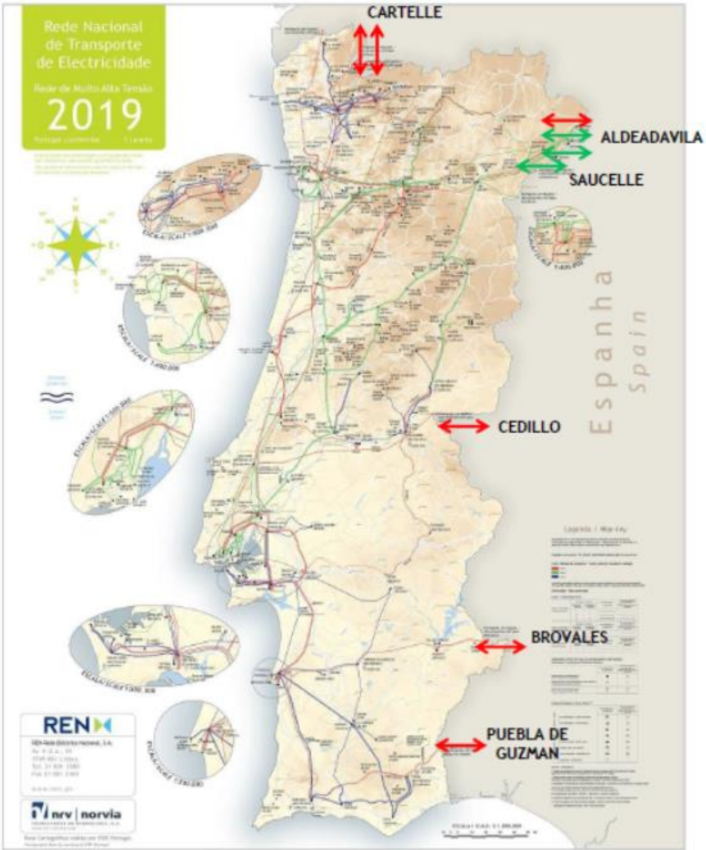


Figure 4 - Approximate locations of the interconnection lines between Portugal and Spain (green 220kV, red 400kV) [3].

Figure 4 depicts the interconnection lines between Portugal and Spain, one can observe in red the 400 kV tie-lines and in green the 220 kV tie-lines. There are other tie-lines with lower voltage, namely 130 kV, 60 kV, 15 kV. However, they are not considered in this study.

In the next figure, Figure 5, the import and export energy flows registered in 2019 are presented. It demonstrates that the lower voltage tie-lines (namely the 130 kV *Lindoso-Conchas*, 60 kV *Elvas-Badajoz* and 15 kV *Vila Verde de Ficalho-Rosal de la Frontera*) may be excluded from this Case Study. This fact is due to the non-existent physical exchanges verified in these interconnection lines, they were excluded in the analyses of this deliverable.

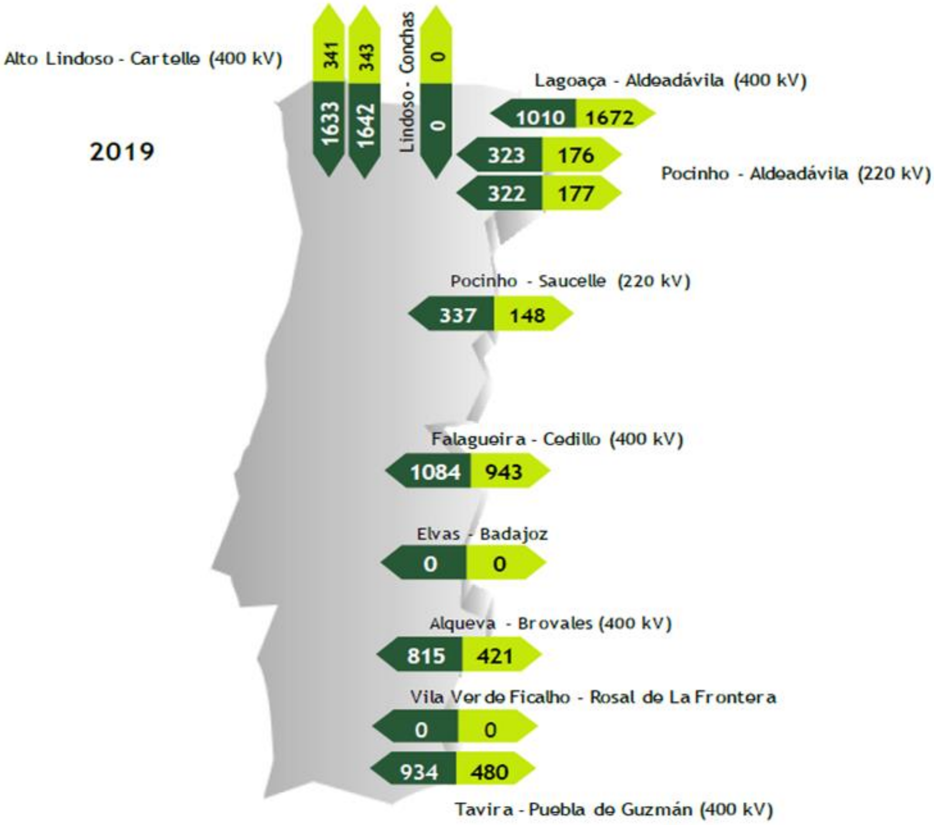


Figure 5 - Energy flow of all interconnection lines between Portugal and Spain in 2019 [4].

The energy flow data registered in 2019, is indicated in Table 1, confirming the option to exclude the low voltage tie-lines due to the non-existent physical exchanges verified in these lines.

Table 1 - Energy flow of all interconnection lines between Portugal and Spain in 2019 [4].

Tie-line name	Designation	Voltage level [kV]	Import [GWh]	Export [GWh]
Alto Lindoso-Cartelle 1	LAL.CTL1	400	1,633	341
Alto Lindoso-Cartelle 2	LAL.CTL2	400	1,642	343
Lindoso-Conchas (*)	LLS.CCH	130	0	0
Lagoaça-Aldeadavila	LLGC.AAV	400	1,010	1,672
Pocinho-Aldeadavila 1	LPN.AAV1	220	323	176
Pocinho-Aldeadavila 2	LPN.AAV2	220	322	177
Pocinho-Saucelle	LPN.SLL	220	337	148
Falagueira-Cedillo	LFR.CLL	400	1,084	943
Elvas-Badajoz (*)	LELV.BDJ	60	0	0
Alqueva-Brovales	LAV.BVL	400	815	421
Vila Verde de Ficalho-Rosal de la Frontera (*)	LVVF.RLF	15	0	0
Tavira-Puebla de Guzmán	LTVR.PGN	400	934	480

*due to the non-existent physical exchanges verified in these interconnection lines, they were excluded in the analyses of this deliverable.

The tie-lines with zero net transfer will be excluded since they have no impact on MIBEL outcomes since they are at the distribution grid level and are open ended.

The length of each line is described in Table 2. It presents the total length of each line, the length located in the Portuguese territory as well the length located in the Spanish side.

Table 2 - Interconnection lines total length.

Tie-line name	Voltage level	Length PT	Length ES	Total Length	Length PT
	[kV]	[km]	[km]	[km]	[%]
Alto Lindoso-Cartelle 1	400	1.118	47.680	48.798	2.3%
Alto Lindoso-Cartelle 2	400	1.118	47.680	48.798	2.3%
Lagoaça-Aldeadavila	400	4.687	1.537	6.224	75.3%
Pocinho-Aldeadavila 1	220	41.129	0.378	41.507	99.1%
Pocinho-Aldeadavila 2	220	41.310	0.378	41.688	99.1%
Pocinho-Saucelle	220	30.222	0.100	30.322	99.7%
Falagueira-Cedillo	400	26.151	0.245	26.396	99.1%
Alqueva-Brovales	400	39.899	40.970	80.869	49.3%
Tavira-Puebla de Guzmán	400	33.806	25.170	58.976	57.3%

In Table 3, a characterization of the interconnection lines between Portugal and Spain is made, as well as the reference ambient temperature of these lines for winter and summer assumed by the Portuguese transmission system operator.

Table 3 - Characterization of the interconnection line between Portugal and Spain.

Tie-line name	Voltage level	Number Phase C	Conductor type		Cable Max. Temp.		Amb. Temp. Winter	Amb. Temp. Summer
	[kV]	#	PT	ES	PT [ºC]	ES [ºC]	[ºC]	[ºC]
Alto Lindoso-Cartelle 1	400	2	Rail	Rail	85	85	15	29
Alto Lindoso-Cartelle 2	400	2	Rail	Rail	85	85	15	29
Lagoaça-Aldeadavila	400	2	Rail	Rail	85	85	15	32
Pocinho-Aldeadavila 1	220	1	Zebra	Lapwing	85	85	15	32
Pocinho-Aldeadavila 2	220	1	Zebra	Lapwing	85	85	15	32
Pocinho-Saucelle	220	1	Zebra	Zebra	85	85	15	32
Falagueira-Cedillo	400	2	Zambeze	Zambeze	85	70	15	33
Alqueva-Brovales	400	2	Rail	Rail	85	85	15	35
Tavira-Puebla de Guzmán	400	2	Rail	Rail	85	85	15	32

Both transmission system operators have their own criteria regarding the type of cable used. For instance, *Rede Eléctrica Nacional* uses Zebra for the 220 kV and Zambeze for the 400 kV. *Rede Eléctrica de España* uses also Zebra for the 220 kV and Rail for the 400 kV. REE used the new type Lapwing for the upgrade of the 220 kV double circuit tie-line from Pocinho to Aldeadavila.

For each new line, REN and REE agree to use the same conductor for both countries. The most common conductor used is the Rail since has more steel and it is more secure.

As can be seen in Table 3, the *Falagueira-Cedillo* tie-line have different maximum conductor temperatures, 85º and 70º in Portugal and Spain, respectively. The 70ºC exception on the Spanish side does not create any thermal restriction. This is true given the fact that the last span is only 245 meters long and there are no physical obstacles below this section of the line.

In Figure 6, it is presented the Portuguese map where depending on the location of the overhead lines, their summer reference temperature will vary. For the remaining seasons, this spatial dependency is not applicable.

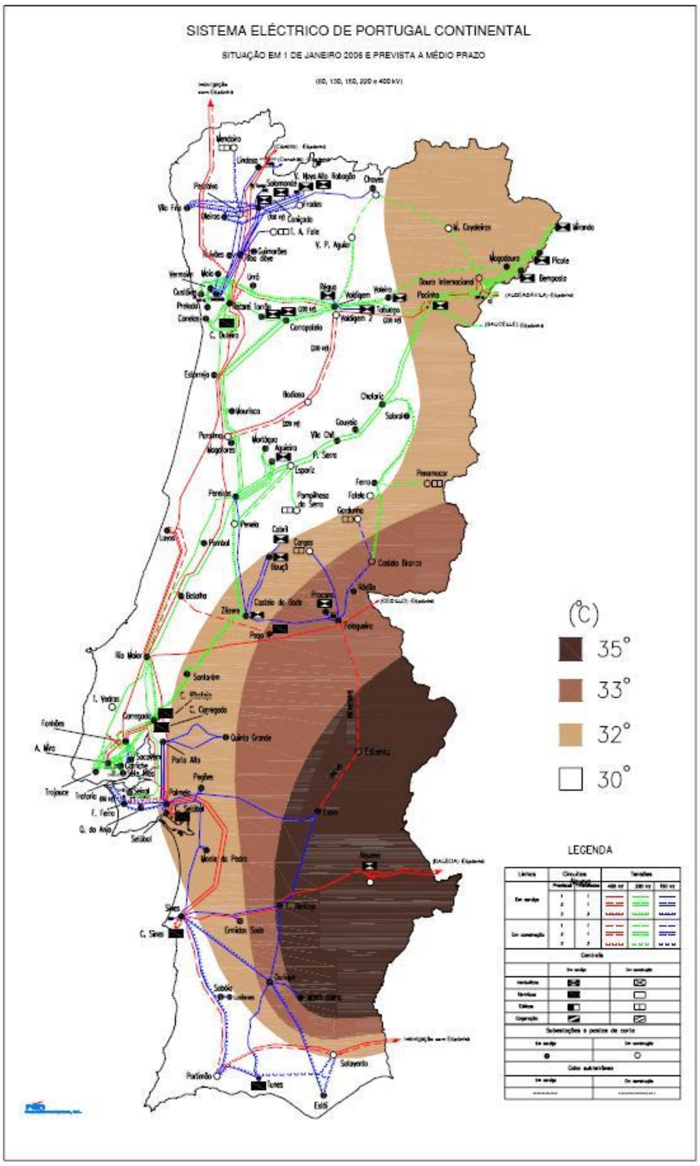


Figure 6 - Summer tie-line reference temperature map [5].

Most tie-lines are in the 30ºC, 32ºC, 33ºC or 35ºC area. The exceptions are the tie-lines of *Alto Lindoso – Cartelle*, which are located mainly in Spain, and the reference temperature of Spain for that region, 29ºC, was adopted.

The thermal capacity of each tie-line relies on the reference ambient temperature for each month in Portugal, and corresponding to each season in Spain as can be observed in Table 4 for the a generic interconnection.

Table 4 - Portuguese interconnection line reference ambient temperature compared to Spanish seasons.

Months	PT Temp. Amb. [ºC]	ES Seasons
JAN	15	Winter
FEV	15	Winter
MAR	15	Winter
ABR	20	Spring
MAI	25	Spring
JUN	30	Summer
JUL	30	Summer
AGO	30	Summer
SET	30	Summer
OUT	25	Autumn
NOV	20	Winter
DEZ	15	Winter

For Portugal, since winter reference ambient temperature is 15ºC and summer reference ambient temperature is 30ºC, two months transition using the 20ºC and 25ºC reference ambient temperature are used.

For Spain, each season does not last 3 months, as in Portugal, but are adjusted to maximize capacity using 5 months for winter, and minimize risk using 4 months for summer. The remaining months are used for the transition season months, with 2 months for spring and only one for autumn.

The next Figure 7, show the reference ambient temperature alignment from REN with the seasons from REE, in a monthly basis.

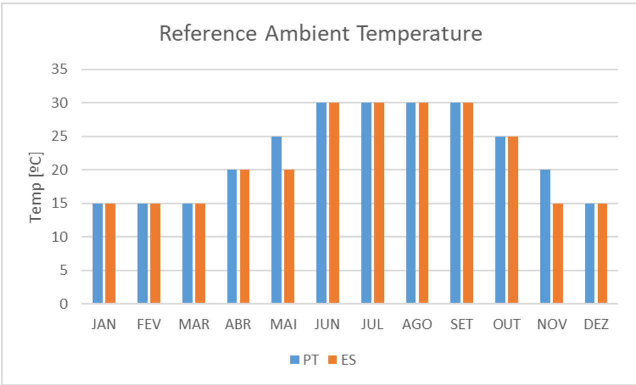


Figure 7 - Reference ambient temperature of interconnection lines [REN&REE].

The annual net transfer results shown in Table 1 are complemented with Figure 8, where the available hourly import and export capacity in the interconnection lines during 2018 are presented, as well as the hourly transferred import and export values.

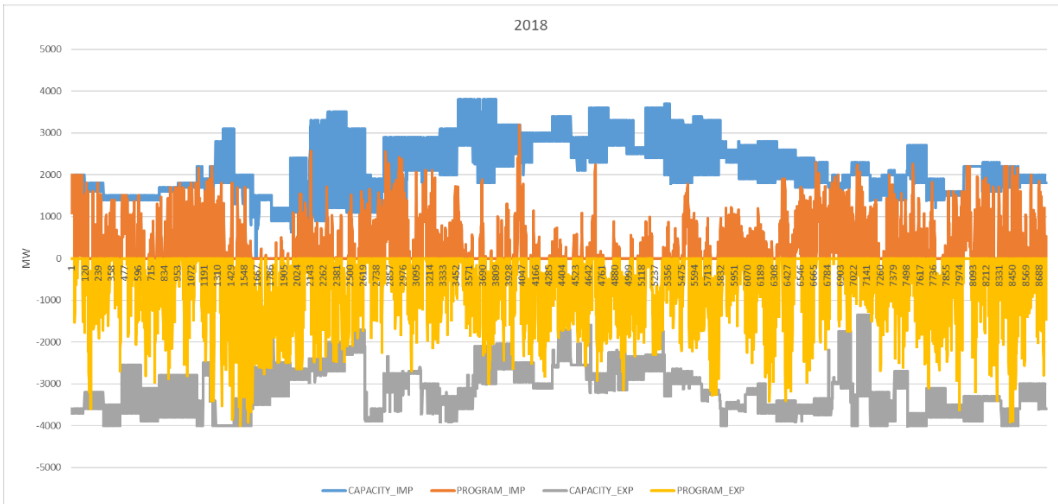


Figure 8 - Import and Export available capacity and their final program [REN].

During 2018, in Portugal the year proved to be mainly an exporter year, as can be seen during the summer months. March was the month that registered the highest export balance with total of 876 MWh being exported. On the other hand, October was the month where the highest import balance was registered, with a total of 151 MWh being imported [3].

The capacity limitations existing on the Portuguese side and on the Spanish side can be seen in Table 5, where it is shown the total of hours that the capacity was limited and the average limited power (MW). From the analysis of this table, it is verified that the Portuguese side limited more the import capacity and the Spanish side, until 2018, limited more export capacity.

Table 5 - Capacity limitation by the TSOs [3].

	IMPORTAÇÃO E → P										EXPORTAÇÃO P → E									
	2019		2018		2017		2016		2015		2019		2018		2017		2016		2015	
	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE	REN	REE
Número de horas	7785	810	8664	96	7360	1238	8222	319	7040	174	6424	1702	3920	4393	2774	5296	2495	5895	2274	5768
Número de horas (%)	89	9	99	1	84	14	94	4	80	2	73	19	45	50	32	60	29	67	26	66
Potência média limitada (MW)	1146	331	1324	39	838	132	770	374	699	335	376	412	280	539	177	542	228	1039	312	619

In Figure 9, it is presented the monthly percentage of the hours where the use rate of the interconnection capacity was above 95%.

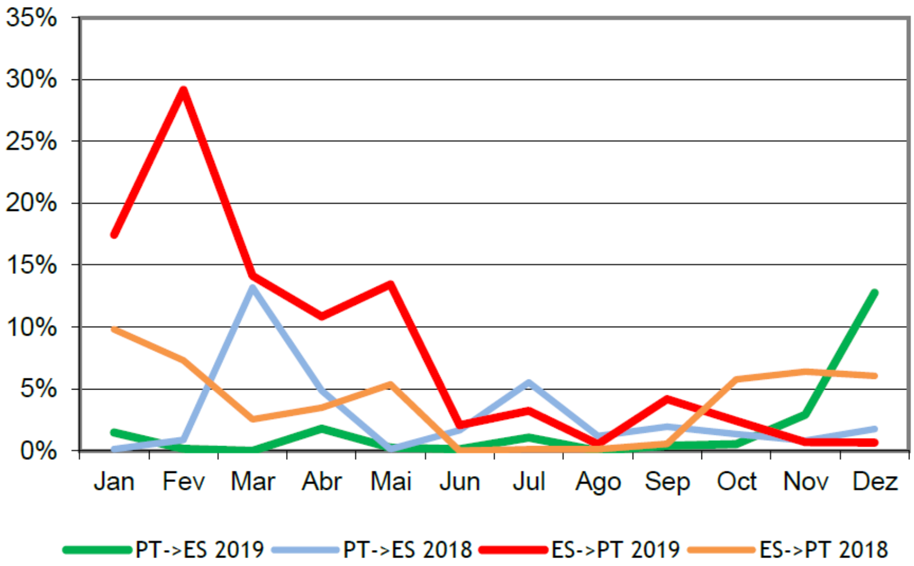


Figure 9 - Percentage of time that the interconnection capacity use rate is above 95% [3].

Figure 9 compares the values between 2018 and 2019. It shows a slight increment of the interconnection capacity use rate above 95%, during 2019 in the PT-ES direction, due to the increase of precipitation during the months of January to May. During summer months, the verified use rate values are related to the work done in some of the grid elements, reducing the interconnection capacity values, and consequently increasing the use rate percentage.

With regard to the verified imports (ES-PT direction), the months with the highest use rate of the interconnection capacity coincides with the months with lowest available capacity, caused by the traffic verified in the 400kV interconnection lines, *Alto Lindoso-Cartelle 1* and *2*.

This increment of the use rate of interconnection lines also coincides with an increase of the amount of available interconnection capacity. Its evolution from 2015 to 2019 is illustrated in the figures below.

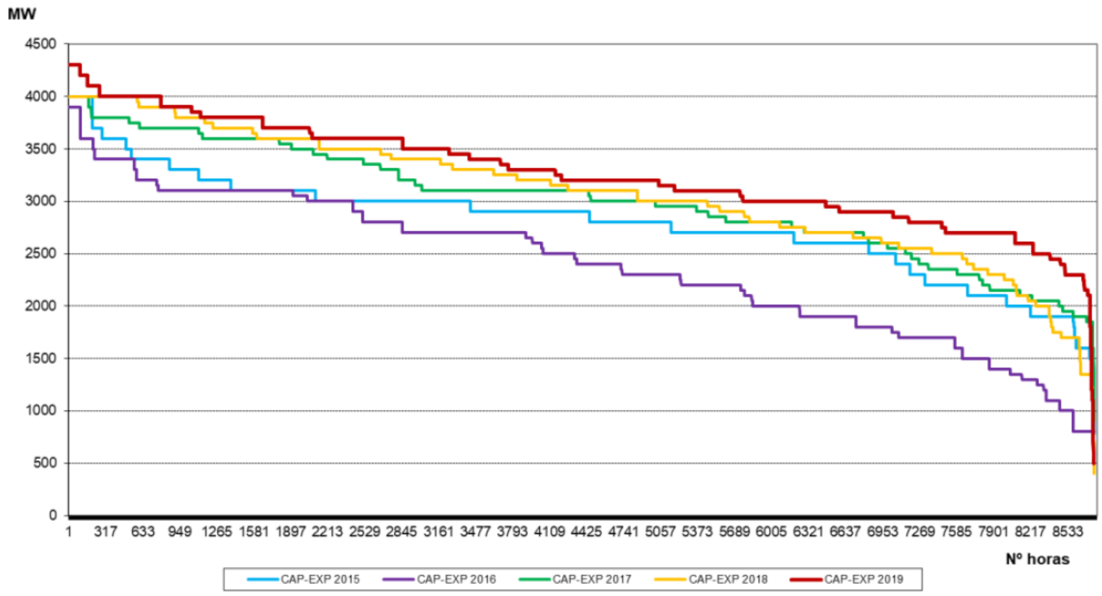


Figure 10 - Interconnection export capacity from 2015 to 2019 - PT-ES [3].

The export capacity in 2019, depicted in Figure 10, faced a growth tendency for the second year in a row, due to the contribution of a hydrologically favorable year in conjunction with the new hydro production centers. The low values registered in this year were caused by the outage periods of the grid elements.

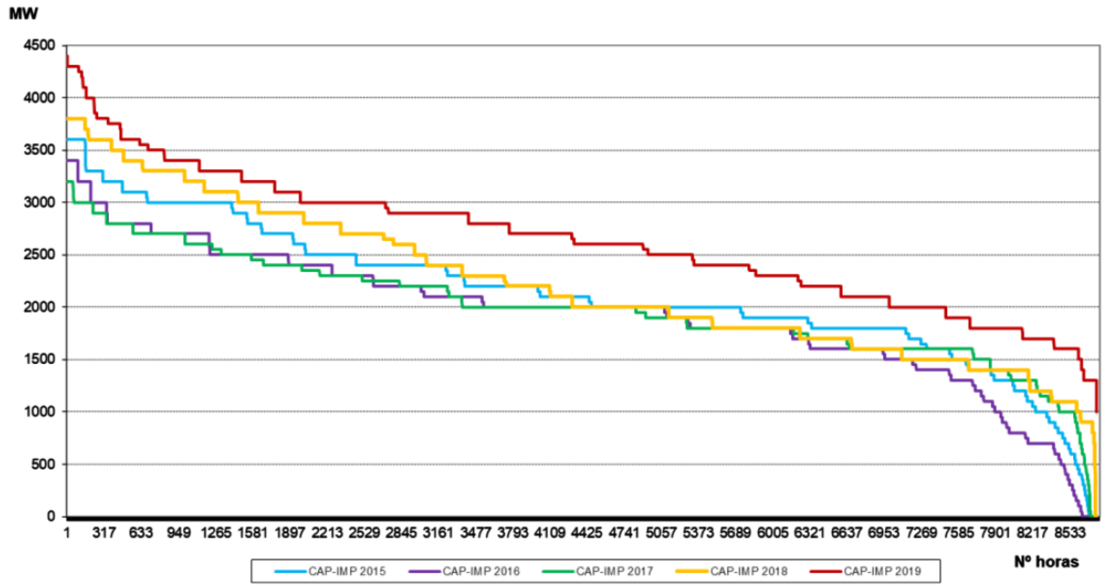


Figure 11 - Interconnection import capacity from 2015 to 2019 - ES-PT [3].

The import capacity in 2019, depicted in Figure 11, increased drastically due to the above average interconnection capacity values verified during the spring/summer.

In 2019, as in previous years, it was necessary to occasionally reduce the commercial capacity of the interconnections after the completion of the day-ahead market, as a way to guarantee the levels of generation reserve while maintaining the necessary reserve capacity for the system.

In Figure 12 and Figure 13, it is shown the impact of this reserve guarantee in the interconnection capacity after the day-ahead market, demonstrating the values before and after the closure of this market.

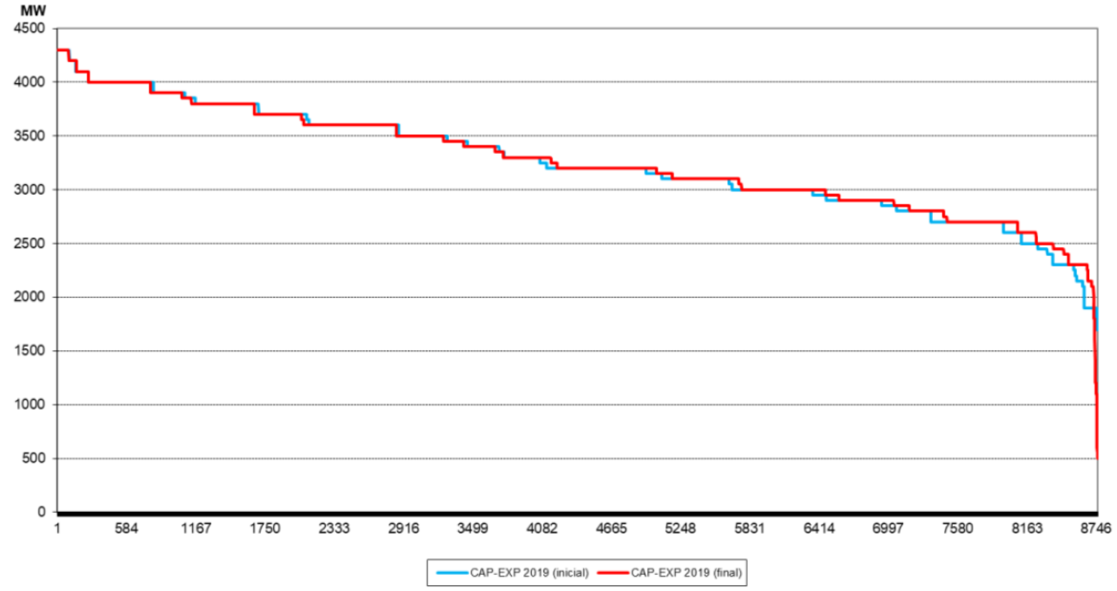


Figure 12 - Interconnection export capacity in 2019 - PT-ES (reserve effect) [3].

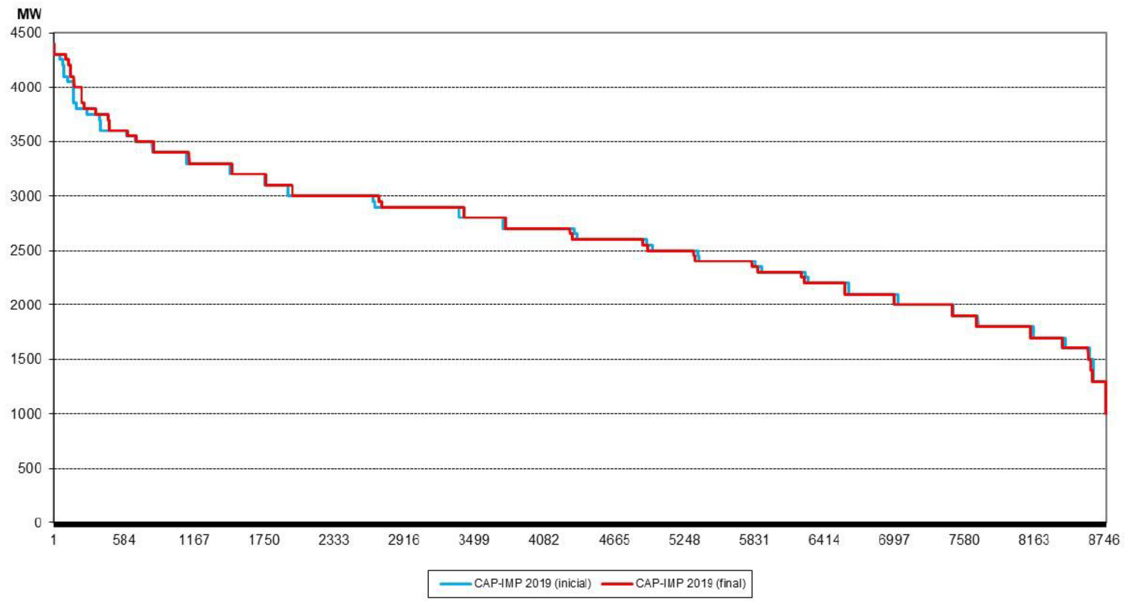


Figure 13 - Interconnection import capacity in 2019 - ES-PT (reserve effect) [3].

2.2.2. Market splitting in MIBEL

The Iberian Electricity Market resulted from the cooperation between the Portuguese and Spanish Governments with the aim of promoting the integration of both countries' electrical systems. The interconnections between the Portuguese and Spanish electrical system play an essential role for the efficient well-functioning of MIBEL, since whenever the commercially available interconnection capacity does not support the cross-border energy flow, Portugal and Spain are obliged to split their markets into two different areas and define their own prices. This mechanism is also known as **market splitting**.

During 2018, there was market splitting in 5,2% of the total of hours, representing 456 hours during that year [6], depicted in Figure 14. It can be noted that the Hour 9 was the most common time of the day where the market splitting occurred.

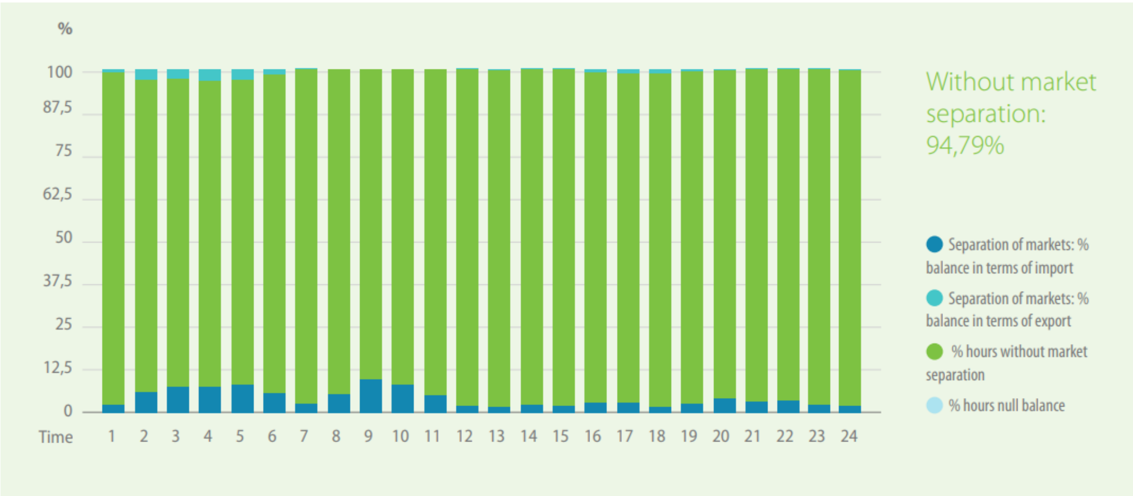


Figure 14 - Percentage of hours with market splitting in 2018 [6].

Figure 15 presents the evolution of monthly prices in Portugal and Spain and their market splitting time during 2017 and 2018.

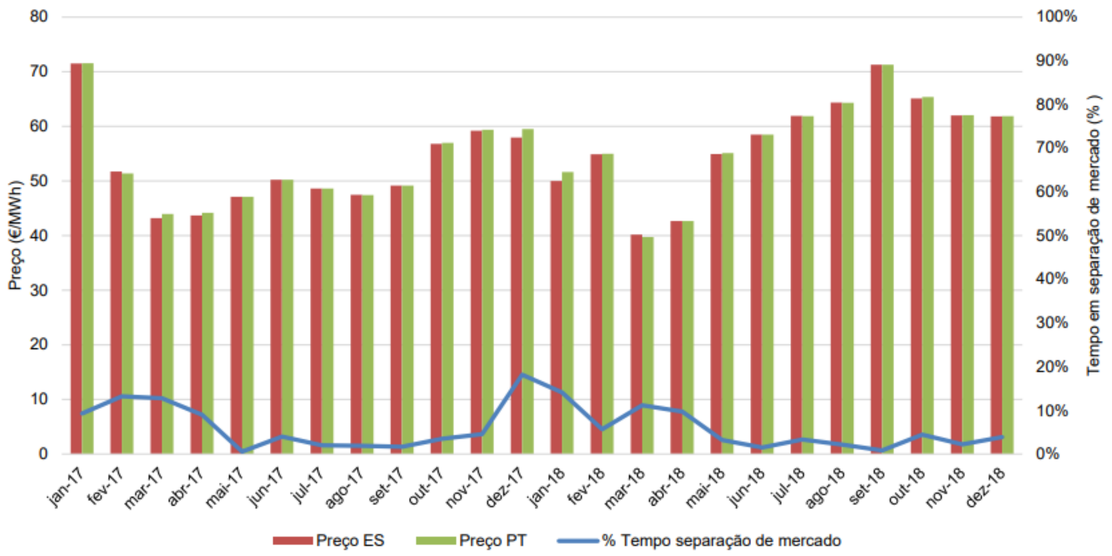


Figure 15 - Monthly average prices and market splitting time percentage in 2017 and 2018 [7].

In 2018 the average price in Portugal was 57.45 €/MWh, representing an increment of 9% of the registered price in 2017 (52.48 €/MWh) [7]. This variation was mainly caused by the favourable hydrological year in which increased the hydro power generation. It can also be noted that the number of hours with market splitting time in 2018 decreased when comparing to the previous year.

To better complement Figure 15, the following Figure 16 a) and b) represent the difference in the average market prices registered in the interconnection lines during 2018 and 2019, respectively. This difference is calculated by the subtraction of the Portuguese daily market price with the Spanish daily market price.

a) b)

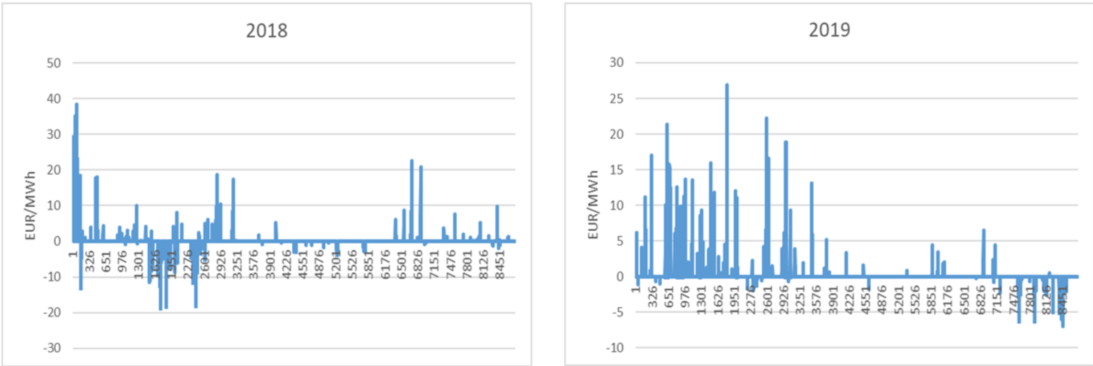


Figure 16 - Market price differences registered in a) 2018 and b) 2019 [REN].

In Figure 17 [8], it is shown the final interchanged capacity and usage from 2016 until 2020, the periods where it was verified congestion in the grid and the periods where occurred market splitting in MIBEL.

	2016		2017		2018		2019		2020	
	IMP	EXP	IMP	EXP	IMP	EXP	IMP	EXP	IMP	EXP
Capacity [MW]										
Daily Market Average	1 935	2 392	1 996	3 005	2 221	3 096	2 636	3 277	2 977	2 960
Average	1 928	2 391	2 000	3 016	2 230	3 050	2 619	3 273	2 970	2 925
Utilization [%]	12%	34%	18%	22%	15%	21%	31%	13%	25%	19%
Final Program [GWh]	**1 972**	**7 056**	**3 071**	**5 756**	**2 996**	**5 650**	**7 035**	**3 640**	6 397	4 942
Intraday and Daily Market	1 796	7 020	2 915	5 715	2 898	5 623	6 964	3 572	6 231	4 837
Weighted Price [€/MWh]	*39.10*	*39.10*	*49.70*	*55.20*	*51.80*	*57.60*	*43.30*	*44.70*	*26.60*	*37.40*
Coordinated Balance Actions	0	0	0	2	1	1	2	3	0	14
Total Reserve	176	36	156	39	98	26	69	65	166	91
Periods with Congestion [%]	1%	7%	3%	2%	3%	2%	6%	1%	3%	3%
Periods with market Splitting [%]	8%		7%		5%		5%		4%	
PT Congestion Revenue [k€]	2 604		2 499		2 538		2 083		1 286	

Figure 17 - Interchange capacity exchange and usage evolution from 2016 until 2020 [8].

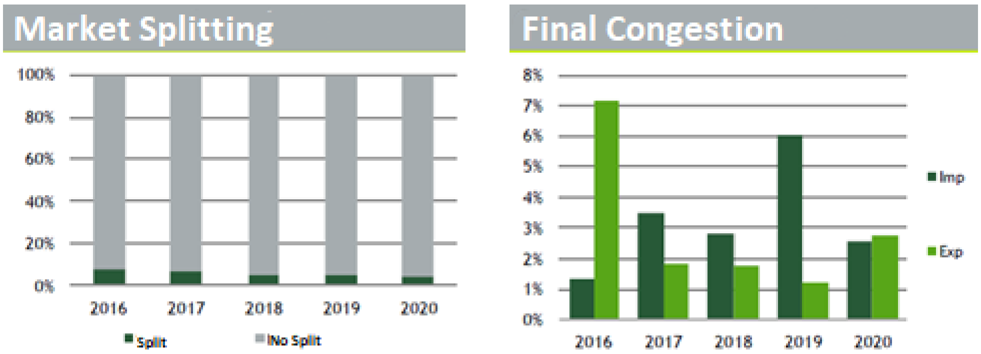


Figure 18 - Market splitting and congestion evolution from 2016 until 2020 [8].

The market splitting and congestion verified in MIBEL throughout the years 2016-2020 is depicted in [8], confirming a decreased tendency of the number of hours with market splitting, as well as of the congestion periods verified during these years.

3. Conclusions

Based on the monthly capacity of each tie-line, and comparing the possible expansion of the limits in the Portuguese section by using DLR to not exceed the Spanish limit imposed by REE, we can assess the monthly available capacity for the Case Study C. Individual analysis of each tie-line is available in *annex A*.

The capacities of each tie-line registered by REN and REE are shown in Table 6, where it is shown the monthly registered values as well the total sum for each month.

Table 6 - Tie-line monthly available capacities for DLR.

Tie-line	LAL.CTL	LLGC.AAV	LPN.AAV	LPN.SLL	LFR.CLL	LAV.BVL	LTVR.PGN	Sum
#	x2	x1	x2	x1	x1	x1	x1	
JAN	82	74	155	0	0	0	0	548
FEB	82	74	155	0	0	0	0	548
MAR	82	74	155	0	0	0	0	548
APR	7	0	132	0	0	0	0	278
MAY	75	58	149	0	0	0	0	506
JUN	23	41	146	0	0	0	0	379
JUL	23	41	146	0	0	0	0	379
AUG	23	41	146	0	0	0	0	379
SEP	23	41	146	0	0	0	0	379
OCT	5	0	129	0	0	0	0	268
NOV	147	139	172	12	0	0	0	789
DEC	82	74	155	0	0	0	0	548
Average	**55**	**55**	**149**	**1**	**0**	**0**	**0**	**462**

The sum of all the tie-lines capacities registered in the table above is illustrated in Figure 19, where April was the month with less available capacity and November was the month with the highest available capacity.

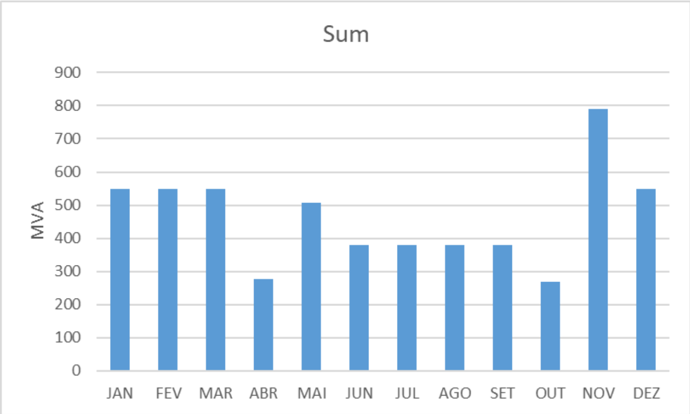


Figure 19 - Tie-line monthly available capacities for DLR [REN].

The available capacity for DLR related to the tie-lines from Portugal and Spain, are in a range of few hundreds of MVA, meaning that market split can be reduced partially but not entirely.

The amount of interchange capacity available in the Iberian market, has reduced the market split to less than 5% of the time during the year under analysis. The research work expected to be performed within the Case Study C, will focus on these periods to quantify the amount of reduction in the market split by using the tools under development in this project.

References

[1] R&D Nester, LNEG, "Development of RES Case studies A and B: regions predominantly with a) wind distributed generation and b) with photovoltaic distributed generation," Lisbon, 2019.

[2] LNEG, "D2.1 - Validation of transmission network and MIBEL data," OPTIGrid, 2020.

[3] REN - REDE ELÉCTRICA NACIONAL, S.A., "Caracterização das interligações," 2019. [Online]. Available: http://www.mercado.ren.pt/PT/Electr/ActServ/AcessoRedes/CaractRNT//BibRelAnoInter/CIRel2019.pdf .

[4] REN, "Caracterização Da Rede Nacional De Transporte Para Efeitos De Acesso À Rede," 2019. [Online]. Available: http://www.mercado.ren.pt/PT/Electr/ActServ/AcessoRedes/CaractRNT//BibRelAno/CaracterizacaoRNT2019.pdf.

[5] REN, "Temperatura ambiente de Verão e capacidade de carga nas linhas MAT," RL PRPR, Lisboa, 2006.

[6] OMICLEAR, "Integrated Group Report," 2018. [Online]. Available: https://www.omiclear.pt/system/files/2020-01/omi_informe_integrado_2018_eng_navegable_web_1.pdf.

[7] ERSE, "Relatório anual sobre mercados de electricidade e gás natural," 2018. [Online]. Available: https://www.ceer.eu/documents/104400/6693346/C19_NR_Portugal_NL.pdf/2d8c066b-c74d-87b8-e1dc-47a771d7340e.

[8] REN, “Mercado Eletricidade Sintese Anual 2016-2020,” 2021. [Online]. Available: http://www.mercado.ren.pt/PT/Electr/InfoMercado/PressReleases/BibInfAnual/MercadoEletricidadeSinteseAnual2016_2020.pdf.

Appendix A – Case Study C: Market splitting scenarios in MIBEL

Table for the 400 kV and 220 kV overhead interconnection lines: (Portuguese Side)

Table 7 - 400 kV and 220 kV tie-line electric parameters.

Voltage Level (kV)	Start Substation	End Substation	Cable Type	Line Length (km)	R (pu)	X (pu)	B (pu)
400	Alto Lindoso	Cartelle 1	Rail	1.1	0.0009	0.00952	0.28796
	Alto Lindoso	Cartelle 2	Rail	1.1	0.0009	0.00952	0.28796
	Lagoaça	Aldeadavila	Rail	4.7	0.00014	0.00127	0.0348
	Falagueira	Cedillo	Zambeze	25.7	0.0005	0.0056	0.1499
	Alqueva	Brovales	Rail	39.9	0.00165	0.01585	0.47306
	Tavira	Puebla de Guzmán	Rail	33.9	0.00128	0.01156	0.34479
220	Pocinho	Aldeadavila 1	Zebra	41.1	0.0063	0.03584	0.05497
	Pocinho	Aldeadavila 2	Zebra	41.4	0.00636	0.03628	0.05564
	Pocinho	Saucelle	Zebra	30.2	0.00481	0.0267	0.03939

Legend:

Voltage Level (kV)
Start Substation
End Substation
Cable Type
Line Length (km)
R (pu) - resistance
X (pu) - reactance
B (pu) - susceptance

Interconnection line capacity by tie-line

In the next tables and figures, the thermal capacity for each month is presented for REN (Portuguese side) and for REE (Spanish side).

The available slack for DLR is REE minus MIN, since the REE limit cannot be exceeded.

In cases were the limit is due to the current transformer (2000 A) of REN, there is no available capacity for DLR.

1. *Alto-Lindoso – Cartelle*

Table 8 - Tie-line LAL.CTL monthly capacities.

Month	REN	REE	MIN	Slack
JAN	1668	1750	1668	82
FEB	1668	1750	1668	82
MAR	1668	1750	1668	82
APR	1603	1610	1603	7
MAY	1535	1610	1535	75
JUN	1477	1500	1477	23
JUL	1477	1500	1477	23
AUG	1477	1500	1477	23
SEP	1477	1500	1477	23
OCT	1535	1540	1535	5
NOV	1603	1750	1603	147
DEC	1668	1750	1668	82

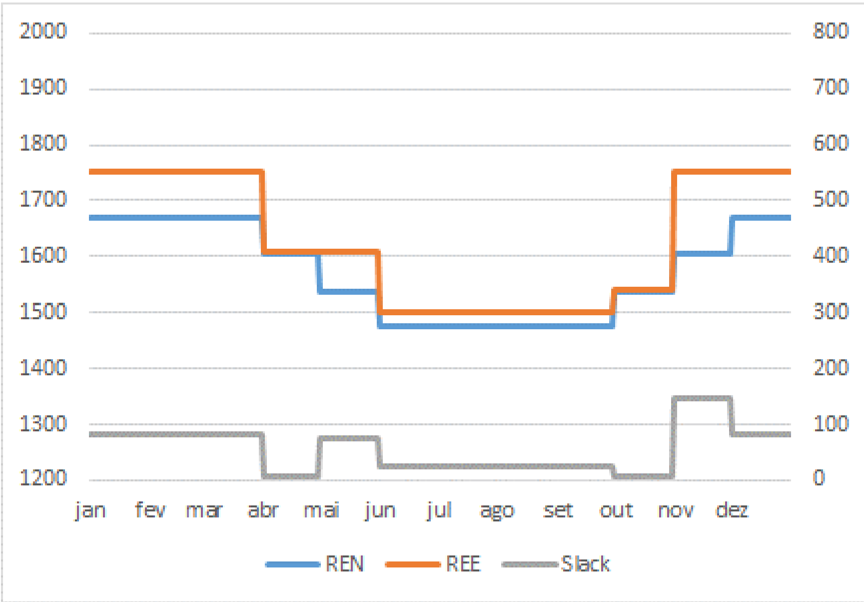


Figure 20 - Tie-line LAL.CTL monthly capacities.

2. *Lagoaça – Aldeadávila*

Table 9 - Tie-line LLGC.AAV monthly capacities.

Month	REN	REE	MIN	Slack
JAN	1706	1780	1706	74
FEB	1706	1780	1706	74
MAR	1706	1780	1706	74
APR	1641	1630	1630	0
MAY	1572	1630	1572	58
JUN	1469	1510	1469	41
JUL	1469	1510	1469	41
AUG	1469	1510	1469	41
SEP	1469	1510	1469	41
OCT	1572	1550	1550	0
NOV	1641	1780	1641	139
DEC	1706	1780	1706	74

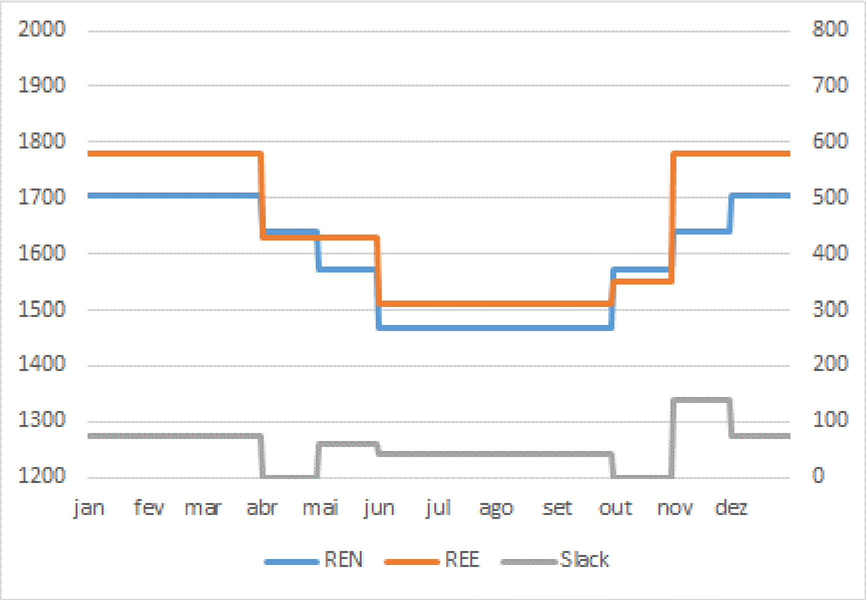


Figure 21 - Tie-line LLGC.AAV monthly capacities.

3. *Pocinho – Aldeadávila*

Table 10 - Tie-line LPN.AAV monthly capacities.

Month	REN	REE	MIN	Slack
JAN	435	590	435	155
FEB	435	590	435	155
MAR	435	590	435	155
APR	418	550	418	132
MAY	401	550	401	149
JUN	374	520	374	146
JUL	374	520	374	146
AUG	374	520	374	146
SEP	374	520	374	146
OCT	401	530	401	129
NOV	418	590	418	172
DEC	435	590	435	155

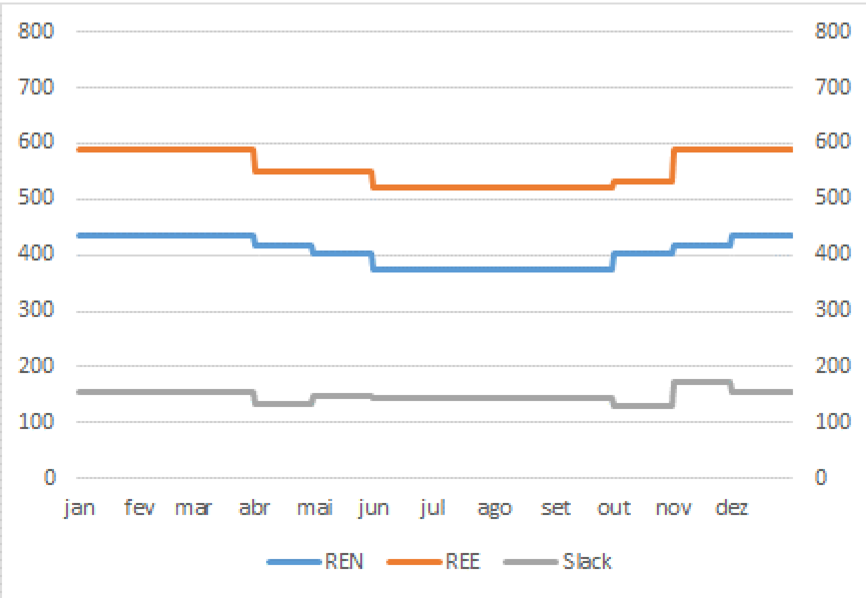


Figure 22 - Tie-line LPN.AAV monthly capacities.

4. *Pocinho – Saucelle*

Table 11 - Tie-line LPN.SLL monthly capacities.

Month	REN	REE	MIN	Slack
JAN	435	430	430	0
FEB	435	430	430	0
MAR	435	430	430	0
APR	418	390	390	0
MAY	401	390	390	0
JUN	374	360	360	0
JUL	374	360	360	0
AUG	374	360	360	0
SEP	374	360	360	0
OCT	401	370	370	0
NOV	418	430	418	12
DEC	435	430	430	0

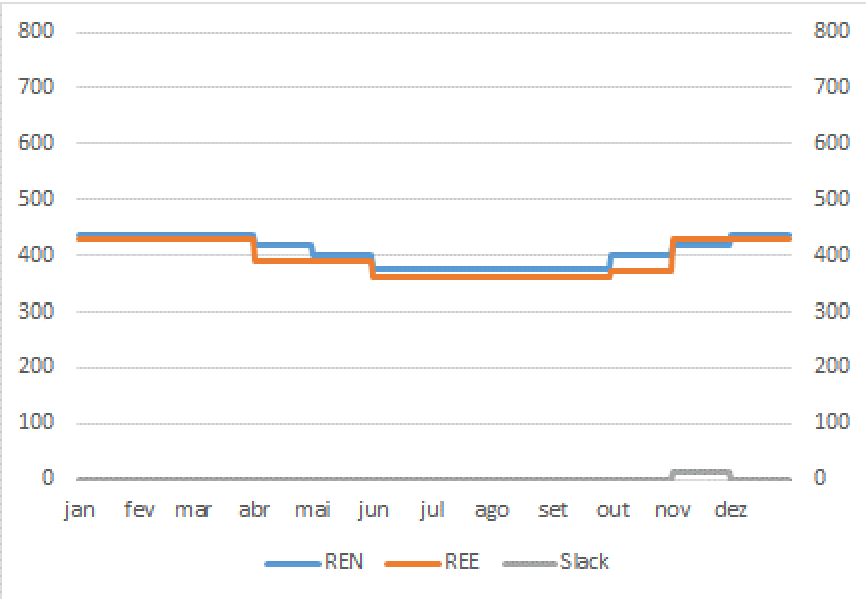


Figure 23 - Tie-line LPN.SLL monthly capacities.

5. Falagueira – Cedillo

Since the REN limits is due to the current transformer (2000 A), there is no available capacity for DLR.

Table 12 - Tie-line LFR.CLL monthly capacities.

Month	REN	REE	MIN	Slack
JAN	1386	1700	1386	0
FEB	1386	1700	1386	0
MAR	1386	1700	1386	0
APR	1386	1580	1386	0
MAY	1386	1580	1386	0
JUN	1386	1400	1386	0
JUL	1386	1400	1386	0
AUG	1386	1400	1386	0
SEP	1386	1400	1386	0
OCT	1386	1460	1386	0
NOV	1386	1700	1386	0
DEC	1386	1700	1386	0

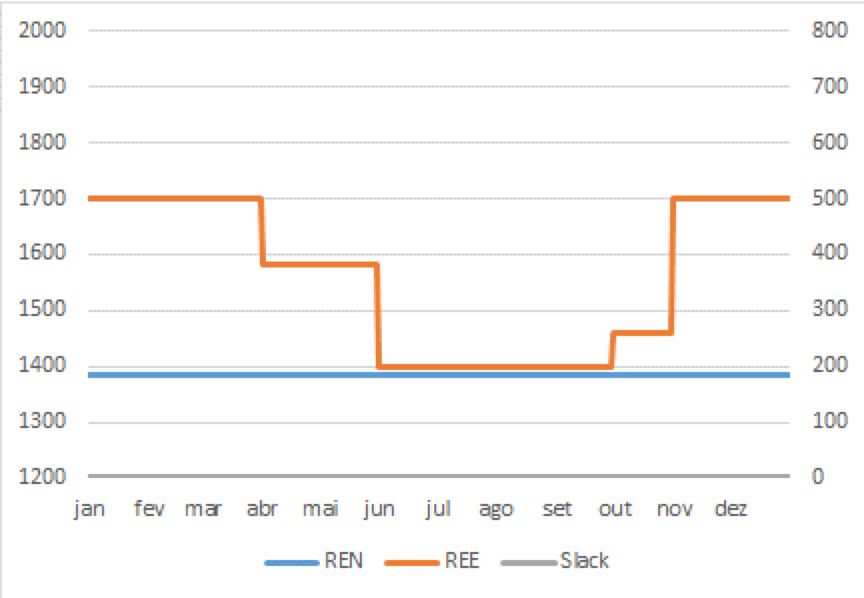


Figure 24 - Tie-line LFR.CLL monthly capacities.

6. *Alqueva – Brovales*

Since the REN limits is due to the current transformer (2000 A), there is no available capacity for DLR.

Table 13 - Tie-line LAV.BVL monthly capacities.

Month	REN	REE	MIN	Slack
JAN	1386	1640	1386	0
FEB	1386	1640	1386	0
MAR	1386	1640	1386	0
APR	1386	1450	1386	0
MAY	1386	1450	1386	0
JUN	1386	1280	1280	0
JUL	1386	1280	1280	0
AUG	1386	1280	1280	0
SEP	1386	1280	1280	0
OCT	1386	1350	1350	0
NOV	1386	1640	1386	0
DEC	1386	1640	1386	0

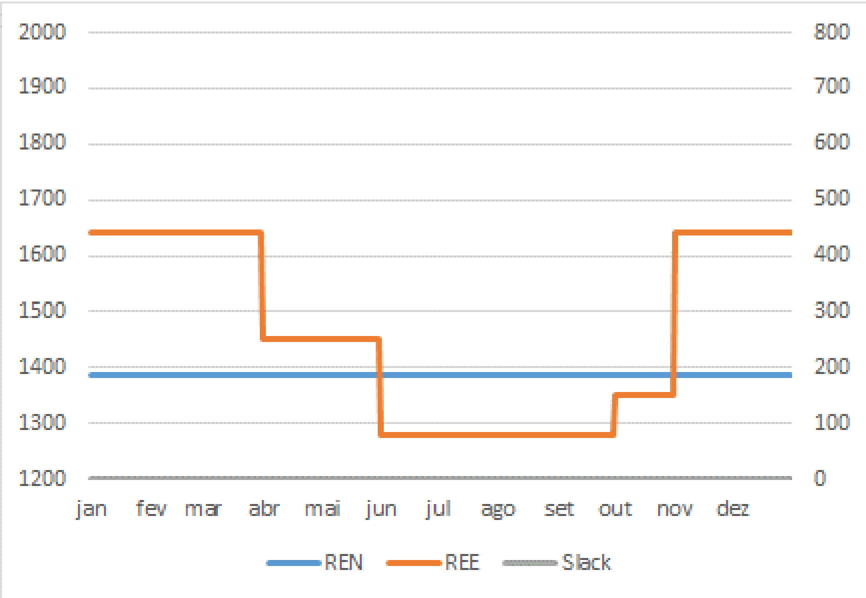


Figure 25 - Tie-line LAV.BVL monthly capacities.

7. Tavira – Puebla de Guzmán

Since the REN limits is due to the current transformer (2000 A), there is no available capacity for DLR.

Table 14 - Tie-line LTVR.PGN monthly capacities.

Month	REN	REE	MIN	Slack
JAN	1386	1700	1386	0
FEB	1386	1700	1386	0
MAR	1386	1700	1386	0
APR	1386	1550	1386	0
MAY	1386	1550	1386	0
JUN	1386	1450	1280	0
JUL	1386	1450	1280	0
AUG	1386	1450	1280	0
SEP	1386	1450	1280	0
OCT	1386	1480	1350	0
NOV	1386	1700	1386	0
DEC	1386	1700	1386	0

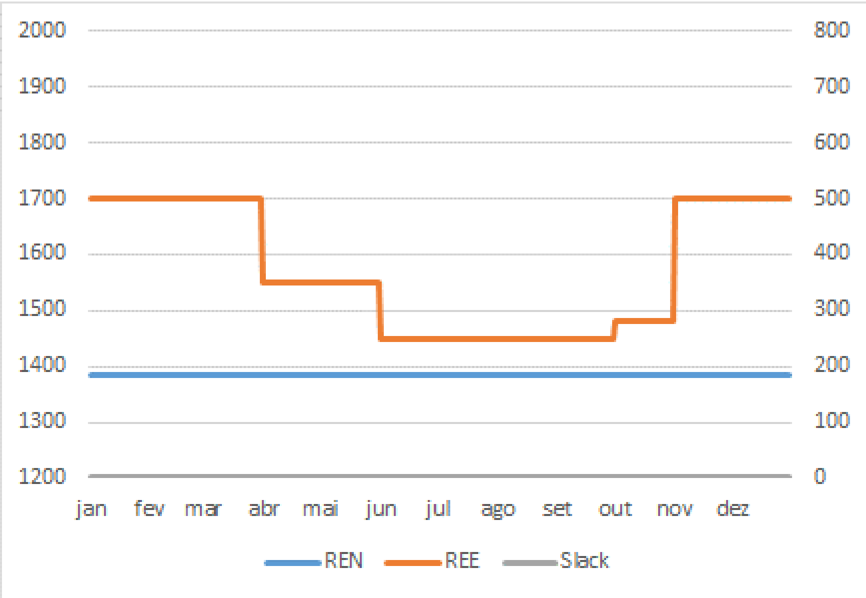


Figure 26 - Tie-line LTVR.PGN monthly capacities.