Many works in this field have approached this issue by providing analysis of the existing congestion management methods for distribution networks with high penetration of renewables, such as [1], [2] or [3]. A more modern view of the problematic is considering the complementarity of multiple energy resources in energy hubs (EHs) to mitigate possible distribution network congestions, combining different types of energy resources [4] or combining it with storage [5]. This paper does not attempt to analyze the problem itself or propose any solution, but to find a correlation between the cost and the phenomenon itself.

The grid congestion costs considered in this paper include re-dispatching costs as well as countertrading costs. Re-dispatching refers to the situation when the day-ahead market clearing solution results in grid congestion. This problem may be resolved in different ways, the common practice in Europe implies delivery of energy to the consumer from some other (often more expensive) producer. That is, it can oblige a generator to increase generation on one side of the bottleneck, and another generator to decrease generation on the other side, compensating both accordingly [6]. The grid operator is forced to assume those costs and include them as congestion management costs. Countertrading[1], on the other hand, refers to the possibility of compensating foreign generators (or consumers) for adjusting their output (or demand), to tackle congestion by using cross-border exchange.

The data used in this paper to evaluate those costs has been obtained from ENTSOE transparency [7]. It must be pointed out that the data available differs greatly in quality and granularity from country to country and from year to year. Furthermore, the data provided by some countries, for example Germany, even differs from the data provided in the country by internal sources, see data provided in Reference [8].

3. Assumptions and Research Method

The main assumption in this work is that the bigger the share of non-dispatchable energy sources, wind and solar power plants, in gross electricity production, the higher are congestion management costs.

To investigate the correlation, the data from ENTSOE's central collection and publication of electricity generation, transportation and consumption data and information for the pan-European market [8] were explored, as well as from the Publications Office of the European Union. The latter publishes the annual statistical pocketbook "EU energy in figures" [10].

The scope of this work is limited to the countries of North-West Europe, as it is shown in Fig. 1.

[1] There is some unclarity in the definition of countertrading depending from the source [9]. The authors decided to use the definition presented in reference [6].

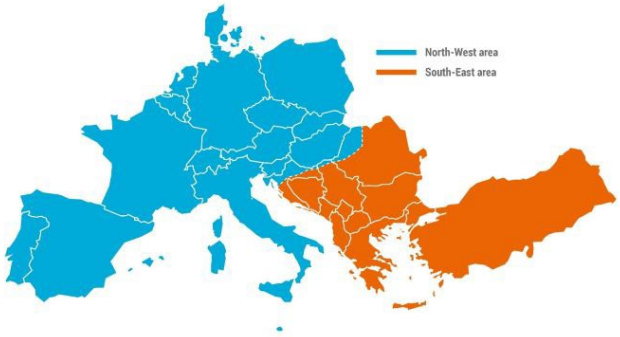

Fig. 1. System Separation in the Continental Europe Synchronous Area on 8 January 2021 – update (image from ENTSOE [7])

ENTSOE provides data on electricity generation by forms and by years from 2000 to 2020. As the target criteria, the congestion management costs themselves and then those costs related to the amount of electricity consumed and to the installed capacity were analyzed.

Among the countries from North-West area, the following countries were selected for the analysis: Germany, Spain, France, Italy, Austria, and Poland. There is more complete dataset provided by these countries.

It should be noted that the application of some statistical indicators for correlation analysis was not possible, since reliable data on costs was available only for five years so far (2015-2020). That is why, the comparison in the next section is given only in the form of diagrams, to show tendencies and identify similarities.

The table below summarizes the data which were taken into account during the analysis.

Table I. –Datasets analysed

Electricity production	Costs
• Gross electricity generation per country [TWh] • Share of wind and solar production [%] • Installed capacity of electric generators [MW] • Share of wind and solar capacity [%] • Total electricity consumption [TWh]	▪ Total congestion management costs [k€] ▪ Available data for re-dispatching costs [k€] ▪ Available data for countertrading costs per country [k€]

4. Preliminary Results

4.1 General Trends and Notes

First of all, it should be noted that the analyzed countries vary greatly in gross electricity production, as it is shown in Fig. 2. For example, Germany and France, each produce at least twice as much electric energy as any other country among the selected ones. The analyzed countries also vary