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The impact of Nord Stream 2 on the European gas market bargaining positions

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ABSTRACT

We investigate the impact and the possible consequences of the construction of the Nord Stream 2 pipeline. We model the European gas network as a cooperative game between regions as players over the pipeline network. Our model offers several novelties compared to earlier cooperative studies. Firstly, we focus on cost saving rather than on the profits of cooperation. Secondly, we introduce liquefied natural gas as a player. Thirdly, we apply an iterative linear program to account for the long term bilateral contracts that still drive the gas market. This modelling technique also allows us to identify individual gas flows. We focus on the change of influence of the players in three different scenarios. We investigate how the power of the agents shift when the Nord Stream pipeline is expanded, when the Ukrainian pipeline is shut down and finally when both of these happen. Our calculations show that when Nord Stream 2 is operational, Russia and Western Europe improve their position compared to the base scenario, while other suppliers, notably Norway, together with Central- Eastern- and Southern Europe suffer losses, especially when the Ukrainian route is dismissed. The results highlight that both the supporters and adversaries of Nord Stream 2 are governed by self-interest and solidarity and trust, the values proclaimed by the EU and the Energy Union, remain but a slogan.

1. Introduction

Satisfying Europe's hunger for energy has always been a difficulty. Despite efforts to increase the use of renewable sources, with the mounting sentiment against nuclear energy, reliance on fossil fuels is more important than ever. Natural gas is, in particular, a very versatile energy source with extensive industrial and domestic uses. Nearly three-quarters of the European Unions natural gas consumption is imported and 40% of the total import comes from Russia (European Commission, 2014).

To combat this weakness, the European Union (EU) has established a strategic plan for secure, affordable and environmental-friendly energy for all its citizens. As part of this plan, the Third Energy Package, adopted in 2009, has the goal to open up the internal electricity and gas markets of the European Union. It pushes for a separation of energy production and transmission, stipulates the establishment of national regulatory authorities and creates the Agency for the Cooperation of Energy Regulators. *Solidarity* in energy matters is a key point in the Treaty on the Functioning of the European Union as well as in the Energy Union. In fact, the first point of the EU's energy union strategy is: security, solidarity and trust.[1] In the 2014 Energy Security Strategy Communication the European Commission clearly declared how this should be interpreted.

> "Government interventions that affect this market framework, such as national decisions on renewable energy or efficiency targets, decisions to support investment in (or decommissioning of) nuclear generation, or decisions to support key infrastructure projects (such as Nord Stream, South Stream, TAP or a Baltic LNG terminal) need to be discussed at European and/or regional level to ensure that decisions in one member state do not undermine security of supply in another member state". (European Commission, 2014)

Natural gas is commonly transported via a network of national and international pipelines. The Nord Stream pipeline, which connects Russia and Germany, respectively the largest supplier and consumer in Europe, became operational in 2011. Nord Stream 1 has already led to political tensions within the EU: Central European Member

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[1] See https://ec.europa.eu/commission/priorities/energy-union-and-climate_en.

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States viewed it as a Trojan horse, a way to undermine the region's diversification efforts (European Policy Strategy Centre, 2016). The EU introduced restrictions allowing the pipeline to be utilized at only 27.5 from 55 billion cubic metres (bcm) or half of its capacity. Recently the limitations were lifted, utilization reached 93% by 2017 and negotiations started to double transmission capacity to 110 bcm.

By August 2018, the project received permits from Russia, Finland, Sweden and Germany, but not yet from Denmark. To prevent further delay, Gazprom identified an alternative route avoiding Danish territorial waters and started the construction. A year later, three quarters of the work was completed and soon Denmark gave consent to construct the pipeline through her continental shelf area. Meanwhile the US threatened participating companies with sanctions and as a final twist Swiss pipelay contractor Allseas halted work. Gazprom remained adamant that they will find a solution to complete the pipeline. We study the consequences of opening Nord Stream 2.

Propagators of Nord Stream 2 argue that the project is commercially viable.

⊕ Declining European production capacities cannot meet rising net demand.

⊕ Nord Stream 2 helps to lower gas prices in the EU.

⊕ Key pipelines in Ukraine are reaching the end of their service life and lack viable alternatives.

⊕ Ends the uncertainty of the Ukrainian transit route.

What are the main arguments *against* the project?

⊖ Does not diversify the EU's energy supply.

⊖ Adds to an infrastructure overcapacity in the EU.

⊖ Undermines the economic sanctions towards Russia.

⊖ Incompatible with the Energy Union's strategic goals and with the Third Energy Package.

Let us elaborate on the above points.

The demand for natural gas has declined in Europe during the 2010–2013 period largely due to the 2008 financial crisis and the subsequent recession and the migration of manufacturing industry to other world regions, but the lack of population growth and high prices have also contributed to the effect. Although there is currently an oversupply in the market, the trend has already reversed. Asia continuously diverts the LNG production surplus, while the US shale gas with its high variable cost and high sensitivity to LNG market prices cannot currently compete with the cheap Russian gas. The International Energy Agency (2017) forecasts flat demand and an average annual decline of −2.5% for European production. This amounts up to 34 bcm deficit in the 2017–2022 period and possible more in the future. Nord Stream 2 aims to close this gap.

Russia claims that renovating Ukrainian lines would cost more than €9.5 bn, the construction cost of Nord Stream 2 (National Energy Security Fund, 2016). The new route is shorter and more efficient due to the inner pipeline coating which reduces friction and lowers the amount of compression needed to push the gas through (Barnes, 2017). Furthermore, alternatives, such as the planned Southern Gas Corridor, connecting Azerbaijan to Europe, are too small to make any difference. As a result of lower average EU gas prices, Hecking and Weiser (2017) forecast a €13–35 bn annual welfare benefit for the EU-28.

Gazprom has also obtained half of the funds from five European energy companies, suggesting that these firms also expect profits, although four of them (Uniper and Wintershall from Germany, Engie from France, and Shell from United Kingdom/Netherlands) are based in countries that are clear beneficiaries of the project (cf. Table 3; the fifth firm being the Austrian OMV).

On the other hand, Nord Stream 2 received harsh criticism from both sides of the Atlantic. In March 2016, eight EU leaders, the prime ministers of the Czech Republic, Estonia, Hungary, Latvia, Poland, Slovakia and Romania and the president of Lithuania have signed a letter warning that Nord Stream 2 would generate "potentially destabilizing geopolitical consequences". A European Parliament resolution adopted in the same year describes Nord Stream 2 as harmful to energy security, diversification and European solidarity (European Economic and Social Committee, 2016). According to the European Policy Strategy Centre (2016), the European Commission's in-house think tank "Nord Stream 2, seen from a common EU perspective, is a project with neither economic rationale nor political backing", furthermore the project far exceeds the renovation costs of the Ukrainian route at €6 bn. Riley (2016) argues that Nord Stream 2 threatens to plunge the Central Eastern European states back into a pre-2004 market of greater supply security risk and greater Russian leverage in their markets. Similar concerns were raised before the construction of Nord Stream 1 and these turned out to be well-founded. While Nord Stream 1 brought new supplies to compensate declining internal production, EU officials documented various abusive practices of Gazprom's market power, primarily in Eastern Europe (European Commission, 2018).

Ukraine alone is to lose an estimated $2 billion from transfer fees and, to a lesser extent, the EU members Slovakia, Hungary and Poland would be also harmed by Nord Stream 2 (Fischer, 2016) — violating the principle of solidarity of Treaty on the Functioning of the European Union. The European Commission has therefore proposed to explicitly extend EU internal energy market rules to cover offshore gas pipelines. The legal services of the Council of the European Union – where, incidentally, the constructing countries have a blocking minority – has opposed the legislative proposal. Eventually a compromise was reached in February, 2019. Although the adopted text is less clear-cut than the original proposal had been, it is the first document declaring the Union's jurisdiction over Nord Stream 2. It asserts, that the Member State with the first interconnection point is primarily responsible for applying EU rules on pipelines with third countries. The legal framework for the entire pipeline will be established either through bilateral German–Russian talks or an intergovernmental agreement between the EU and Russia, negotiated by Germany or the European Commission (Łoskot-Strachota, 2019).

There is already an infrastructure overcapacity in the EU in the sense that imports amount to less than half of the existing infrastructure capacity (European Policy Strategy Centre, 2016). Finishing Nord Stream 2 and Turkstream, Russia's overall export capacity of 340.5 bcm (198.5 bcm without the Ukrainian corridor) will tower over the 161 bcm of estimated upper limit of her exports to the region in 2025 (Vatansever, 2017). Nord Stream 2 does not diversify the EU's energy supply neither from an energy source perspective nor from a route perspective as (i) Russia is already the main supplier of Europe and (ii) the pipeline would lead to a concentration of routes in the Baltic corridor. Similar concerns have been expressed by senior figures in the US administration — although they are hardly impartial as Europe is a prime target for future shale gas exports. Vainio (2019a,b) on the other hand looks at energy transformation to renewables and the risks related to "geopolitical changes in countries dependent on fossil fuel production" Vainio (2018), that is, — *sine nomine* — Russia.

Both narratives have compelling elements, and both are true to some extent (see Goldthau, 2016 for a more in-depth analysis). As Fischer (2016) put it, the EU has to decide on what should drive its natural gas policies: the market approach or the geopolitical approach. In this paper, we aim to answer whether the concerns are well-founded or not. We model the European gas network as a cooperative game and numerically assess the influence of the stakeholders in the different scenarios.

The structure of the paper is accordingly. After a brief literature overview, we introduce our model, and explain the limitations. Next we discuss the data we have used and present the main findings. Finally, we discuss the possible network development alternatives in the conclusion.

2. Literature overview

The cooperative game theoretic approach in studying natural gas networks was pioneered by Hubert and Ikonnikova (2011), and was soon followed by a number of papers that analysed different segments of the European and Central Asian markets. Roson and Hubert (2015) presents a detailed discussion of bargaining games on network markets.

Hubert and Ikonnikova (2011) analyse how Russian natural gas reaches the European market through the Eastern-European gas network, and derived bargaining powers by calculating the Shapley-values for the stakeholders. The scope of the paper is limited to seven countries, among which Russia was the only supplier. Hubert and Coblani (2015) extend this framework to a full scale analysis of the European network comparing three scenarios corresponding to the Nord Stream 1, Nabucco, and the South Stream pipeline projects. They construct a cooperative game by calculating profits of coalitions. In contrast, we focus on how much cost a coalition can *save* by cooperation. An even more important difference is that instead of optimizing the network flows of a coalition in one step, we do it iteratively, country-by-country according to a given order. We do this in order to obtain a more fitting model of the gas market with predominantly long term bilateral contracts. One advantage of this approach is that flows corresponding to the consumption of individual countries are well-defined.

Cobanli (2014) also uses the cooperative approach to assess the bargaining power of Central Asian countries. He considers various projects, both East- and Westbound,[2] and concludes that there is no demand competition between Europe and China. To deal with the externalities raised by the third-party-access policy imposed by the EU regulations, Csercsik et al. (2019) replace the characteristic form approach and represent the game in partition function form (Kóczy, 2018).

Among other approaches Holz et al. (2008) and recently Abada et al. (2013) consider strategic, while others highly detailed numerical models including the EUGAS model by Perner and Seeliger (2004); the TIGER model developed by EWI Institute in Cologne (Petrovich et al., 2016; Lochner, 2011); the ambitious Global Gas Model (Egging et al., 2010). A non-linear model is presented by Bouwmeester and Oosterhaven (2017).

Additionally, there is a handful of papers that offer scenario analyses or consider the potential impact of new pipelines: Mitrova et al. (2016) reviews a number of scenarios, including the disruption of the Ukrainian transit, and conclude that the European gas mix is fairly robust, and will include a significant share of natural gas from Russia in all studied scenarios. Richter and Holz (2015) also analyses Russian natural gas supply disruption scenarios using the Global Gas Model. Dastan (2018) investigates the bargaining positions of Russia and Turkey in view of the Turkstream (formerly Turkish Stream) project. Aune et al. (2017) use the numerical energy market model LIBEMOD to investigate long-run effects of increased export capacity of piped Russian gas. They find that the projects Nord Stream 2, Turkish Stream and Power of China all lead to moderate increases in net total Russian export, but the increases are lower than the capacities of the new pipelines.

3. Model

In this section we describe our model. We are interested in calculating the *values* of countries or country-groups, representing their bargaining power. First, we shortly define the cooperative game theoretic framework, and the Shapley value. Following this, we describe our modelling assumptions, and discuss how the coalitional values are determined in our case.

3.1. Coalitional cooperative games

The bargaining between a buyer and a seller – or a consumer and a producer – is best modelled by a cooperative game. When we have more buyers and/or sellers we may also want to consider trades among more than two players, especially when the transmission of the goods must also be taken into account. Such trading groups are *coalitions* and the members are the *players*. Of course, we can consider the possible trade with any group or coalition of players — the realized utility is called the characteristic value of the coalition.

Formally, the *characteristic function* $v : 2^N \to \mathbb{R}$, where N is the set of players, gives the value a coalition is able to obtain via cooperation without the help or participation of players outside the coalition. One-member coalitions are termed *singletons*.

In our case, the values of the coalitions will be defined as the savings resulting from transporting (trading) gas within the coalition. We interpret these savings in the following context. We assume that every consumer node of the network has a given (inelastic) demand for gas. If this is not fully supplied, it must use its (expensive) backstop source: alternative energy sources (renewables, coal, etc.), or alternative technologies requiring less energy. The backstop source can also be interpreted as the cost of government intervention to mitigate damages due to the gas shortage. The gain of a coalition is then the cost saving from consuming natural gas instead of the expensive backstop source.

The cost function $c : 2^N \to \mathbb{R}$ assigns a non-negative value to each coalition, the cost of supplying that coalition using only the network connections and resources that are available within this coalition. Then

$$v(S) = \sum_{i \in S} c(\{i\}) - c(S), \tag{1}$$

that is, the difference between the cost of coalition S and the total cost of its members as singletons (when consumers use their backstop sources).

Later in Section 3.5 we describe the details how the cost savings are calculated for each coalition, and in Section 3.6 we provide an example of how these values are calculated in the case of a simple network. In the next subsection, we introduce the Shapley-value, which represents the bargaining power of individual payers in a characteristic function form cooperative game.

3.2. The Shapley-value

Usually, full cooperation is the most beneficial scenario for the players (that is players are expected to form the so-called *grand coalition*, N). On the other hand, it is not trivial how the gains of $v(N)$ are divided.

The share a player manages to secure from the value of the grand coalition $v(N)$ can be considered as an indicator of power. We discuss different solution concepts in Section 6.3. In general, more successful a player is in generating value for himself or others, the more he in entitled from the whole cake.

In consumers-only coalitions there is no cost saving, each player uses its backstop source. Similarly, without consumers there is no opportunity for cost saving. Finally, in mixed coalitions, suppliers and consumers without connections cannot reduce costs. Consequently, when a player joins a coalition, his contributions can be one or more of the following types: production, consumption and transit.

1. A new, inexpensive gas source is the most obvious way to reduce costs by replacing some of the more expensive sources. By our assumption, all players can satisfy demand by alternative energy forms if no gas is available, so the first contribution is to replace these alternative forms.
2. Producers cannot reduce costs unless there is demand. A consumer would normally use its own backstop sources; in cooperation these backstop sources are replaced by natural gas, thereby saving costs. Therefore consumer countries create value (i.e. cost saving) by having a demand that can be satisfied.

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[2] Including the TAP, TANAP and TCP projects, which we also review in Section 7.

3. Finally, gas must travel from producers to consumers. By linking them, transit countries make the aforementioned savings possible. For existing routes, a less expensive alternative may also reduce costs.

When a coalition forms, members join one-by-one, and each member contributes a non-negative amount to the cost saving. Existing members are not harmed if (almost all) of this saving is kept by the new entrant. Considering all possible orders we can calculate the average marginal contribution to the cost saving of each of the members of the coalition. This is known as the Shapley-value (Shapley, 1953). Formally, the Shapley-value of a player i, denoted by $\phi_i(v)$ can be calculated as follows:

$$\phi_i(v) = \sum_{S \subset N, S \not\ni i} \frac{|S|!\,(|N \setminus S| - 1)!}{|N|!}\,(v(S \cup \{i\}) - v(S)) \tag{2}$$

where $|S|$ denotes the number of players in coalition S.

What do the Shapley-values tell us in our context? As our game will represent natural gas trading on the European network, the Shapley-values are the expected contributions of players to savings in the entire European market. Regarding on consumers, the saving originates partly from replacing the backstop source by cheaper gas and is partly from helping others to save by providing transit lines. In the latter case part of the saving is kept as a transit fee, which comes on top of the transfer costs and can be seen as the profit of the transit operation. Both reduce costs and with some simplification we can say that a higher Shapley-value implies cheaper gas in a region. Much of the value is, however is simply due to the size of countries. It is more interesting to see how the power distribution *changes* with the network: what is the effect of new pipelines built, who gain and who lose with them. Similarly, the closing of certain pipelines may harm some, but may benefit others.

3.3. Modelling assumptions

In this subsection, we summarize the assumptions, which are used through the modelling calculations.

Players. We identify the stakeholders of the gas market with countries, represented by nodes in the graph of the pipeline network corresponding to the main distribution hubs. Considering the strategic importance of managing gas supply it seems fair to assume that production, transportation and consumption are coordinated at the national level in each country and is also in line with the strive for national energy authorities as stipulated by the Third Energy Package. Note that the legislative negotiations within the EU concerning the regulation of Nord Stream 2 also took place on a country level.

Demand. For each node, we assume a non-negative perfectly inelastic demand (zero for source nodes).

Regions. For computational reasons – the calculation of the Shapley-value is factorial (cf. Eq. (2)) – we need to simplify the player set. We assume that certain countries always act together: join or leave coalitions collectively. Players may then represent individual countries or *regions* consisting of multiple nodes of the network. The latter is an important point: The underlying pipeline network is unaffected; supplies, demands and eventual flows are considered for each member country separately.

Ordered players. We assume that suppliers focus first on the largest markets that provide the largest part of their revenues: countries with higher demand have, effectively, priority over countries who import less gas. In the context of our model, this implies that 'large' players grab the less expensive sources and the remaining supply (and transmission capacity) is shared among the rest. We formalize this assumption in Section 3.5 and check for robustness in 6.2.

Transportation costs. Pipelines constitute the other component of the network. While there may be specific costs to using each pipeline, we assume that the transportation costs are uniform, proportional to the volume and to the length of the pipeline (1.5 m$/bcm/100 km). Having a fixed number is convenient both for estimation, but is also in line with the mid-term goals in the European Union to liberalize access to (international) pipelines.

Sourcing costs. In order to calculate the cost savings we specify the production or *sourcing cost* for the suppliers and the price of the alternative or backstop source for consumers. We use expert estimations for sourcing costs; we assume that the Russian gas is somewhat cheaper than the Norwegian and North-African gas. The price of the backstop source is uniform across all consumers and is 2–3 times higher than the sourcing cost. Our robustness analysis in Section 6.2 includes sensitivity checks to sourcing costs and backstop prices.

Quality. We assume that the natural gas transported over the network is homogeneous. Gas coming from different sources will differ in calorific value by up to 10% (Chandra, 2006, Chapter 1). Interestingly, consumers pay for the energy content, while for transportation capacities and costs the volume must be considered. As a result better quality gas is a little less costly to transport. Taking calorific capacities into account seems feasible, but transporting gases of different qualities over the same pipeline segment can be difficult. Either we have to handle 'cocktails' or add a complex scheduling problem. Cancelling counter-directional flows over the same pipeline is problematic if we do not assume homogeneous gas sources, as the gas quality may not be the same.

Now we move on to the technical details of our model.

3.4. Model formulation

We consider the European natural gas pipeline network as a graph, where each country is represented by a node and the pipelines connecting countries are the arcs of the network. The set of nodes is denoted by V, $|V| = n$ with a generic element denoted by i or j. The set of arcs is denoted by L, $|L| = m$ with generic element ℓ. The player set is denoted by N, a generic coalition by $S \subseteq N$. When N is considered as a coalition, we refer to it as the grand coalition. A player may correspond to multiple nodes in the network.

Now, we turn to the physical characteristics of the network. The network itself is described by an incidence matrix $A \in \mathbb{R}^{n\times m}$ where $A_{i\ell} = -1$ and $A_{j\ell} = 1$ means that arc ℓ runs from node i to j.

Edges, representing the pipelines are characterized by a maximal transfer capacity. The vector of transfer capacities is denoted by q. Transporting gas over these pipelines has its costs. A pipeline may travel across several regions and therefore it is convenient to define costs by a cost matrix $C \in \mathbb{R}_+^{n\times m}$ where C_{ij} is the cost of transferring a unit gas over pipeline j occurring in region i.

Each node is characterized by exogenous or perfectly inelastic demand and a production value, $d^0 \in \mathbb{R}_+^n$ denotes the vector of demands and $s^0 \in \mathbb{R}_+^n$ the vector of (maximum) supplies. In the following we modify these to obtain the net demand and net production vectors, $d, s \in \mathbb{R}_+^n$: There are fundamentally two types of regions: those where the production capacity is higher than the domestic demand and those where it is not. In the first group we assume that domestic consumption is fully satisfied by domestic production, and domestic production is reduced by this amount. In the latter the domestic consumption uses up all the production and the net import is the remaining part. Hence, we define

$$d_i = (d_i^0 - s_i^0)^+ \quad \text{and} \quad s_i = \left|d_i^0 - s_i^0\right| \tag{3}$$

where $(\cdot)^+$ denotes the positive part, that is $(x)^+ = \max\{x, 0\}$ for any $x \in \mathbb{R}$. Note, that if $d_i^0 > s_i^0$, then country i has no real excess supply, still s_i is positive. We will come back to this issue in a moment.

As mentioned in Section 3.1, we assume that countries that do not receive enough gas to satisfy their demand use some kind of backstop source: We model it by providing the countries with a virtual energy source that can satisfy all residual demand, but this alternative is more expensive.

Production has different costs in different countries, in particular, the backstop energy source has a unit price $\bar{p}$ that is (much) higher than the cost at any of the producers. The price of producing one unit of gas is called the sourcing cost and is represented by a vector $p \in \mathbb{R}^n_+$. For consumer countries, where demand exceeds domestic supply capacities, p_i is set to $\bar{p}$ — the price of the backstop energy source. That is, consumer countries also have supply capacities (that is the reason we defined s_i as $\left|d^0_i - s^0_i\right|$), but they can produce gas only for the price of the backstop source ($\bar{p}$/bcm). This technical detail ensures that each country can satisfy its own demand albeit in this case at a higher price.

3.5. Optimal flows

In this subsection, we describe how the cost saving of a coalition is determined as gas trade takes place on the available pipelines. The first best approach would be to minimize the overall cost of satisfying all demand. This can be done by transporting supplied gas to the demand sites via the cheapest available route, but more expensive sources, routes or even backstop sources may be used due to bottlenecks of production or transportation capacities.

Under the optimum, which describes the cheapest possible supply of a given coalition, the flow over the pipelines is given, but in the case of multiple sources or consumption sites and branching flows it is not clear which gas molecules turn left or right at a node. Hence, we cannot necessarily distinguish between the flows of individual countries.

The approach we opted for resolves this issue. As foreshadowed in Section 3.3, we assume that producers supply the larger consumers first. In practice, this means that 'large' players grab the less expensive sources and the remaining supply – and transmission capacity – is shared among the rest. As a result, we may run out of transfer capacity too soon making some smaller players unable to use optimal, inexpensive sources. The overall cost will therefore increase, giving us a second best solution: In the order of demand, countries satisfy their needs at the lowest possible cost using the available sources and transport capacities; this consumption is removed from the market and for the next player the flows are calculated using residual production and transfer capacities and so on.

Similar calculations are also possible when only a subset S of players participate in the network transfer. In this case the optimization is restricted to the supply of the elements of S using the production and transportation capacities of S. The latter condition also implies that only pipelines where both endpoints belong to the coalition can be used. We do not exclude pipelines that travel through regions belonging to a third party. Using these calculations the total cost of supplying the coalition can be determined. Comparing this cost to the individual (singleton) costs of gas supply we obtain the cost saving due to cooperation. The flow chart of this calculation process is shown in Fig. 1.

The iterative method we described here stands in contrast with the approach of Hubert and Ikonnikova (2011), Hubert and Coblani (2015) and Cobanli (2014), where the optimal flows for each coalition is calculated in one step. The natural gas market is driven by long-term contracts. Suppliers negotiate with each consumer one-by-one. Here we assume that bigger markets have priority over smaller ones. In case of a capacity shortage this seemingly technical detail makes a difference. In addition, we can distinguish between the flows of each player, even when they are integrated in a coalition. Hence, the individual cost can be accounted for, which is helpful if we want to keep track which region benefits from the cheap Russian gas.

Note that because of the ordering the game is not superadditive, that is there might exists some coalitions, S, T such that $S \cap T = \emptyset$ and $v(S) + v(T) > v(S \cup T)$. The intuitive explanation is that, when a player with higher priority joins a coalition, he may request that some cheap gas previously supplied to a lower priority player should be delivered to him. Although the amount of gas that is replaced by the backstop source might not change, the overall cost of the coalition could decrease, because the route from the supplier to the high priority player is longer and more costly than the route to the low priority paper.

In the following, we define the formalism required for the determination of the cheapest possible supply of a coalition: the solution of a linear programming (LP) problem. Readers who are less interested in mathematical details should note that the following description is just a simple flow model with multiple sources and sinks.

Formally, let $f^+_\ell \in \mathbb{R}_+$ denote the flow in the positive direction over edge ℓ, and let $f^-_\ell \in \mathbb{R}_+$ denote flow in the opposite direction, f^+ is the vector of positive directional flows on all edges while f^- is the vector of negative directional flows on all edges. Let $I \in \mathbb{R}^n_+$ denote the inlet values at the nodes. The variable vector is then

$$x = \begin{pmatrix} f^+ \\ f^- \\ I \end{pmatrix} \in \mathbb{R}^{2m+n}_+. \tag{4}$$

Let e^i and e^S denote n-dimensional indicator vectors for player i and coalition S, respectively:

$$e^i_k = \begin{cases} 1 & \text{if } k = i \\ 0 & \text{otherwise} \end{cases} \quad \text{and} \quad e^S_k = \begin{cases} 1 & \text{if } k \in S \\ 0 & \text{otherwise.} \end{cases}$$

Let E_S denote a diagonal matrix with e^S over the diagonal, let 1_n denote an n-dimensional vector of 1's, let $I^{k \times k}$ denote a k dimensional identity matrix, and let $0^{k \times l}$ denote a $k \times l$-dimensional 0 matrix.

We now describe the linear programming problem and then interpret the constraints. We minimize the cost of supplying player i in coalition S:

$$\min_x \begin{pmatrix} 1_n^\top C & 1_n^\top C & p^\top \end{pmatrix} x \tag{5}$$

such that

$$\begin{bmatrix} A & A & E^S \end{bmatrix} x = d_i e^i \tag{6}$$

$$I_j \leq s_j \tag{7}$$

$$\begin{pmatrix} I^{2m \times 2m} & 0^{2m \times n} \end{pmatrix} x \leq \begin{pmatrix} q^+ \\ q^- \end{pmatrix} \tag{8}$$

$$x \geq 0 \tag{9}$$

The objective function and the constraints are, actually, rather straightforward. We want to minimize the total cost that is the sum of the transportation costs in the positive direction, the transportation costs in the negative direction and the cost of gas itself. Naturally, gas does not flow over the same pipeline in both directions, it is only for the purposes of calculation that we separated the two flows. The first constraint explains that no gas is lost at any of the nodes: the total of inputs, inflows, outflows must add up to the consumption (d_i) that is zero except for player i. Inlets cannot exceed the supply capacities. The last condition merely insists on positivity. Finally constraint (8) explains that the flows must not exceed transmission capacities. Initially,[3] we set $q^+ = q^- = q$. Then in each round we recalculate the capacities. If over pipeline j the two capacities have been q^+_j and q^-_j and a flow f was allocated, then the capacity in the positive direction becomes smaller: $q^+_j - f$, but at the same time the capacity in the opposite direction has been expanded to $q^-_j + f$. The reason is that any flow in the opposite direction would be realized by reducing flow in this direction. This, of

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[3] Each pipeline has a characteristic transmission capacity in each direction: these are rarely symmetric. We could use these different capacities. Note, however, that necessary compression facilities to inverse the flow can be built at a relatively small cost. We therefore chose to consider the maximum of the two capacities and calculate less constrained optima.

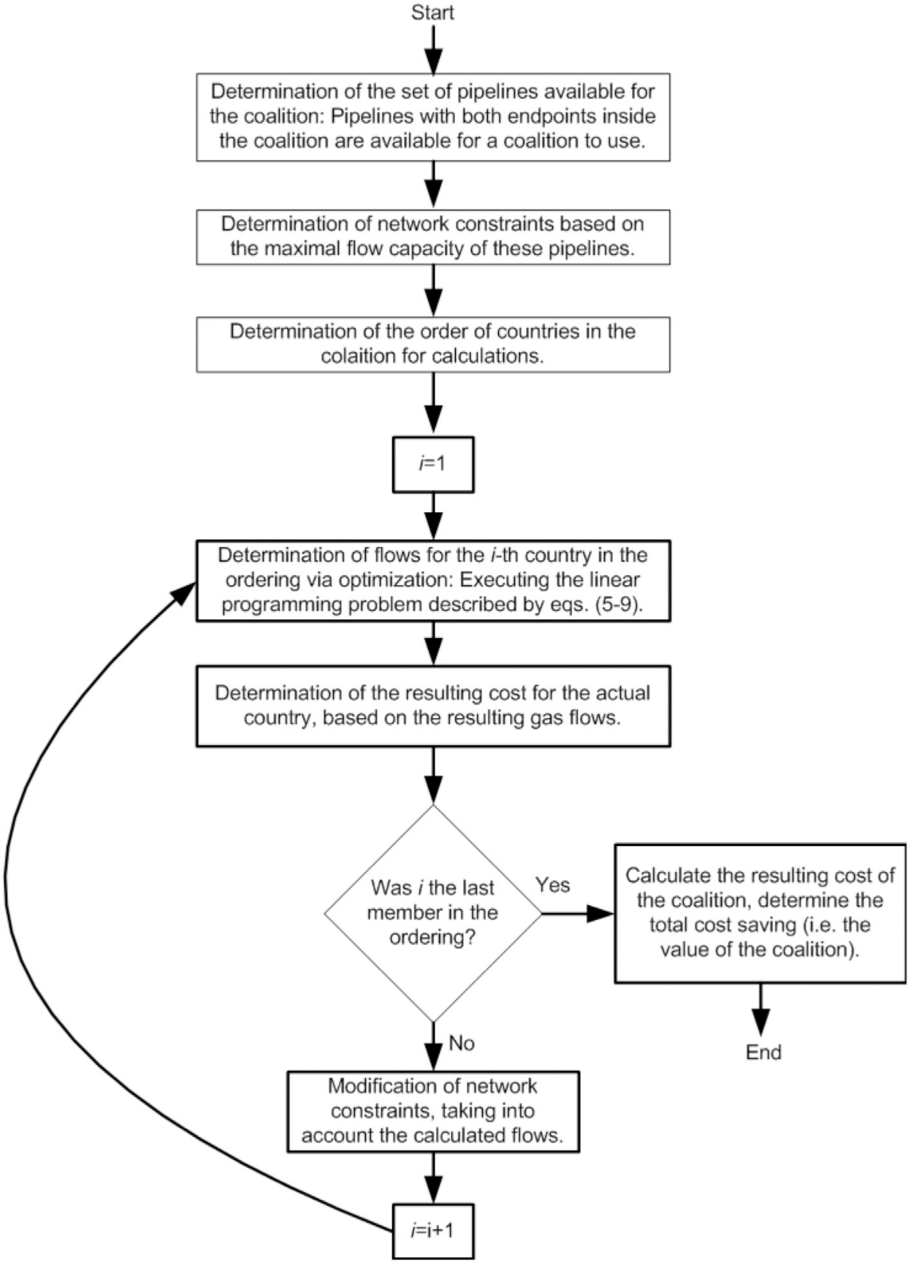

Fig. 1. Flow chart of the iterative flow calculations for a given coalition.

course relies on the assumption that gas is commodity where molecules are not labelled. We return to this assumption in the last section.

Let us summarize how the value of coalition $v(S)$, is computed.

1. For each $i \in S$ we compute the country's singleton cost $c(i)$, which is just $\bar{p}$ times its net consumption d_i.
2. In the predefined order (which depends on d_i) we compute the individual costs of the countries using the above LP iteratively. After each iteration we update the network (i.e. the flows and capacities).
3. We set $v(S) = \sum_{i \in S} c(\{i\}) - c(S)$ where $c(S)$ is the sum of the individual costs computed in Step 2.

3.6. Numerical example

Let us see an example how this works in practice. Consider the network depicted by Fig. 2, where each node represents a country. Four players are involved in this game, two suppliers S_1, S_2, and two consumers C_1, C_2. Note that C_1 is an aggregated region consisting of two countries. The numbers inside the nodes represent the priority ordering of the consumers, based on the decreasing ordering of their consumption values (100, 60 and 40 respectively), as described in Section 3.3. The numbers below the nodes show the available gas capacity of the country in bcm. Positive gas capacity shows that the country is a supplier, while negative gas capacity means that the country is a consumer. The numbers above the nodes represent the sourcing cost, or – in case of consumer countries – the price of the backstop source (in m$s). To make things simple each pipeline has unlimited transfer capacity and uniform transportation cost: 10 m$/bcm.

Let us see how the worth of the grand coalition (N) is calculated. First we look at the individual costs denoted by $c(\{i\})$ in Eq. (1), which serve as reference in the process of determining the value of the

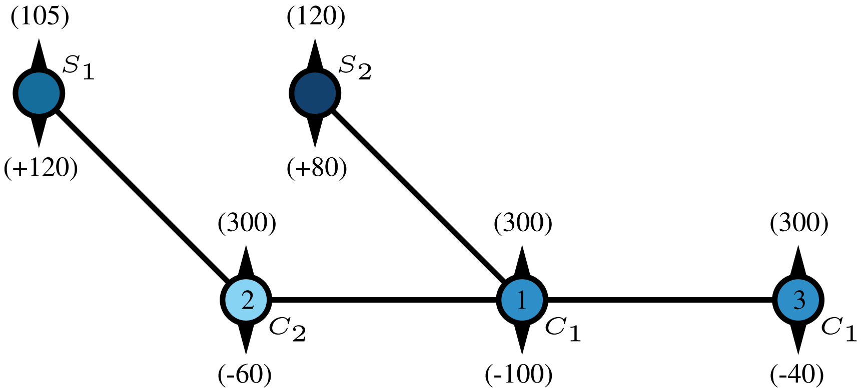

Fig. 2. Example of a gas network game. Numbers below the nodes correspond to production/consumption amounts, while numbers above the nodes correspond to production/backstop prices.

coalition. These cost are

$$c(C_1) = (100 + 40) \cdot 300 = 42000$$

$$c(C_2) = 60 \cdot 300 = 18000$$

Thus the sum of the individual costs is 60 000 (suppliers have a cost of 0).

As we consider the grand coalition, each pipeline and gas source is available for the consumers. Consumer countries are served in their order of priority.

The left node of C_1 is the largest consumer and the first in the ordering. This node imports 100 units of gas from the cheapest source S_1 for 125 m$/bcm (105 m$/bcm sourcing cost + 20 m$/bcm transportation cost).

In the case of this simple example, the calculations of optimal flows for the individual nodes are trivial, in general, this is done via solving the LP described in Eqs. (5)–(9).

Node C_2, the second in the ordering, imports 20 bcm from S_1 and the rest (as S_1 is depleted) from S_2. The problem is that the capacity of $C_2 - C_1$ pipeline is used in the reverse direction. The network operators solve this by letting less amount of gas through, that is, C_2 and the leftmost node of C_1 exchange gas molecules (but not suppliers). This technicality does not affect the import cost, which is $20 \cdot (105+10) + 40 \cdot (120 + 20) = 7900$ m$/bcm. Finally, the rightmost node of C_1 imports from S_2 for $40 \cdot (120 + 20) = 5600$ m$/bcm. The total cost and the characteristic value (cost saving) of the grand coalition is,

$$c(N) = 12500 + 7900 + 5600 = 34000$$

$$v(N) = \sum_{i \in N} c(i) - c(N) = 60000 - 34000 = 26000.$$

The same steps are repeated for each coalition (with the actually available lines and sources) to determine all costs and all values of the characteristic function (Appendix A, Table A.5).

Once the characteristic function is determined, the Shapley-values of the players can be determined via Eq. (2):

$$\phi(S_1) = 6.72 \cdot 10^3 \quad \phi(S_2) = 4.6 \cdot 10^3 \quad \phi(C_1) = 7.97 \cdot 10^3 \quad \phi(C_2) = 6.72 \cdot 10^3.$$

4. Data and calculations

Considering the data, our first task is to specify the network we consider. Our focus is on the international connections; we need to make a number of simplifications and in the following we outline the steps we had to take to make the network manageable.

4.1. Network simplifications

In our network model nodes are countries and arcs are international pipelines.

By “country” we mean a geographical location and the arcs connecting them are typically combinations of international and national pipeline segments. For the geographical location we use the main gas distribution hub; in Italy, a long country with hubs in the North and the South we picked an artificial location near Rome; in Germany, a country with a circular distribution network and multiple hubs we picked an idealized point near Frankfurt. For idealized points pipeline-distances are estimated. Russia operates with delivery prices. We provided the sourcing costs at the border. There is no benefit in further modifying to some hypothetical location inside the country and subtracting the cost of internal transportation from the sourcing costs to later add them back during the computations. The same applies to North-Africa, taken as a single player.

For computational reasons – the calculation of the Shapley-value is of non-polynomial complexity – we must reduce the number of players, therefore we calculate the values of *groups of countries* or *regions* as players (Fig. 3).

Finally, parallel pipelines connecting the same two countries were combined into a single pipeline with aggregated capacity and average length. Transportation costs were fixed at 1.5 m$/bcm/100 km on each pipeline.

4.2. Liquefied natural gas

In the past years, Liquefied Natural Gas (LNG) appeared as a new player on the European gas market. Liquefying is an alternative transportation method with a very different cost structure: While the required infrastructure is expensive and liquefying and gasifying is expensive, as tankers use the evaporated gas – the loss – from their tanks, distance-related transportation costs are negligible. LNG is a cheaper transportation method for distances beyond 4000 km than delivering compressed natural gas (Economides et al., 2006).

On the other hand supply depends very much on world market conditions elsewhere. In the past East-Asia was the strongest LNG market, lately more LNG appeared on the European market. Initially to serve remote, poorly connected areas, but increasingly to input into the pipeline network.

We include LNG as a new player with zero consumption, a production corresponding to current LNG imports to Europe and links to every player with significant LNG terminals. The low transportation costs would create wormholes in the network, connecting remote nodes with free pipelines so we shift the LNG source cost to transportation cost by assuming long “pipelines” (see supplementary data in Appendix B). Overall this does not affect the cost of using LNG.

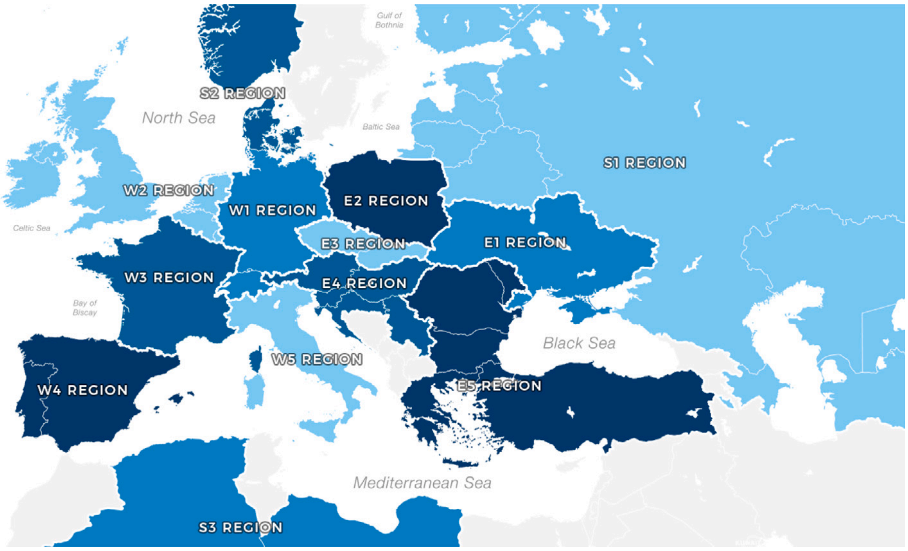

Fig. 3. Regions for calculating the Shapley-value.

Table 1
Sourcing costs and maximum supply by country.

Supplier	Sourcing cost (m$/bcm)	Supplied quantity (bcm)
Algeria	230	64.3
Central Asia	200	50.5
Denmark	225	1.9
Russia	220	192.8
Norway	225	118.7
LNG	240	56.6
backstop source	600	∞

Table 2
Data sources.

Data type	Sources	Homepage
Transmission capacities	IEA	www.iea.org
Pipeline length	ENTSOG	www.entsog.eu
Production/Consumption	BP,	www.bp.com,
	IndexMundi	www.indexmundi.com
Data verification	EIA,	www.eia.gov,
	HEA	www.mekh.hu/home

4.3. Sourcing costs

Table 1 compiles the sourcing costs. We assumed that the Russian gas is somewhat cheaper than the Norwegian and North-African gas. LNG is the most expensive alternative, however, it is still cheap compared to the price of the backstop source. Although the Central Asian sourcing cost appears to be lower than the Russian gas, considering the transfer costs of the circa 2000 km long pipeline that delivers the gas, it is equal in fact to the North-African sourcing cost.

4.4. Backstop sources

When local production and imports are insufficient to cover demand some of the demand for natural gas must be directed to other energy sources. In some cases this may be relatively easy, but in others nearly impossible. Ideally such a model should take a detailed replacement cost-function into account. In the absence of such information we have taken the replacement cost to be 600 m$/bcm. This is 2–3 times higher than the price of natural gas including transportation costs over the most extreme distances: consuming gas is always preferred even if it is far from the consumer. Our results proved to be robust to a wide range of replacement costs (see Section 6.2).

4.5. Data sources and implementation

Fortunately, developments of the natural gas market are well documented and data concerning national resources like oil and gas are published regularly by a number of reliable sources. Transmission capacities were compiled from the data sheet provided by the International Energy Agency (2020). Pipeline lengths were derived from the European Natural Gas Network Map published by the European Network of Transmission System Operators for Gas (ENTSOG, 2019). For consumption and production data we relied on the statistical yearbook of BP (2019). Missing data were gathered from IndexMundi, which in turn uses CIA Factbook as a source. LNG data were obtained from Rogers et al. (2018) and International Energy Agency (2020). We used alternative sources to verify our database, like the US Energy Information Administration and the private database of Hungarian Energy and Public Utility Regulatory Authority. The reference year was chosen as 2019 since at the time of the analysis this year had the most complete data available. The dataset is provided in Appendix B (for the sources see Table 2).

The model was implemented in the OPTI toolbox of MATLAB (Currie and Wilson, 2012), and the linear programming task was solved by the CLP solver, using the Dual simplex method (Vasilyev and Ivanitskiy, 2001).

5. Results

We have made use of a number of simplifications to translate a complex economic, engineering and even political problem into a simple mathematical setting. The calculation of the Shapley-values is based on the simplified game with 14 players. Beyond an evaluation of the current network we have looked at two modifications.

Firstly, the 2009 Ukrainian gas crisis, when Russia stopped exports via Ukraine was a scary incident for many countries in Southeastern Europe. More recent events did not reduce Ukrainian–Russian tensions and the risk of a future crisis remains high. As these pipelines are nearing the end of their service life, in the absence of refurbishment plans, closing seems inevitable. Our first alternative scenario is therefore the stopping of all Russian (and Central-Asian) gas exports via Ukraine.

Perhaps the most important recent and future development of the network is the construction of the Nord Stream, the longest sub-sea pipeline in the world, directly connecting Russia and Germany over the Baltic Sea. Nord Stream is already fully operational and its capacity is planned to be doubled by 2020; our Nord Stream 2 scenario looks at the network once the pipeline is completed.

At last, we consider a combined scenario: what happens if Nord Stream 2 is fully developed and then the Ukrainian connection is shut down: with the excess transportation capacities, Russia is likely to shift gas transports to the more efficient pipeline to save costs even if we ignore the geopolitical considerations (Vainio, 2019a,b).

Our results showing savings per region are presented in Table 3 and visually in Fig. 4. Since the figures exclude own consumption and are showing savings with respect to the estimated backstop costs, the absolute values are less interesting. What one should look at is the *change* in incomes or savings. Substantial changes may have drastic effects on a country's consumer gas price and even its financial stability.

Shutting down the connection via Ukraine harms Ukraine... but also Russia. It clearly affects Central-Eastern Europe negatively, since this area is supplied mostly by Russia, via Ukraine. On the other hand Norway, Algeria and the LNG suppliers come out positively, since they can be more competitive. Poland improves its position as an important transit country, but Slovakia and the Czech Republic lose this role. Simulations show that the Southeast Europe would have been negatively affected without the recently commissioned Turkstream pipeline (see Appendix B, Table B.7).

Expanding Nord Stream brings more Russian gas on the market, but we also see that some of the gas gets rerouted. Most of the benefit goes to Russia and Germany, while other suppliers and transit countries get competitors: Norway gets much cheap Russian gas right at its doorstep, Ukraine, Poland the Czech Republic, and Slovakia on the other hand, can now be bypassed with most of the Russian gas export.

It is interesting to see how a combination of these two changes would affect the players. Since Russia can bypass Ukraine via Nord Stream, we expect that it becomes less important to maintain the connection via Ukraine's Brotherhood pipeline. We find that the country that reaps the benefits again is Germany: it gets a direct connection to cheap Russian gas, plus it becomes its main distributor in most of Europe. Central-, and Eastern Europe is harmed, although to different extent. Poland is less affected, due to the fact that it remains a transit country. On the other hand, Ukraine, Central Europe and some part of the Balkans are severely harmed in this scenario.

If we consider Nord Stream 2 as a certainty and view the closing of the Ukrainian route as possibility occurring with some fix probability, then we can take the expected outcome of the Nord Stream 2 and Combined scenarios. Looking at the data like this, Western Europe comes out as winner, while Eastern Europe suffer massive losses. From this viewpoint, the political stance of the protesting Eastern European countries seems perfectly logical.

Finally, let us address the validity of the fears expressed by Fischer (2016), Riley (2016) and Vatansever (2017), namely, that Russia will completely bypass the Ukrainian transit route. From Table 3 we see that the closure of the Ukrainian route would decrease the Shapley-value of Russia from +7.5% to 0.8%. A fair assumption would be that should Russia decide to cease the supply through Ukraine, the Russian natural gas export revenues would not decline more than 10%. The volume of Russian export[4] in 2017 was around $342 bn from which natural gas took 5.2%, ca. $18 bn. Thus, the potential revenue loss for Russia is at most $2 bn.

In comparison, the Crimean conflict and the ensuing economic sanctions cost very likely more. Russian business newspaper, Kommersant estimated[5] the yearly cost of integrating Crimea into Russia around $3 bn. The effects of sanctions on Russian GDP is less clear. Kholodilin and Netšunajev (2019) found weak evidence that Russian and euro area GDPs declined as a result of the sanctions. On the other hand, Bloomberg Economics calculated[6] that the economy of Russia is more than 10 percent smaller compared with what might have been expected at the end of 2013. Admittedly, part of the loss is due to the plummeting oil prices, but 60% of the gap, ca. $137 bn, can be attributed to the sanctions.[7] The truth is possibly in between these two estimations. There are other costs, which are hidden or even harder to measure numerically, e.g. that EU countries supported the suspension of negotiations over Russia's joining the OECD and the International Energy Agency, for further details see a compilation in Tyll et al. (2018).

The point is, the Crimean conflict provided a precedent where Russia was willing to take financial losses to achieve political gains (both domestic and international). The question is whether the geopolitical gains exceed the costs of the closure of the Ukrainian route? In any case, a credible threat will likely increase the geopolitical influence of Russia.

6. Discussion

Our analysis uncovers strong predictions on the consequences of Nord Stream 2 — but is also built on a number of assumptions. In this section we discuss the possible relaxation of these assumptions and a sensitivity analysis to a wide range of parameters.

6.1. Relaxing assumptions

We have started our analysis with a series of simplifying assumptions in Section 3.3. Now we return to these to check if these could be relaxed — in the next subsection we also test the sensitivity to some of the assumed parameters.

Transportation costs. The differences between transportation costs is one of the arguments in support of Nord Stream 2 and yet we consider homogeneous costs. We are also aware of the differences between old pipelines and those still in the financing stage. Such differences could be accounted for artificially by an appropriate adjustment of pipeline length; a generalization to heterogeneous transportation costs is also feasible. For Nord Stream 2, an optimistic estimate of a 20% cut of transportation costs is equivalent to an 3.6 m$/bcm saving on transportation costs, which is not a dealmaker for any of the countries *vis-à-vis* the Ukraine route. Sensitivity analysis reveals that such a change would alter the bargaining positions by a few decimal points.

Sourcing costs. In our model we assume uniform sourcing costs for all consumers. Weiner (2016) reports a substantial variance between the Russian export prices which cannot be explained by the difference of transportation costs alone. Hinchey (2018) concludes that alternative options, such as LNG, increase the consumers' ability to lower prices and so, in practice, deals with different consumers may vary considerably. From a cooperative game theoretic point of view, however, it does not matter which country is successful in the price negotiations. The value of a coalition remains the same no matter whether the supplier or the consumer manages to impose his will. The final transactional price will only decide how this value is shared among the cooperating parties.

Our model, where any consumer can buy gas from consumers at the advertised price is somewhat different from reality. Consumers purchase gas in two different ways: At commodity exchanges at major pipeline hubs or – more commonly – via direct long-term contracts for undisclosed prices. For such contracts the supplier takes responsibility

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[4] https://oec.world/en/visualize/tree_map/hs92/export/rus/all/show/2017/.

[5] https://www.kommersant.ru/doc/2425287 (In Russian).

[6] https://www.bloomberg.com/news/articles/2018-11-16/here-s-one-measure-that-shows-sanctions-on-russia-are-working.

[7] Russia's GDP in 2013 was $2297 bn (source: https://data.worldbank.org/).

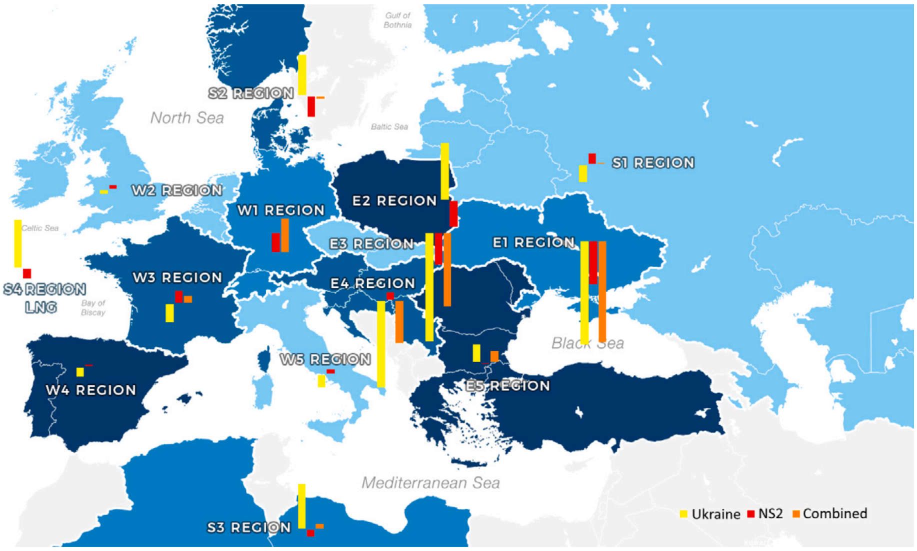

Fig. 4. Relative benefits per region versus the baseline scenario.

Table 3
Relative benefits per region versus the baseline scenario.

		Base	Relative change to base		
		(m$)	Ukraine	Nord Stream 2	Combined
	Suppliers				
S1	Russia, Belarus, Central Asia, Finland, Baltics	33 592	−12.1%	7.5%	0.8%
S2	Norway, Denmark	17 026	28.5%	−14.6%	−2.0%
S3	Algeria, Libya	8 518	31.6%	−5.2%	3.6%
S4	LNG	7 673	33.2%	−7.0%	−0.5%
	Western Europe				
W1	Germany, Switzerland	18 295	0.0%	13.8%	23.8%
W2	UK, Ireland, Benelux	13 605	−2.8%	3.3%	0.7%
W3	France	6 859	−13.2%	8.4%	5.0%
W4	Spain, Portugal	6 423	−6.6%	1.6%	0.1%
W5	Italy	11 114	−9.2%	3.5%	− 0.5%
	Central Eastern Europe				
E1	Ukraine	5 683	−71.8%	−30.3%	−69.9%
E2	Poland	4 040	39.4%	−18.2%	0.7%
E3	Czech, Slovakia	2 996	−75.0%	−22.0%	−50.9%
E4	Austria, Hungary, Croatia, Serbia, Slovenia	3 206	−60.3%	5.5%	−29.3%
E5	Turkey, Greece, Bulgaria, Romania, Moldova	11 040	12.6%	−1.1%	8.0%

for the delivery reserving transportation capacities. Undisclosed prices mean that producers may apply favouritism and price discrimination between consumers. The European Union is moving towards a more transparent market similar to the one modelled in this paper.

In Section 6.2, we look at an alternative scenario, where all sourcing costs (except LNG and backstop source) are set to 220 m$/bcm to check robustness.

6.2. Robustness analysis

We have performed a sensitivity analysis to see how much the obtained results depend on our modelling assumptions by looking at seven alternative setups:

- All sourcing costs equal to 220;
- Price of the backstop source is increased/decreased by 20%;
- Transportation costs are increased/decreased by 20%;
- Countries are ordered by consumption from the smallest to the largest one (i.e. in reverse order compared to the baseline);
- Transporting on Nord Stream 2 is 20% cheaper than the uniform transportation cost.

Rather than presenting figures for these artificial scenarios, in Fig. 5, we compare the changes in Shapley-values between scenarios under the nominal parameters (black marker; data from Table 3) to their range under varied parameters (box).

We have found that our results are robust: while each parameter has a measurable impact on the Shapley-value small variations do not change our main conclusion. In other words, the drastic shift in the bargaining power of the players is due to the changes in the network, namely the construction of Nord Stream 2 and the possible closure of the Ukrainian route.

6.3. Shapley value or nucleolus?

There are several approaches to “solve” cooperative games. We use the Shapley-value to calculate the power of the stakeholders. The nucleolus (Schmeidler, 1969) is also a possible choice for measuring power (Montero, 2013). The nucleolus is obtained through a lexicographic optimization process, where the profit of the poorest coalitions

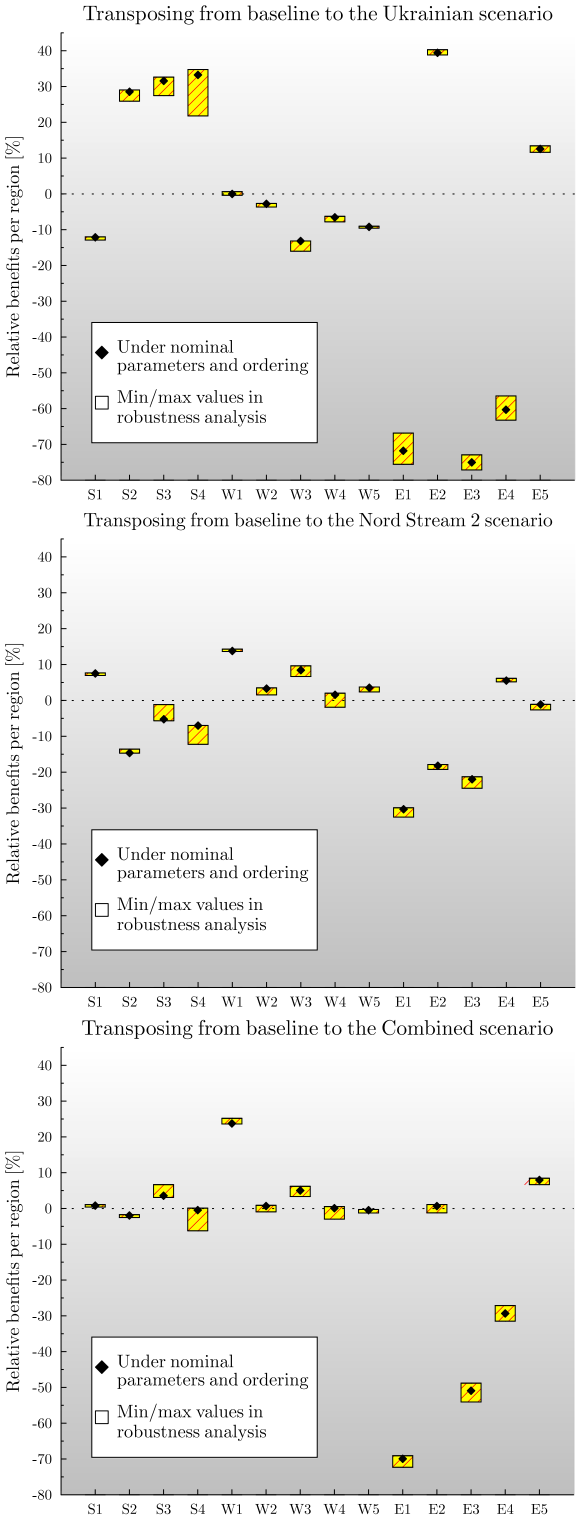

Fig. 5. Robustness analysis.

are maximized first. In this sense the nucleolus implements a kind of social justice while the Shapley-value rewards productivity, as the players' payoffs depend on their marginal contributions. Thus, it is not surprising that the Shapley-value proves to be a more reliable indicator of power in distribution networks (Hubert and Ikonnikova, 2011; Hubert and Coblani, 2015).

The *core* of a cooperative game shares the savings in a way that makes all coalitions happy, too: the total payoff of any coalition is greater than or equal to its characteristic value. The Shapley-value is commonly criticized for not – always – being a core allocation even if the core is non-empty. In such a case part of the network would refuse cooperation and would form a detached subnetwork reducing the overall saving. In practice, such a secession is not possible due to the complex legal framework supporting the pipeline network, but we may want to eliminate such risks or tensions anyway.

The nucleolus always lies inside the core — provided that the core is nonempty. There are various heuristics that make its computation simpler than that of the Shapley-value (Solymosi and Sziklai, 2016). For the sake of completeness, we have also computed the nucleoli (Appendix B, Table B.6) using a novel algorithm of Benedek et al. (2020). The result has been verified using the Kohlberg-criteria (Kohlberg, 1971).

Much like Hubert and Coblani (2015), we have found it difficult to interpret the numbers: Russia gains power when the Ukrainian route gets closed down, then loses power when the Nord Stream 2 is built? It is also hard to imagine that Norway becomes twelve times more powerful in the Ukrainian scenario.

In two out of the four scenarios the advantage of the nucleolus vanishes as the core of the game is empty, but even if the core is nonempty it may produce counter-intuitive results: The cooperative game that depicts the gas trade is very similar to a so-called glove game. In a glove game owners of left (say suppliers) and right-hand gloves (consumers) form valuable pairs (trade to reduce costs). In such games, the core is strangely biased: The side with the fewer gloves gets all the value. In our story, as the Ukrainian route and Nord Stream 2 gets switched on and off, the model alternates between over- and undersupply, which in turn might swing any core-based solution from one extreme to the other.

Another possible explanation is that the nucleolus focuses on the satisfaction of coalitions without considering their size. For instance, the satisfaction of Poland, and its complement coalition (the rest of the countries) are treated equally important. Variants of the nucleolus, the so-called *per-capita nucleolus* (Grotte, 1970), which considers the satisfactions of coalitions normalized by their sizes or the *proportional nucleolus* (Young et al., 1982), which considers relative satisfaction, might be more suitable for such games if one insist on having a core based solution.

7. Conclusion and policy implications

One interpretation of our result is that each country in Europe is governed by self interest. The past positions/actions taken by the countries strengthen this analysis. Jirušek (2020) inspects the attitude of Visegrád countries towards the Nord Stream 2 project and concludes that despite the declared unity, the Visegrád Group members pursue their own goals determined by economic interests or long-standing foreign policy stance.

Russia and Germany are the main beneficiaries and supporters of the Nord Stream 2 project. Northeast Europe, namely, Poland, Ukraine, Czech Republic and Slovakia oppose it because they will lose their advantage as transit countries. Central- and Eastern Europe fear that the construction of Nord Stream 2 will ultimately result in closing down the Ukrainian route in which case there will be a shortage of cheap Russian gas in the region. The Southeastern part is less affected thanks to the recently commissioned Turkstream pipeline. Without Turkstream, Turkey and neighbouring countries would have been in a much more difficult position in the case of a supply disruption via Ukraine. Network flows show, that even if Nord Stream 2 would provide significantly cheaper gas, the benefits would never reach the Eastern part of Europe. A way to maintain solidarity would be to introduce a compensation scheme or to support the construction of a pipeline in the direction of the cancelled Nabucco or South Stream pipelines.

Table 4
Possible pipeline projects. Capacities (cap.) in bcm; date of commission.

Name	Source	Destination	Integrate with	Cap.	Date
TANAP+	Georgia/Turkey	Turkey/Greece	SCP, TAP, Tesla?	15	n.a.
TAP	Turkey/Greece	Italy	TANAP, Turkstream?	10–20	2020
IAP	Albania	Croatia	TAP	5	n.a.
Tesla	Turkey	Austria	Turkstream, TANAP?	27	n.a.
TCP	Turkmenistan	Azerbaijan	SCP	30	n.a.
Persian	Iran	Turkey	TANAP?	37–40	n.a.
East Med	Israel	Greece/Italy	Cyprian gas fields	9–12	n.a.

One cannot but wonder if Nord Stream 2 and similar, somewhat controversial developments are consequences of the changes in the decision making in the Council of the European Union under the Lisbon Treaty (Kóczy, 2012). The changes increased the Council's ability to act, but also along the interest of a smaller majority than before. The changes have not affected all countries equally, medium sized countries typically losing some of their power. While under earlier, Nice-rules countries harmed by the project had formed a blocking minority, under the new voting rules they do not.

It is worth considering how the situation in the European gas market may change in the near future. The substantial investment costs, the interstate nature of pipeline projects and rapidly changing geopolitical interests make the gas network development very volatile. Hubert and Coblani (2015) analyse, among others, the impact of the Nabucco and South Stream projects, but by the time of publication both projects were officially cancelled. Declining inland production and the need to increase supply security, forces EU decision makers to commit themselves on further developing the European gas network. Consequently there is no shortage of project plans, but not all are equally viable. Table 4 summarizes the potential projects.

The most promising alternative of Russian gas is to connect Central Asian gas fields with the European market. The Southern Gas Corridor consist of three independent pipeline segment: the South Caucasus Pipeline (SCP), the Trans-Anatolian Natural Gas Pipeline (TANAP), and the Trans-Adriatic Pipeline (TAP). The SCP connects the Shah Deniz gas field of Azerbaijan, through Georgia, to the Eastern edge of Turkey. TAP starts from the Turkish/Greek border and runs to Italy, first through Albania, then under the Adriatic Sea. The recently commissioned TANAP runs through Turkey connecting SCP and TAP. Although SCP has 25 bcm annual capacity, TANAP can only transmit 16 bcm, which is little more than half of Western Turkey's net gas demand. It is unlikely that TAP will run dry though, as Turkey aims to increase TANAP's capacity to 22 bcm based on demand, and to 31 bcm immediately after with additional investments[8] and [Turkstream also became operational recently]. Turkstream will also supply the Tesla pipeline which in turn is planned to link the Black Sea with the Baumgarten gas hub in Austria. The Ionian Adriatic Pipeline (IAP) would connect TAP with the planned LNG terminal in Krk, Croatia.

Turkmenistan has the largest proven reserves of natural gas in Central Asia, 9.4% of the world total. The planned Trans Caspian Pipeline (TCP) would help to feed the SCP. The traditional route for Turkmen gas to Europe is through Russia, which is supposedly not happy of the prospect of having a competitor. Let us note that all the Turkmen pipelines are owned by Gazprom.

Iran possesses even larger reserves, 18% of the world total, and produces more gas than Qatar. However, it consumes nearly all of it. Now and then there are rumours of the Persian Pipeline that would run parallel with TAP and TANAP, but Iran has to invest in its production first, as they already have a gas pipeline to Turkey, which they are yet unable to fill.

Although the production in Europe is declining, this is not true for all countries. Romania may soon become a net exporter due to the increasing production on the Black Sea. The Middle-East might be another supply source. Apart from Iran, Egypt and Israel can also become potential producers. The former due to the discovery of the giant Zohr gas field, the latter due to rapidly developing gas industry in the Levantine Basin.

Meanwhile market diversification is not only important for Europe. Russia also made efforts to protect itself from disruptions. Visenescu (2018) reports that Russia is shifting its attention towards ASEAN markets. Ozawa et al. (2019) argue that the recently inaugurated Power of Siberia pipeline can have the double positive effect of creating more interstate stability between Russia and China plus greater regional and international power for Russia as the emerging main supplier for the Asia Pacific Region.

The profitability of these developments rests on many factors. Notably oil and LNG prices in general, which in turn depend on the demand in Asia, and the costs of the production of shale gas in the US (Rogers, 2015). Game theoretic analysis of the different scenarios can help us deciding which projects will be realized in the future.

CRediT authorship contribution statement

Balázs R. Sziklai: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **László Á. Kóczy:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Dávid Csercsik:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Software, Validation, Visualization, Writing - review & editing.

Declaration of competing interest

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

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[8] https://www.tanap.com/media/news/turkey-historic-tanap-gas-pipeline-project-goes-live/.

Appendix A. Numerical example

Table A.5
The cost and characteristic function values of the example in Section 3.6.

S	$c(S)$	$v(S)$	S	$c(S)$	$v(S)$	S	$c(S)$	$v(S)$
$\{S_1\}$	0	0	$\{S_1, C_1\}$	42 000	0	$\{S_1, C_1, C_2\}$	38 800	21 200
$\{S_2\}$	0	0	$\{S_1, C_2\}$	6900	11 100	$\{S_2, C_1, C_2\}$	46 400	13 600
$\{C_1\}$	42 000	0	$\{S_2, C_1\}$	28 400	13 600	$\{S_1, S_2, C_1\}$	28 400	13 600
$\{C_2\}$	18 000	0	$\{S_2, C_2\}$	18 000	0	$\{S_1, S_2, C_2\}$	6900	11 100
			$\{S_1, S_2\}$	0	0			
$\{\emptyset\}$	0	0	$\{C_1, C_2\}$	60 000	0	$\{N\}$	34 000	26 000

Appendix B. Supplementary data

Table B.6
Relative benefits per region versus the baseline scenario using the nucleolus as a power measure.

		Base	Relative change to base		
		(m$)	Ukraine	Nord Stream 2	Combined
	Suppliers				
S1:	Russia, Belarus, Central Asia, Finland, Baltics	24 567	0.5%	0.7%	−6.9%
S2:	Norway, Denmark	1 668	1191.8%	−39.3%	80.4%
S3:	Algeria, Libya	1 970	2.9%	−4.5%	10.3%
S4:	LNG	1 902	3.1%	−7.6%	0.3%
	Western Europe				
W1:	Germany, Switzerland	27 116	−22.0%	1.0%	8.8%
W2:	UK, Ireland, Benelux	22 671	−41.3%	1.4%	−6.2%
W3:	France	14 777	−51.7%	1.8%	0.1%
W4:	Spain, Portugal	9 831	−31.8%	1.3%	0.0%
W5:	Italy	21 489	−37.1%	0.5%	−1.1%
	Central- Eastern- Europe				
E1:	Ukraine	2 436	−21.2%	−9.7%	−23.2%
E2:	Poland	3 155	88.3%	0.2%	2.5%
E3:	Czech Republic, Slovakia	2 303	−29.0%	−2.4%	−5.2%
E4:	Austria, Hungary, Croatia, Slovenia, Serbia	3 834	−24.6%	−1.2%	−14.4%
E5:	Turkey, Greece, Bulgaria, Romania, Moldova	12 347	−2.4%	0.0%	−0.3%

Table B.7
Relative benefits per region versus the baseline scenario in 2016.

		Base	Relative change to base		
		(m$)	Ukraine	Nord Stream 2	Combined
	Suppliers				
S1:	Russia(+Belarus), Central Asia, Finland, Baltics	29 430	−16.1%	7.2%	−2.5%
S2:	Norway, Denmark	15 451	33.1%	−14.4%	−2.7%
S3:	Algeria(+Libya)	7 964	34.6%	−4.6%	5.1%
S4:	LNG	5 253	37.5%	−5.7%	−0.5%
	Western Europe				
W1:	Germany(+Switzerland)	17 953	8.0%	11.7%	30.4%
W2:	UK(+Ireland), Benelux	11 206	2.8%	3.0%	1.5%
W3:	France	6 968	−11.9%	7.0%	4.1%
W4:	Spain+Portugal	6 022	−5.2%	1.3%	0.0%
W5:	Italy	10 359	−9.3%	3.2%	−1.0%
	Central- Eastern- and Southern Europe				
E1:	Ukraine	5 495	−86.5%	−27.2%	−78.9%
E2:	Poland	3 326	59.2%	−19.0%	9.5%
E3:	Czech Republic, Slovakia	2 755	−58.7%	−18.8%	−25.8%
E4:	Austria, Hungary, Croatia, Slovenia, Serbia	3 257	−62.8%	6.1%	−32.4%
E5:	Turkey, Greece, Bulgaria, Romania(+Moldova)	7 271	−1.9%	−1.1%	−0.3%

Pipeline and LNG data can be found online at https://doi.org/10.1016/j.enpol.2020.111692.

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