WP2 Methodology and VoO Analysis Report

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1. Introduction

The aim of WP2 is to identify:
1. The RES surplus potential of Member States and
2. The readily exploitable part of this potential (which we refer to as Valleys of Opportunity).

The idea behind the concept of Valley of Opportunity (VoO) is that, because of differences in RES supply between countries, cooperation in reaching the targets can bring benefits in the form of lower cumulative costs. In particular, a Member State (MS) could reach its RES target more cost-efficiently by exploiting part of the surplus potential of a different MS.

According to the RES-Directive 2009/28/EC, cooperation between member states could be implemented via a suitable mechanism falling under one of the following three categories: statistical transfer, joint projects or joint support schemes. RES 4 Less is mainly focused on the two latter cooperation methods.

Within WP2 a methodology has been devised to systematically analyze the surpluses and pin-point the most promising VoO's, independently of the cooperation mechanisms that may be put in place.

As shown in Figure 1.1, the expected outcome of this analysis can be described, on a coarse scale, as Sun in the South, Wind in the North, Biomass in the East.

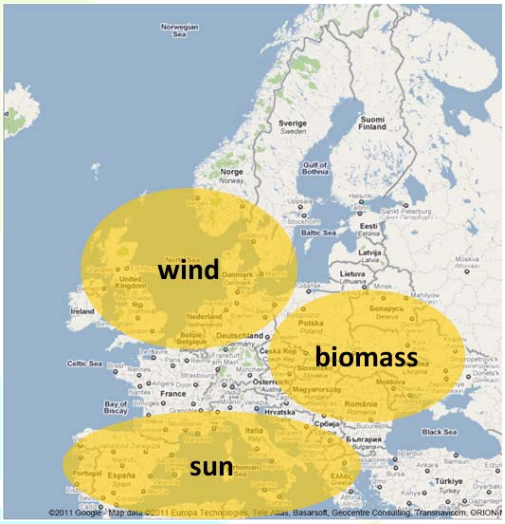

Figure 1.1 Expected VoOs

2. Conceptual Methodology

2.1 Surplus Analysis

Surpluses are identified by constructing the RES energy cost supply curve for each MS, and plotting the corresponding RES target against it. This is shown in Figure 2.1, where the cost supply curves of two MS's are displayed: the shaded areas beyond the targets (bullet points in the graph) represent the surpluses of the two MS's.

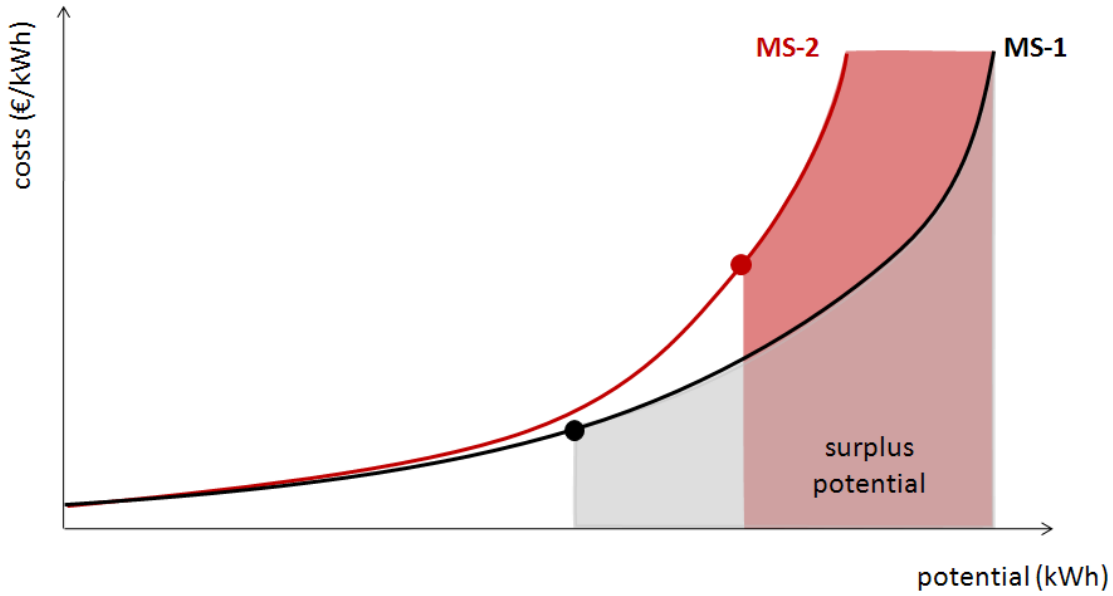

Figure 2.1 Surplus potential is identified as the part of a cost supply curve beyond the target (bullet point)

2.2 VoO – Pair-Wise Analysis

In the conceptual example of Figure 2.1, MS-1 (black line) has a lower target and lower costs than MS-2 (red line). Therefore a candidate VoO is easily identified as the part of surplus potential of MS-1 up to the target of MS-2. This is highlighted in Figure 2.2.

In the following we will adopt the terminology:

- *Host Country* = MS who wants to sell its surplus potential, i.e. MS-1 in Figure 2.2
- *User Country* = MS who wants to exploit the surplus potential of the Host Country, i.e. MS-2 in Figure 2.2

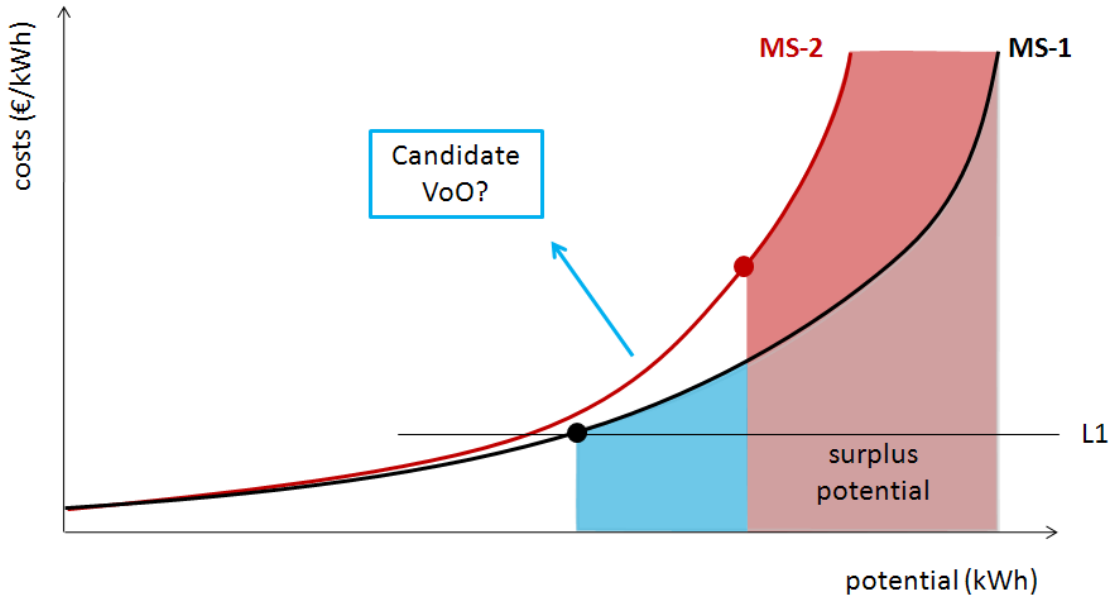

Figure 2.2 Example of candidate VoO

With reference to Figure 2.3, the User Country, MS-2, is potentially interested in exploiting the surplus potential of the Host Country, MS-1, as soon as the costs of its own energy technologies are above line L1, representing the marginal costs of MS-1's RES target. If allowed to make use of the Host Country's surplus, the User Country will likely choose to develop in parallel the cheapest part of its own potential (Δp_{MS-2}) and of MS-1's surplus (Δp_{MS-1}). This will process will continue till the total potential developed ($\Delta p_{MS-1} + \Delta p_{MS-2}$) enables MS-2 to reach its RES target.

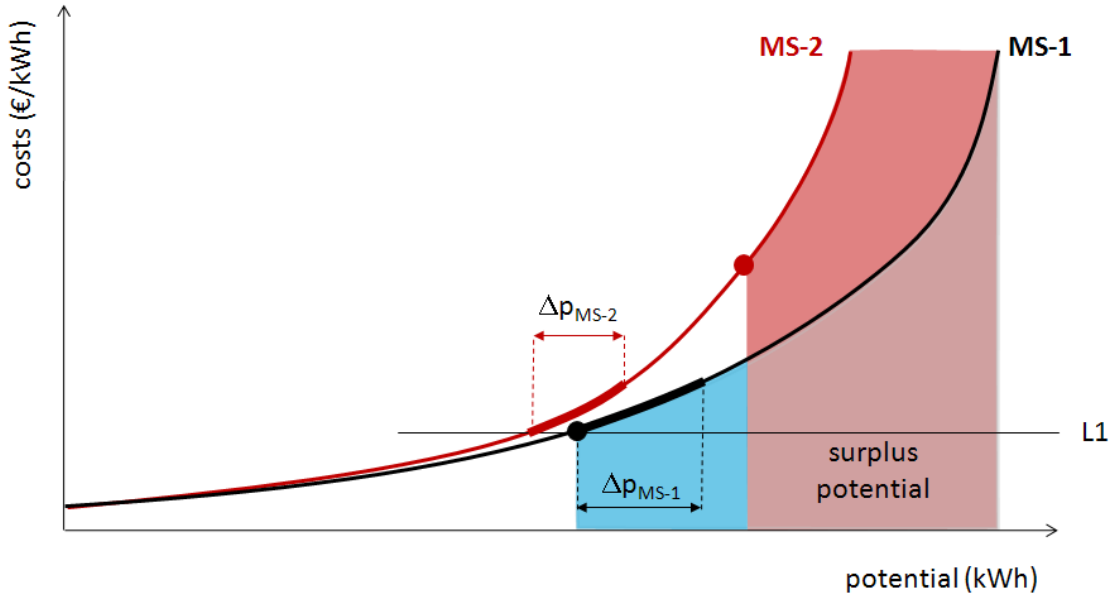

Figure 2.3 When cooperation is allowed, the User Country will develop the cheapest potentials Δp_{MS-1} and Δp_{MS-2}

The exact amounts Δp_{MS-1} and Δp_{MS-2} can be easily calculated by performing a *virtual demand-supply analysis* on the relevant segments of the cost supply curves, as shown in Figures 2.4 and 2.5. First, the supply curve of MS-1's surplus potential and the segment of MS-2's supply curve above L1 up to MS-2's target are isolated and

compared in Figure 2.4. The red curve in the figure represents *the price that the User Country is willing to pay in order to achieve its target.* With this in mind, we can then use this data to construct a *demand* for the surplus potential of the Host Country. This is simply done by flipping the red curve horizontally in Figure 2.5. It is now straight forward to determine a series of quantities that can be used to assess and characterize the candidate VoO's:

- the *equilibrium price* L2 at which the Host Country is willing to sell its energy (and, conversely, at which the User Country is willing to buy it)
- the *User Country cost savings*: the white area between L2 and the red curve, commonly named in economic terms the *consumer surplus*
- the *Host Country gain*: the white area between L2 and the black curve, commonly named *producer profit*
- the fraction of surplus potential exploited, or equivalently the *size of the candidate VoO*: the potential level at which supply meets demand.

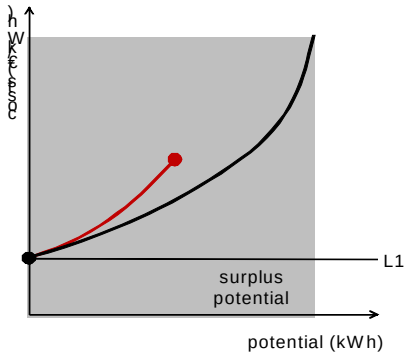

Figure 2.4 Comparison of the relevant parts of the two cost supply curves

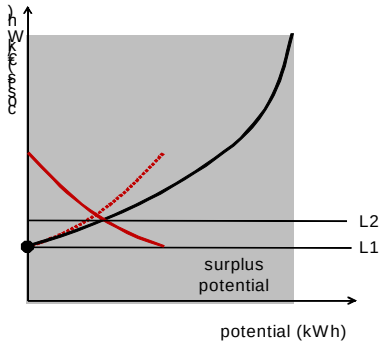

Figure 2.5 A demand segment is created by flipping the relevant part of the cost supply curve of the User Country

While this analysis does not necessarily reflect the details of a real cooperation between two Member States (e.g. the market price might vary per RES technology instead of being constant, the Host Country might decide to save some of its surplus for its own use, etc.), it give us a simple way of systematically and consistently characterize the candidate VoO's. In particular, thanks to the four indicators, by performing pair-wise comparisons between all possible couples of Member States, it is possible to evaluate which of the candidate VoO's are most attractive from an economic perspective. For example, the higher the *cost savings*, the *gain* and the *VoO size*, the most attractive the (candidate) VoO is. Once again, it should be remarked that these cost figures do not necessarily represent actual values: they are *only used to compare* the VoO's with one another. The actual cost figures will depend on the details of the specific cooperation mechanisms in place (including specific policy measures and subsidies), and will be analyzed within the case studies of WP3.

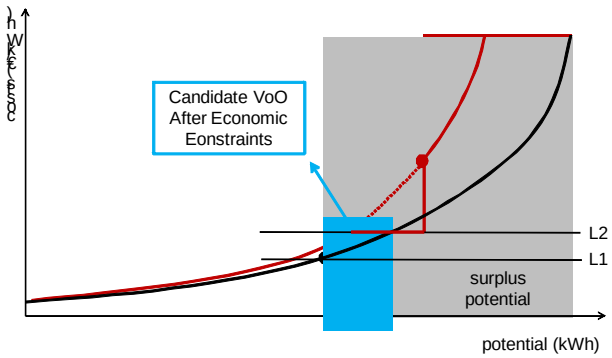

Figure 2.6 VoO after economic constraints

By exploiting part of the surplus potential of the Host Country, the cost supply curve for the User Country changes as indicated in Figure 2.6. The effect of the economic constraint on the size of the candidate VoO is also shown.

2.3 VoO - Generalization

The methodology outlined in Section 2.2 can easily be generalized to the case of cooperation among three or more countries. The analysis starts again by identifying the surplus potential of each MS. Next a *global virtual supply curve* can be constructed by "patching" together all the surpluses. Similarly, all the non-surplus parts of the cost supply curves of each MS can be patched together to construct a *global virtual demand curve*. These two global curves can then be used to perform the virtual demand-supply analysis of Figures 2.4 and 2.5. This will result in the following four indicators:

- the *global equilibrium price* at which the Host Countries are willing to sell their energy (and, conversely, at which the User Countries are willing to buy it)
- the *total cost savings for the User Countries*, commonly named in economic terms the *consumer surplus*
- the *total gain for the Host Countries*, commonly named *producer profit*
- the fraction of surplus potential exploited, or equivalently the sum of the *sizes of all the candidate VoO's*: the potential level at which supply meets demand

This analysis can be applied to any number of countries, and yields an optimal allocation of the surpluses among these countries. In contrast to the pair-wise analysis described in section 2.2, a Host Country is now allowed to sell its surplus potential to multiple User Countries.

When the number of MS's and RES energy technologies is high, the main advantages of this approach are:

- it provides a quick overview of where the cheapest surpluses and the most expensive non-surpluses are
- it gives an estimate of the maximum achievable cost savings and a benchmark RES energy market price

On the other hand, the detailed analysis of "who is buying what from who" becomes very impractical, and can be better understood via the pair-wise approach. Therefore the two approaches can be considered complementary, shedding light on different aspects of the problem.

3. Practical Implementation

3.1 Cost supply curves

In order to construct cost supply curves for a sound VoO analysis the following choices have been made:

Sectors: The Renewable Electricity (RES-E) sector has been chosen because of high availability of input data and because it represents the most interesting sector for cooperation mechanisms from a practical point of view. Later the analysis may be extended to the Renewable Heating (RES-H) sector depending on time and budget. The transport sector has been excluded because trade of biofuels is already a reality.

Cost Data: The costs in the supply curves are the Levelized Production Costs (LPC). These represent the pure costs of the technologies. Therefore the possible influence of country-specific support policies is not included in the cost supply curves. It appears that this approach bring several advantages: (i) A clear view on the technology costs in each MS, and thereby (ii) a clear view on where the cheap surpluses are; (iii) The possibility for cooperating countries to come up with specific policies (joint support schemes) to promote the cooperation itself; (iv) A clear separation between energy costs and financing, giving the cooperating countries the opportunity to properly share the costs of support schemes.

Input Data: The cost and potential data used to construct the cost supply curves are produced with the ECN model of the EU Renewable Electricity sector RESolve-E[1]. The model has recently undergone a major update. In case the analysis will be extended to the Renewable Heating sector the ECN model RESolve-H will be used to produce the corresponding cost and potentials.

Targets: The RES targets for the years 2015 and 2020 in the analysis are the values of projected renewable electricity production specified in the National Renewable Action Plans (NREAPs). Targets for the year 2030 will be specified in a second stage based on one or more scenario assumptions.

Years: The VoO analysis is performed for the years 2010, 2015, 2020 and eventually for 2030, once suitable targets have been set. Given that the analysis produces a large data output, this proved to be a good compromise in order to ensure temporal continuity of the identified VoO's, while avoiding having to repeat the analysis for each and every year.

Technologies: The cost supply curves contain the costs of a wide range of diverse technologies (see Appendix A.1). However, when presenting the results, the technologies will most of the times be grouped into broader classes, such as Biomass technologies, Solar technologies and Wind technologies.

[1] The RESolve-E model is formerly known as ADMIRE-REBUS: Daniëls, B.W. & M.A. Uyterlinde (2005): *ADMIRE-REBUS: modelling the European market for renewable electricity. Energy 30 (2005), 2596-2616, 2005.*

3.2 Pair-wise vs. Global

In Section 2.1 the methodology for the VoO analysis has been introduced considering pairs of Member States. In Section 2.2 the methodology has been generalized to a group of three or more MS's. It has also been outlined how the two approaches can be considered complementary, presenting specific advantages and drawbacks, especially in the case of high numbers of countries and technologies. Therefore it has been decided to perform the VoO analysis both on a pair-by-pair basis and on a global scale (i.e. including all EU countries at once).

The complementary character of the two approaches can be exploited to simplify the analysis of the results. The global approach yields an optimal allocation of the surplus potentials and a benchmark for the electricity price. This information is used to guide the detailed pair-wise analysis, focusing on the cheapest surpluses, the most expensive non-surpluses and the candidate VoO's that present electricity prices close to the benchmark.

3.3 RES4Less Model

Based on the items discussed in the previous chapter, a model has been developed to perform the VoO analysis. The model has been built using AIMMS, a software platform that allows to easily work with large amount of data and multidimensional parameters, and to develop custom user interfaces. Given the large amount of output data, the latter feature has proved particularly useful in this case: a custom user interface has been built that allows to quickly browse through the outputs in a systematic manner.

The input data consist of technology potentials, technology costs and Renewable Electricity targets for the EU27 countries and Norway, in a certain year. As already mentioned, these data are produced using ECN model RESolve-E; however, in principle, any set of data containing potentials, costs and targets could be fed into the RES4Less model.

The input data are used to construct cost-supply curves and identify the surplus potentials. Subsequently, two separate modules perform the VoO analysis:

- the *global module* performs the VoO analysis on a global level yielding an optimal allocation of the surpluses and a benchmark electricity price
- the *pair-wise module* performs the pair-by pair analysis, i.e. it calculates the four indicators for each of the 28 x 28 (in total 784) possible pairs of countries

A graphical representation of the data flow scheme is presented in Figure 3.1.

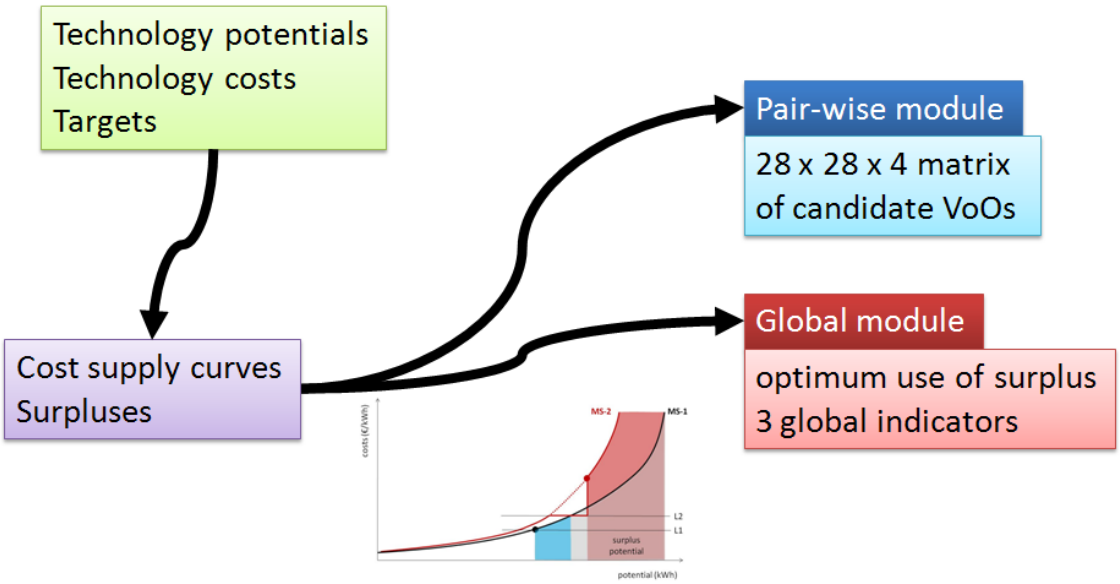

Figure 3.1 RES4Less model data flow scheme

4. Results

Since June 2011 several preliminary runs of the RES4 Less model have been executed and the results presented and discussed at the three RES-4-Less stakeholder consultation workshops. The feedback received from the project partners and the stakeholders has been used to fine-tune input data and improve on the model outcome, leading to the current results presented in this chapter.
The structure of this chapter mirrors the RES4Less model data flow scheme: first an overview of the input data is given, followed by the analysis of the surplus potentials, and finally the results of the VoO analysis are presented.

4.1 Input Data Overview

The initial cost supply curves have been produced using RESolve-E, the ECN model of the European RES-E sector. Based on 2040 realistic potentials and extensive technology, policy and financial parameters databases, RESolve-E can calculate the renewable electricity production and levelized costs per country, per RES-E technology. In order to guarantee utmost reliability of the initial cost supply curves, RESolve-E input data have recently been updated (in collaboration with the other RES-4-Less project partners). The model has then been calibrated to qualitatively[2] reproduce the NREAP renewable electricity production up to 2020. In order to achieve this, it has been assumed that the current policies will be continued in all member states.

Once the calibration was completed, a special run of the RESolve-E model has been executed where all policy measures have been "switched off" from the year 2013 onwards. This procedure resulted in the final set of cost supply curves that have been used as an input to the RES4Less model. These cost supply curves can be characterized as:

- *policy-independent*, i.e. the costs are solely based on the levelized production costs of the different technologies included in the model
- *NREAP-independent,* i.e. the correlation between RESolve-E outcome and NREAP production for the years 2015 and 2020 has been lost, thereby highlighting eventual surpluses or deficits

In order to visualize this last point, the total RES-E production as calculated by RESolve-E has been plotted in Figure 4.1 (bars) and compared with the corresponding NREAP RES-E production (dots). As expected, the 2010 RESolve-E predictions are in line with NREAP while the correlation is (in general) lost in 2015 and 2020, highlighting surpluses and deficits.

[2] A 15% deviation from NREAP has been allowed up to 2010. Higher deviations have been allowed for 2015 and 2020, since these results depend on the actual evolution of policies, technology costs and other parameters. Some discrepancies can be found in the data due to the fact that fine tuning of the calibration is still ongoing at the present time.

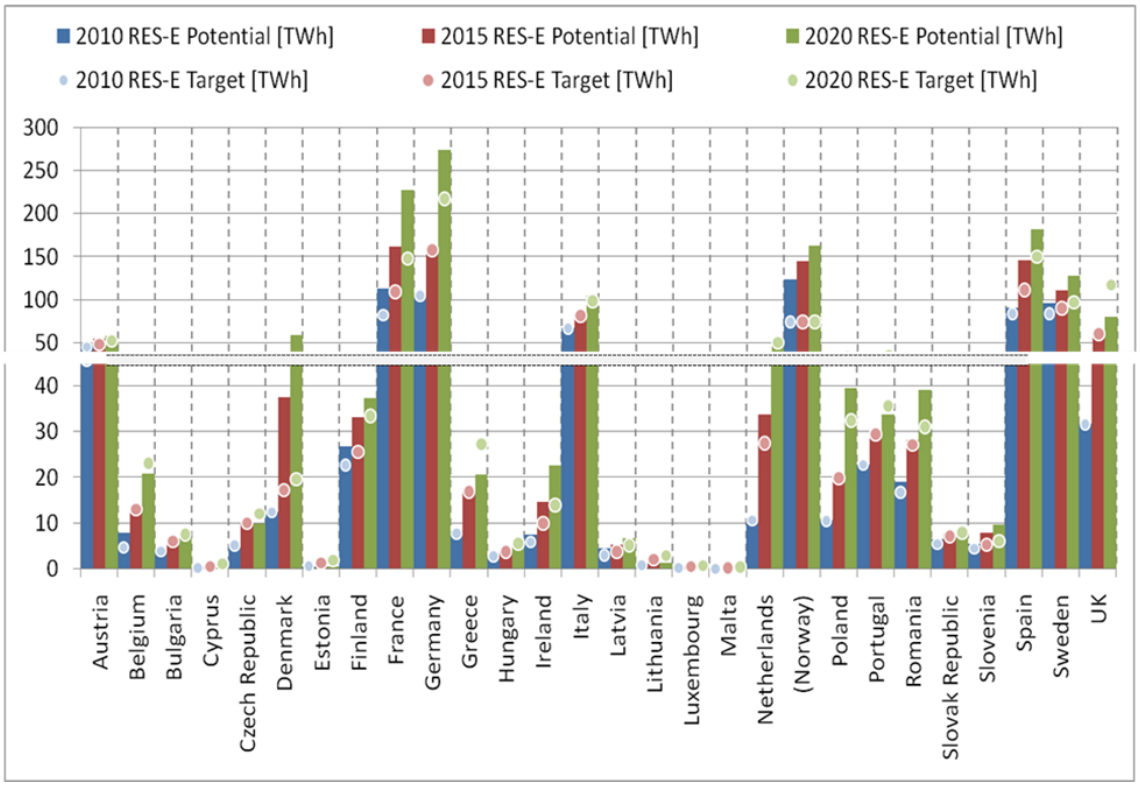

Figure 4.1 RES-E production per country according the RESolve-E (bars) and NREAP (dots) in 2010, 2015 and 2020. Note that a fictitious target has been used for Norway

Since no NREAP data are available for Norway, a fictitious constant target has been set at 74.22 TWh. This introduces an error, invalidating the results obtained for Norway. This problem will be dealt with at a later stage, once a proper target for Norway has been identified.

In the figure a scale break is applied at 45 TWh in order to render the low potentials.

4.2 Surplus Potential Analysis

Figure 4.1 readily shows that several MS's are predicted to have a surplus of RES-E production, compared to the NREAP figures. These surpluses are extracted and displayed in Figure 4.2. The Member States are sorted in descending order starting from the MS with the highest 2020 surplus (France). This display separates the MS's with a more pronounced *host* character on the left side of the chart from the ones with a more pronounced *user* character on the right side.

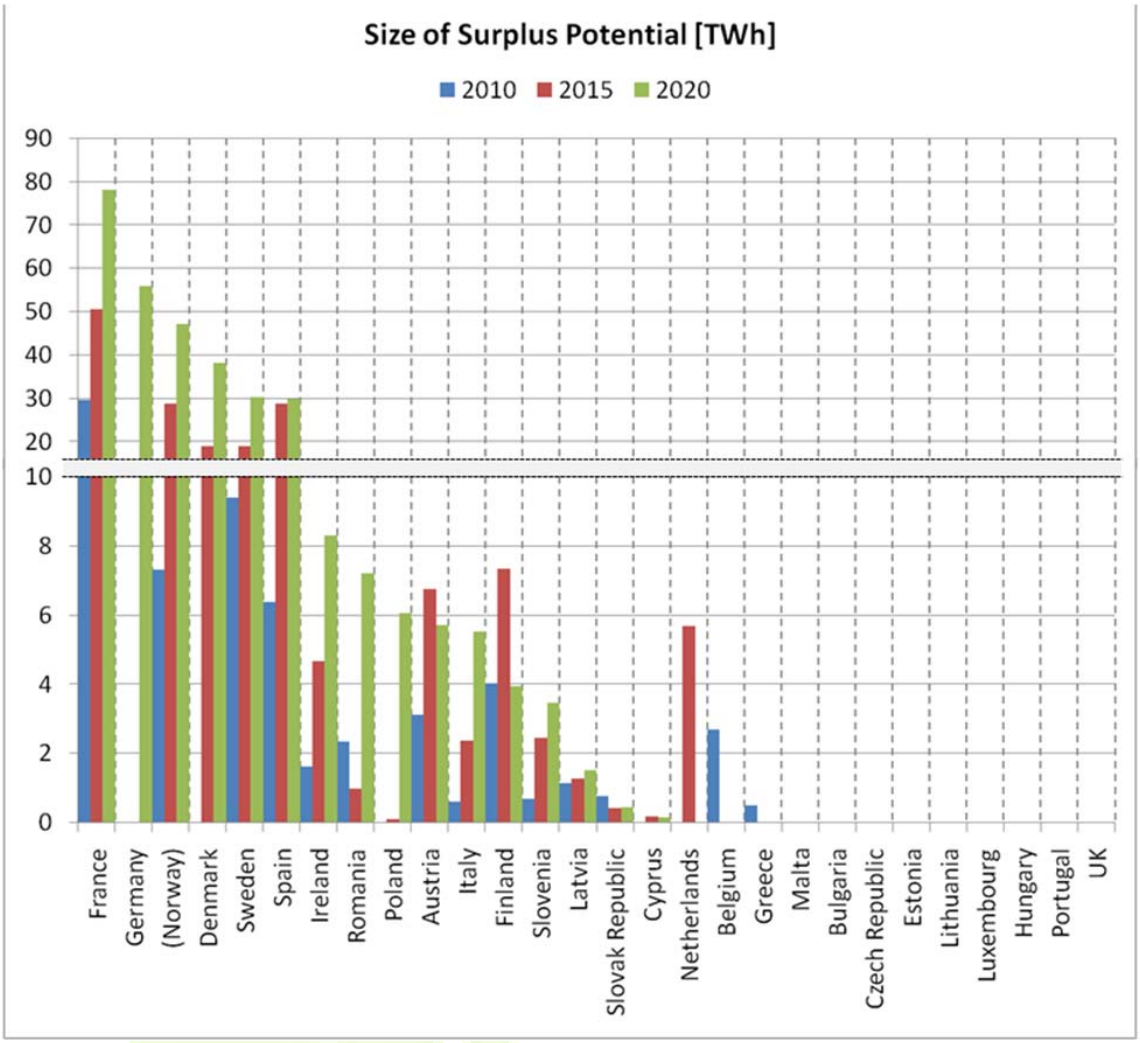

Figure 4.2 Estimate of surplus potentials in 2010, 2015 and 2020

A scale break is applied at 10 TWh in order to render the low surpluses.

The surpluses can be broken down into different RES technology categories. The following table (spread over two pages) gives an overview of such a breakdown.

Table 4.1 Surplus-technology breakdown

	Biomass	Geo-thermal	Small & medium hydro (<10MW)	Large hydro (>10 MW)	Photo-voltaics	CSP	Tidal	Wave	Wind onshore	Wind offshore
Austria										
2010	7%	22%			4%				66%	
2015	3%	1%	37%	1%	7%				52%	
2020	0%	3%	54%	4%	4%				36%	
Belgium										
2010	1%		2%		2%					95%
2015										
2020										
Cyprus										
2010										
2015	14%				22%				45%	19%
2020	0%									100%
Denmark										
2010										
2015	1%				0%				4%	96%
2020	6%				0%			0%	3%	90%
Finland										
2010	37%		26%						37%	
2015	14%		7%	11%	0%				67%	0%
2020	0%		9%		3%				79%	8%
France										
2010	13%	5%	9%		2%		1%		68%	1%
2015	9%	1%	7%		4%		1%		71%	7%
2020	7%	1%	2%		8%		1%	0%	31%	51%
Germany										
2010										
2015										
2020	13%	1%	2%		50%				5%	29%
Greece										
2010	2%			61%	20%				17%	
2015										
2020										
Ireland										
2010	3%		0%						94%	4%
2015	0%		1%		0%				0%	98%
2020			1%		1%			1%		98%
Italy										
2010	2%		0%	0%	86%				11%	
2015			27%	26%	17%				28%	2%
2020		16%	19%	39%	5%				16%	4%
Latvia										
2010	4%		24%	72%					0%	
2015	12%		37%	47%	0%				3%	1%
2020	16%		13%		1%				47%	22%

Table 4.1 Surplus-technology breakdown (continued)

	Biomass	Geo-thermal	Small & medium hydro (<10MW)	Large hydro (>10 MW)	Photo-voltaics	CSP	Tidal	Wave	Wind onshore	Wind offshore
Malta										
2010	93%								6%	2%
2015										
2020										
Netherlands										
2010										
2015	4%		3%		1%					92%
2020										
Norway										
2010			47%	37%					16%	0%
2015			18%	34%	0%				48%	0%
2020			14%	35%	0%			0%	46%	5%
Poland										
2010										
2015			100%							
2020		2%	4%						68%	26%
Romania										
2010	3%		80%						8%	9%
2015			43%		2%					56%
2020	1%		24%		1%				17%	58%
Slovak Republic										
2010	8%		50%	39%	3%				1%	
2015	7%		57%		19%				16%	
2020	16%		39%		22%				23%	
Slovenia										
2010	24%	44%	33%	0%	0%					
2015	11%	48%	23%	18%	0%				0%	
2020	10%	34%	21%	34%	0%				1%	
Spain										
2010	17%		1%	11%	20%	39%			12%	
2015	2%		5%	0%	25%	44%			25%	0%
2020		1%	5%	0%	4%	76%		0%	9%	4%
Sweden										
2010	4%		37%	8%	0%				47%	4%
2015	5%		10%		0%				50%	35%
2020	5%		3%		1%			0%	33%	58%

In the table, the percentages represent the relative contribution of a certain technology to the total surplus of a certain MS in a certain year. The green bars are useful to quickly visualize which technologies play the most prominent role in each MS.

In general most of the surplus electricity production comes from Wind and Hydro, while Biomass technologies, Geothermal and Photovoltaics play a relatively minor role. Notably the surplus of Spain is dominated by Concentrated Solar Power (CSP). Finally, the contribution of Wave and Tidal technologies is negligible.

4.3 VoO Analysis

Eligibility of Surplus

Before presenting the results of the VoO analysis, it is important to remark that only a fraction of the identified surpluses is eligible for cooperation mechanisms, i.e. the part of surplus corresponding to *new installations*. In order to clarify this point let's consider a practical example. In Figure 4.3 the cost supply curve for Spain in 2020 is shown. The segments of surplus highlighted in green correspond to new installations and are therefore eligible to take part in cooperation mechanisms. The blue segments above the target correspond to existing installations and are therefore not eligible for cooperation mechanisms.

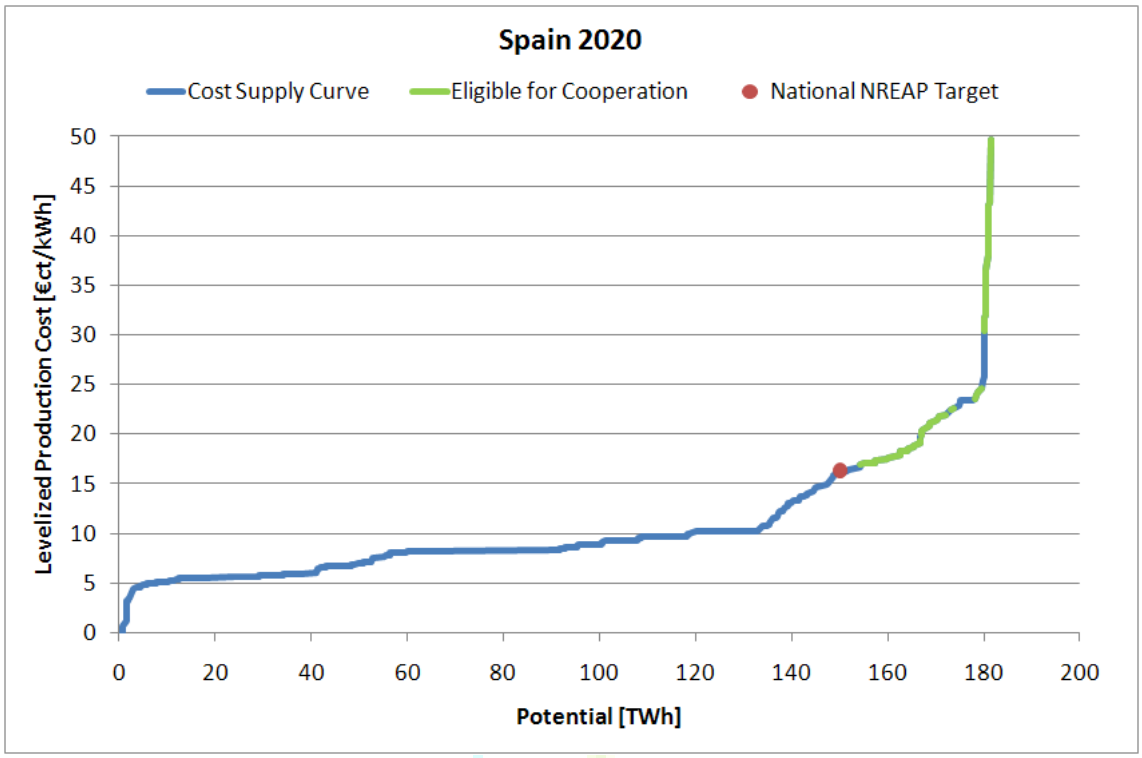

Figure 4.3 Cost supply curve for Spain in 2020, highlighting the surplus segments that are eligible to take part in cooperation mechanisms

Overview of VoO's in 2020

After having taken into account this eligibility constraint and performed the VoO analysis described in chapters 2 and 3 one obtains, for each year of interest, a set of four 28x28 tables containing the four indicators that characterize the VoO's for each possible pair of countries. This set can be further broken down into the 14 technologies considered in the analysis[3].

The full set of results for the year 2020 is presented in appendix A.2. A partial technology breakdown is presented in appendix A.3. The reader wishing to have a thorough overview is therefore reminded to the appendix. In the following some general features are discussed.

[3] In this report the outcome of the *pair-wise* module of the RES4Less model is presented in some detail, while no emphasis is given to the *global* module outcome, since this is solely used as a guideline in the result analysis.

The results reported in the appendix show that the MS's that could benefit the most from cooperation as *User Countries* in 2020 are Portugal, the Netherlands, Belgium, Italy, UK and Greece. Similarly, the MS's that could profit the most from cooperation as *Host Countries* are France, Germany, Denmark, Sweden, Romania and Spain[4]. The results of the technology breakdown for Biomass, Solar and Wind can be summarized as follows:

- *Biomass VoO's* in Denmark, Germany, Latvia, Slovenia and Sweden
- *Solar VoO's* in Spain, France and Germany
- *Wind VoO's* in Denmark, Germany, Finland, France, Romania and Sweden.

This partially confirm the expected outcome of Figure 1.1, the main discrepancy being the absence of sizable opportunities for Biomass in Eastern Europe. This is mainly due to the relatively small RES-Electricity surplus potential of Eastern European countries. In this respect, an extension of the analysis to include the RES-heating sector would be very interesting, as this would allow to draw more robust conclusions.

VoO's in 2020: Examples

In table 4.2 a selection of results of the VoO analysis, mainly addressing possible VoOs for the MS's that have been identified as *User Countries*, is presented. For all the selected *Host-User* pairs the electricity equilibrium price and the size of the VoO per (relevant) technology are reported. For sake of brevity, only the 2020 results are presented; however nearly all the proposed VoO's present an element of continuity from the present time up to 2020.

[4] Note that Norway is presently excluded from the analysis because of the above mentioned reasons.

Table 4.2 Selected VoO's

Host:		*Users:*				
Austria	**-->**	**Portugal**	**Netherlands**	**Belgium**	**Italy**	
Equilibrium Price	*[€ct/kWh]*	*24.2*	*24.0*	*19.7*	*14.6*	
Hydro	[TWh]	1.7	1.2	0.5	0.0	
Wind Onshore	[TWh]	2.0	1.9	1.6	1.5	
Host:		*Users:*				
Denmark	**-->**	**Portugal**	**Netherlands**	**UK**		
Equilibrium Price	*[€ct/kWh]*	*13.3*	*15.3*	*16.9*		
Biomass	[TWh]	2.1	2.1	2.2		
Wind Onshore	[TWh]	0.2	0.8	1.3		
Wind Offshore	[TWh]	6.8	20.5	30.8		
Host:		*Users:*				
France	**-->**	**Portugal**	**Netherlands**	**UK**	**Belgium**	**Italy**
Equilibrium Price	*[€ct/kWh]*	*11.5*	*13.8*	*14.4*	*11.7*	*11.5*
Biomass	[TWh]	0.0	0.0	4.7	0.0	0.0
Photovoltaics	[TWh]	2.3	5.1	5.1	2.7	2.3
Wind Onshore	[TWh]	8.5	16.7	20.2	8.5	8.5
Wind Offshore	[TWh]	0.0	0.3	7.7	0.0	0.0

Host:		Users:			
Romania	-->	Portugal	Netherlands	Belgium	Greece
Equilibrium Price	*[€ct/kWh]*	*17.8*	*17.8*	*16.7*	23.8
Hydro	[TWh]	0.0	0.0	0.0	1.1
Wind Onshore	[TWh]	1.2	1.2	1.2	1.2
Wind Offshore	[TWh]	2.9	2.9	2.5	4.2

Host:		Users:		
Spain	-->	Portugal	Netherlands	Greece
Equilibrium Price	*[€ct/kWh]*	*17.1*	*17.4*	18.3
Wind Offshore	[TWh]	0.8	0.8	1.2
CSP	[TWh]	4.7	4.7	9.4

Host:		Users:		
Finland	-->	Portugal	Netherlands	Belgium
Equilibrium Price	*[€ct/kWh]*	*24.5*	*19.9*	16.8
Wind Onshore	[TWh]	2.2	2.1	2.1

Host:		Users:			
Sweden	-->	Portugal	Netherlands	Belgium	Greece
Equilibrium Price	*[€ct/kWh]*	*12.3*	*16.0*	11.7	14.4
Biomass	[TWh]	1.1	1.1	1.1	1.1
Wind Onshore	[TWh]	5.8	6.2	5.5	6.1
Wind Offshore	[TWh]	0.0	3.9	0.0	1.8

4.4 Extensions and Improvements

The VoO analysis outlined in this report presents some shortcomings, which in turn are also the main points for possible improvements and extensions. These can be summarized as follows:

Input Data: The input cost-supply curves have been produced using the most up-to-date version of the RESolve-E model. However it is still possible that RESolve-E does not capture all the features of the RES-E market in some EU countries (e.g. the lack of a proper RES-E target for Norway invalidates the VoO's where this MS is involved). Future updates of the RESolve-E model will reflect in a new (improved) set of results of the VoO analysis.

Sectors: The current analysis only includes the RES-E sector. In order to get a more complete picture the RES-H sector should also be included. Cost supply curves for the RES-H sector could be produced in the near future with ECN RESolve-H model, which is currently in the calibration/debugging stage.

Static vs. Dynamic: The current analysis can be described as *static,* as does not take into account how the cost supply curves would evolve after a certain VoO is exploited, i.e. the cost supply curves are an exogenous input to the RES4Less model. As an interesting extension, one could introduce some elements of dynamicity in the

analysis. However this is outside the scope of the current modelling work, as the main objective of the present model is to give a quick screening, rather than analysing concrete VoO exploitation options and scenarios.

Another possible extension would involve including RES credits production costs in the cost supply curves, and studying how this would influence the outcome of the VoO analysis. In addition it would be interesting to analyze a scenario that considers possible RES targets beyond 2020.

Some of these items will be addressed to some extent in WP3.

5. Conclusions

In this report the methodology devised to analyze possible Valleys of Opportunity (VoO) for cooperation mechanisms among EU Member States (MS) was presented. The methodology consists of the following steps:

- cost supply curves for each MS in 2010, 2015 and 2020 are produced using the ECN model *RESolve-E*
- the NREAP targets are plotted against these curves, thereby highlighting eventual surpluses and deficits
- the satellite model *RES4Less* is then used to compare the cost supply curves pair by pair; the two MS's being compared are considered as *User Country* (buying energy) and *Host Country* (selling energy), respectively
- a demand curve is created for the surplus potential of the Host Country based on the cost supply curve of the User Country
- a demand-supply analysis is carried out, yielding four economical indicators that characterize the candidate VoO between the two MS's: *equilibrium price, size of the VoO, User Country cost savings* and *Host Country gain*
- the analysis is carried out for each and every possible pair of MS's, yielding a 28x28x4 matrix of final results per each year considered; this can be further broken down into the 14 different technologies considered

The effect of country-specific policy and support schemes have been explicitly excluded from the analysis, i.e. only the pure costs of technology are included in the cost supply curves. This approach brings several advantages, such as: (i) A clear view on the technology costs in each MS, and thereby (ii) a clear view on where the cheap surpluses are; (iii) The possibility for cooperating countries to come up with specific policies (joint support schemes) to promote the cooperation itself; (iv) A clear separation between energy costs and financing, giving the cooperating countries the opportunity to properly share the costs of support schemes.

The results clearly highlight opportunities for surpluses from wind energy in the North of Europe (Sweden, Denmark, Finland, Germany) and from solar energy in the South-West of Europe (CSP in Spain and PV in France). The analysis shows that (a part of) these surpluses could be allocated to countries such as Netherlands, Belgium, Portugal, Greece and Italy via a suitable cooperation mechanism. This would bring economical advantages for both the user and the host countries.

Biomass seems to pay a relatively small role in the VoO analysis. This can be due to a combination of several factors: (i) electricity from certain biomass technologies is relatively cheap and therefore often results as *non-surplus* option in the cost-supply curves, (ii) biomass is an abundant resource in Eastern European countries, however only few of these countries are predicted to have a surplus, and (iii) biomass could play a big role in the RES-Heating sector which is presently not included in the analysis.

Appendix A

A.1 Renewable Electricity Technologies

The following Renewable Electricity technologies have been considered in the model:

Biomass CHP	Photovoltaics
Biomass cofiring	Small & medium hydro (<10MW)
Biomass combustion	Concentrated Solar Power (CSP)
Biomass digestion	Tidal
Biomass gasification	Wave
Geothermal electricity	Wind offshore
Large hydro (>10 MW)	Wind onshore

A.2 VoO Analysis: 2020 – Indicators

In the following tables the 4 indicators (*Equilibrium Price*, *VoO size*, *User Country Cost Savings*, *Host Country Gain*) are displayed for each possible pair of Member States. The color scale from white to dark green should help the reader navigate through the data.

Size of VoO [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		2	2		2					0		1	1	2		2			3		2	4				2		
Belgium																												
Bulgaria																												
Cyprus														0														
Czech Republic																												
Denmark		8	3		4					4	14			7		2			23		16	9				9		34
Estonia																												
Finland	0	2	2		2	1	1			1		1	1	2		1			3		2	3				2		
France	1	12	1	0	1	6	1			16	16	1	1	11					23		19	11		0		12		38
Germany		7									15		0	5					26		17	10				10		34
Greece																												
Hungary																												
Ireland		4	3		3						8	1		1		1			7		7	6				3		
Italy		2	1		2		1					1				1			3			2						
Latvia	0		1	0		0	1	0		1		1	1	1			0	0						0		1		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	6	15	3		3	13	0	2	22	32	15	1	8	22	1	0			30		16	15	13	2	1	30	2	34
Poland		2	3		2		1					1		1		1			3			4						
Portugal																												
Romania	0	4	3	0	3	0	1			1	7	1	1	2		2	0	0	4		4	4		0		3		
Slovak Republic				0						0				0			0	0										
Slovenia	1	2	1	0	2	1	1	0	0	1		1	1	1	0	1	0	0	3			2		0		1		
Spain			2		2						11								6		6	3						
Sweden	2	7	1		2	5	0	1	5	7	9	1	2	7		1	0		11		9	7	3	0	0	7		
UK																												

Equilibrium Price [€ct/kWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		20	21		21					12		13	13	15		14			24		18	24				15		
Belgium																												
Bulgaria																												
Cyprus														20														
Czech Republic																												
Denmark		13	12		12					12	14			13		12			15		14	13				13		17
Estonia																												
Finland	11	17	18		18	11	11			12		11	12	14		12			20		18	25				15		
France	10	12	10	10	10	10	10			12	12	10	10	11				10	14		13	12		10		12		14
Germany		13									13		13	13					14		13	13				13		15
Greece																												
Hungary																												
Ireland		15	15		15						23	14		14		14			17		17	16				15		
Italy		28	23		28		23					22				23			44			26						
Latvia	11		24	11		11	24	9		12		18	13	18			11	11						11		16		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	5	5	4		4	5	3	4	7	11	6	4	5	7	4	3			8		6	5	5	4	4	9	4	13
Poland		20	20		20		20					20		20		20			21			22						
Portugal																												
Romania	11	17	15	11	15	11	14			12	24	14	13	14		14	11	11	18		18	18		11		15		
Slovak Republic				12						12				20			14	18										
Slovenia	10	36	22	9	36	10	15	9	9	12		14	12	16	7	18	8	8	43			32		9		16		
Spain			17		17						18	16		16		16			17		17	17						
Sweden	7	12	7		7	9	6	7	9	12	14	6	7	11		6	6		16		15	12	7	6	6	12		
UK																												

User Country Cost Savings [M€]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		12	35		51					2		48	3	68		10			6		15	86				22		
Belgium																												
Bulgaria																												
Cyprus														2														
Czech Republic																												
Denmark		129	236		141					0	445			138		20			272		358	459				100		65
Estonia																												
Finland	720	14	97		76		6			9		62	13	79		19			13		29	80				15		
France	732	227	286	2	170		6			19	552	66	47	225				6	582		619	614		1		238		107
Germany		136									485		5	131					641		542	480				112		78
Greece																												
Hungary																												
Ireland		49	170		109						46	45		86		12			42		81	328				18		
Italy		6	8		29		2					16				5			0			57						
Latvia	689		6	2			2			0		26	2	22			6	5						0		3		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	1046	705	451		262		9			243	1008	111	157	629		58			1972		1962	1176		3		481		201
Poland		11	42		56		2					21		5		6			11			137						
Portugal																												
Romania	671	14	150	1	99		5			1	35	45	1	73		10	5	5	27		31	248		0		9		
Slovak Republic				0						0				3			2	0										
Slovenia	730	3	17	3	10		4			77		41	15	43		7	10	7	0			36		1		1		
Spain			114		83						185	32		39		8			46		47	270						
Sweden	924	222	386		221		8			1	405	94	115	243		46	14		153		302	543		3		170		
UK																												

Host Country Gain [M€]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		134	154		171					2		9	6	33		27			256		100	261				33		
Belgium																												
Bulgaria																												
Cyprus														1														
Czech Republic																												
Denmark		68	9		13					14	141			28		0			422		215	83				73		926
Estonia																												
Finland		97	116		114	3	2			12		2	10	37		10			172		117	300				54		
France	1	108	1		1	2	1			173	173	1	1	85					499		304	89				108		684
Germany		20									36			2					119		59	20				20		639
Greece																												
Hungary																												
Ireland		26	19		19		18				575	0		1		1			180		141	56				19		
Italy		102	18		102		18					5				21			500			67						
Latvia	2		132	1		4	132	0		8		57	11	57			2	2						2		33		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	19	92	3		3	60	0	1	376	1572	129	0	39	376	0	0			665		240	94	60	1	0	972	1	2138
Poland		7	11		7		2					2		2		2			36			57						
Portugal																												
Romania	2	104	61	1	61	2	18			6	504	18	11	29		29	2	1	149		142	149		1		47		
Slovak Republic				0						0				14			2	10										
Slovenia	8	337	120	2	337	8	44	3	3	16		34	16	51		70	1	1	540			269		3		46		
Spain			6		6						103								24		24	10						
Sweden	9	255	7		11	77	0	8	77	292	448	4	11	224		0	0		612		475	292	17	0		298		
UK																												

A.3 VoO Analysis: 2020 – Technology Breakdown

In the following tables the size of VoO is displayed for each possible pair of MS's, each table representing a different group of technologies. All Biomass technologies have been aggregated into a single category, *Biomass.* Similarly, PV and CSP have been aggregated into *Solar*.

Size of VoO: Biomass [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		0.02	0.02		0.02									0.01		0.01			0.02		0.01	0.02				0.01		
Belgium																												
Bulgaria																												
Cyprus														0.00														
Czech Republic																												
Denmark		2.15	2.15		2.15					2.15	2.15			2.15		1.55			2.20		2.15	2.15				2.15		2.20
Estonia																												
Finland		0.01	0.01		0.01														0.01		0.01	0.01				0.01		
France																												4.73
Germany											1.50								5.64		3.54							6.19
Greece																												
Hungary																												
Ireland																												
Italy																												
Latvia	0.05		0.23	0.05		0.05	0.23	0.04		0.05		0.23	0.05	0.23			0.05	0.05						0.05		0.23		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway																												
Poland																												
Portugal																												
Romania	0.01	0.04	0.04	0.00	0.04	0.01	0.03			0.01	0.04	0.03	0.02	0.04		0.04	0.01	0.01	0.04		0.04	0.04		0.00		0.04		
Slovak Republic				0.05						0.05				0.06			0.06	0.06										
Slovenia	0.13	0.30	0.30	0.05	0.30	0.13	0.30	0.13	0.13	0.13		0.28	0.13	0.30		0.30	0.05	0.05	0.30			0.30		0.13		0.30		
Spain																												
Sweden	1.02	1.11	1.02		1.02	1.11	0.47	1.02	1.11	1.11	1.11	1.02	1.02	1.11		0.84	0.12		1.11		1.11	1.11	1.02	0.47	0.00	1.11		
UK																												

Size of VoO: Solar (PV & CSP) [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		0.07	0.07		0.07					0.07		0.07	0.07	0.07		0.07			0.07		0.07	0.07				0.07		
Belgium																												
Bulgaria																												
Cyprus																												
Czech Republic																												
Denmark		0.02	0.01		0.01					0.01	0.03			0.01					0.04		0.03	0.02				0.02		0.04
Estonia																												
Finland		0.08	0.10		0.10														0.12		0.10	0.13				0.03		
France	0.70	2.72	0.70	0.36	0.70	0.70	0.70			3.45	3.45	0.70	0.70	2.28					5.12		4.40	2.28		0.36		2.72		5.14
Germany		3.19									3.19			2.31					6.38		3.19	3.19				3.19		10.48
Greece																												
Hungary																												
Ireland		0.03	0.02		0.02						0.05	0.01		0.01		0.01			0.05		0.04	0.04				0.02		
Italy																												
Latvia			0.02				0.02					0.01		0.01														
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway																												0.04
Poland																												
Portugal																												
Romania		0.06	0.05		0.05		0.03				0.07	0.03		0.04		0.04			0.06		0.06	0.06				0.05		
Slovak Republic														0.07			0.04	0.07										
Slovenia		0.01	0.01		0.01		0.00					0.00		0.00		0.01			0.01			0.01				0.00		
Spain			2.36		2.36						9.44								4.72		4.72	2.36						
Sweden																			0.14		0.06							
UK																												

Size of VoO: Wind Onshore [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		1.61	1.69		1.75					0.41		0.91	0.91	1.54		1.54			1.91		1.54	1.91				1.54		
Belgium																												
Bulgaria																												
Cyprus																												
Czech Republic																												
Denmark		0.08									0.30								0.80		0.44	0.18				0.18		1.31
Estonia																												
Finland	0.49	2.08	2.08		2.08	0.67	0.57			1.15		0.57	0.95	2.08		0.95			2.08		2.08	2.16				2.08		
France		8.49				5.65				11.73	11.73			8.49					16.74		13.96	8.49				8.49		20.20
Germany											0.59								0.59		0.59							1.29
Greece																												
Hungary																												
Ireland																												
Italy		0.89	0.53		0.89		0.53					0.53				0.53			0.89			0.89						
Latvia	0.37		0.72	0.12		0.43	0.72			0.49		0.50	0.49	0.50			0.26	0.26						0.26		0.50		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	5.96	12.86	2.96		2.96	10.16		1.81	14.65	17.08	12.86	0.83	7.88	14.65	0.83				15.78		13.53	12.86	10.16	1.81	0.83	16.01	1.81	17.43
Poland		0.67	1.10		0.67		0.67					0.67		0.67		0.67			1.62			2.25						
Portugal																												
Romania	0.39	1.21	1.21	0.16	1.21	0.39	0.95			0.73	1.21	0.95	0.95	1.21		1.21	0.39	0.27	1.21		1.21	1.21		0.16		1.21		
Slovak Republic				0.03						0.03				0.07			0.06	0.06										
Slovenia		0.04	0.03		0.04														0.04			0.04						
Spain																												
Sweden	0.74	5.78	0.34		0.74	4.34		0.34	4.34	5.78	6.13		0.74	5.47					6.21		6.13	5.78	1.69			6.13		
UK																												

Size of VoO: Wind Offshore [TWh]	User Country																										
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria																												
Belgium																												
Bulgaria																												
Cyprus														0.12														
Czech Republic																												
Denmark		5.98	1.28		1.40					1.77	11.22			4.59		0.35			19.70		12.98	6.76				6.76		30.79
Estonia																												
Finland			0.15																0.31		0.15	0.32						
France																			0.26		0.16							7.74
Germany		3.47									9.25		0.16	2.55					13.59		9.25	6.51				6.51		15.70
Greece																												
Hungary																												
Ireland		4.38	3.29		3.29						8.09	0.60		1.42		1.42			7.01		6.68	5.80				3.29		
Italy		0.24	0.21		0.24		0.21					0.12				0.22			0.24			0.24						
Latvia			0.34				0.34					0.34		0.34												0.33		
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway										1.13																		2.11
Poland		1.50	1.50		1.50		0.06					0.06		0.06		0.06			1.58			1.58						
Portugal																												
Romania		2.57	1.57		1.57		0.17			0.03	4.17	0.17	0.12	0.74		0.47			2.90		2.67	2.90				1.57		
Slovak Republic																												
Slovenia																												
Spain											1.18								0.86		0.86	0.86						
Sweden											1.83								3.92		1.83							
UK																												

Size of VoO: Hydro [TWh]	User Country																										
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		0.45	0.45		0.45														1.22		0.45	1.70						
Belgium																												
Bulgaria																												
Cyprus																												
Czech Republic																												
Denmark																												
Estonia																												
Finland																			0.16		0.09	0.18						
France																												
Germany																												
Greece																												
Hungary																												
Ireland																												
Italy		0.44			0.44											0.16			0.97			0.44						
Latvia			0.06				0.06					0.03		0.03														
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway	0.04	2.47	0.03		0.03	2.47	0.03	0.03	7.72	13.93	2.47	0.03	0.48	7.72	0.03	0.03			13.93		2.47	2.47	2.47	0.03	0.03	13.93	0.03	13.93
Poland																						0.01						
Portugal																												
Romania		0.15									1.10								0.15		0.15	0.15						
Slovak Republic														0.03				0.03										
Slovenia		0.70	0.23		0.56									0.10		0.18			1.67			0.41				0.10		
Spain											0.02																	
Sweden																												
UK																												

Size of VoO: Geothermal [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria		0.09	0.09		0.09							0.01		0.05		0.01			0.12		0.06	0.12				0.05		
Belgium																												
Bulgaria																												
Cyprus																												
Czech Republic																												
Denmark																												
Estonia																												
Finland																												
France		0.19								0.20	0.20								0.20		0.20					0.19		0.36
Germany											0.01								0.01		0.01							0.11
Greece																												
Hungary																												
Ireland																												
Italy		0.36	0.33		0.36		0.33					0.23				0.33			0.91			0.36						
Latvia																												
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway																												
Poland																												
Portugal																												
Romania																												
Slovak Republic																												
Slovenia	0.42	0.90	0.76	0.23	0.90	0.42	0.66	0.23	0.23	0.54		0.56	0.54	0.66	0.03	0.68	0.04	0.04	0.95			0.90		0.23		0.66		
Spain			0.01		0.01						0.01								0.01		0.01	0.01						
Sweden																												
UK																												

Size of VoO: Wave & Tidal [TWh]	User Country																											
Host Country	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	UK
Austria																												
Belgium																												
Bulgaria																												
Cyprus																												
Czech Republic																												
Denmark																												
Estonia																												
Finland																												
France		0.30								0.30	0.30								0.30		0.30	0.15				0.30		0.30
Germany																												
Greece																												
Hungary																												
Ireland											0.05																	
Italy																												
Latvia																												
Lithuania																												
Luxembourg																												
Malta																												
Netherlands																												
Norway																												
Poland																												
Portugal																												
Romania																												
Slovak Republic																												
Slovenia																												
Spain											0.04								0.04		0.04							
Sweden																												
UK																												

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