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Modelling Natural Gas Markets:

Could We Learn from our Mistakes in the Past? - A Reality Check for MAGELAN

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Abstract

MAGALAN is a global gas market model developed in 2005 that provided forecasts until 2030 for gas production, international trade and other relevant parameters. As investors, policy makers and also researchers have a need of reliable model results, models should be faced with reality from time to time. This paper presents a reality check for some results from MAGELAN for the year 2020. Some forecasts show a very high accordance with actual figures (such as aggregated global gas production or total LNG trades), some other are far from recent developments in the real world (e.g. gas production of individual countries or realised capacities of specific pipeline projects). The paper finish with a brief discussion about reasons for the divergence between model and reality. Beside some improvements are likely with some updates to the model, major exogenous shocks will always be crucial for gas market modelling (respectively modelling in general). In that specific case, the "shale gas revolution" in the USA was such a major shock, that disturbed a wide range of gas market parameters.

Key words: Long term gas market modelling, linear optimisation, gas demand and supply, LNG, shale gas

Contents

1. Introduction

Natural gas investments are characterised by high costs and very long life times of some infrastructure elements, such as pipelines or LNG plants. Given this long-term character of gas investments, forecasting of future developments is an essential need for all players in the gas market. Ideally, those forecasts are based on well-designed, detailed and transparent models. From investors perspective, bottom-up respectively so-called fundamental models which are based on specific infrastructure elements, provide more helpful information compared to top-down models with rather gross aggregation levels (Zweifel et al. 2017, chapter 4 and 5).

As investors, policy makers and also researchers have a need of reliable model results, models should be faced with reality from time to time. This is obviously easier for short-term models, e.g. forecasting day-ahead prices (Gianfreda et al. 2020). Given the long time periods between date of modelling and years to be forecasted (in some cases up to 50 years or more), such reality checks are not as common as in more shorter-term models. Nevertheless, some reviews are undertaken, e.g. oil production and peak oil forecasts (Lynch 1998).

This paper presents a reality check for the global gas market model MAGELAN (Seeliger 2006). This model was developed in 2005 at the Institute of Energy Economics at University of Cologne. As its predecessor EUGAS (Perner/Seeliger 2004) and its successor COLUMBUS (Hecking/Panke 2012), MAGELAN is a powerful tool which helps to analyse global gas markets and to forecast their development over the next decades. Consequently, the model was used in various projects for energy companies or policymakers.

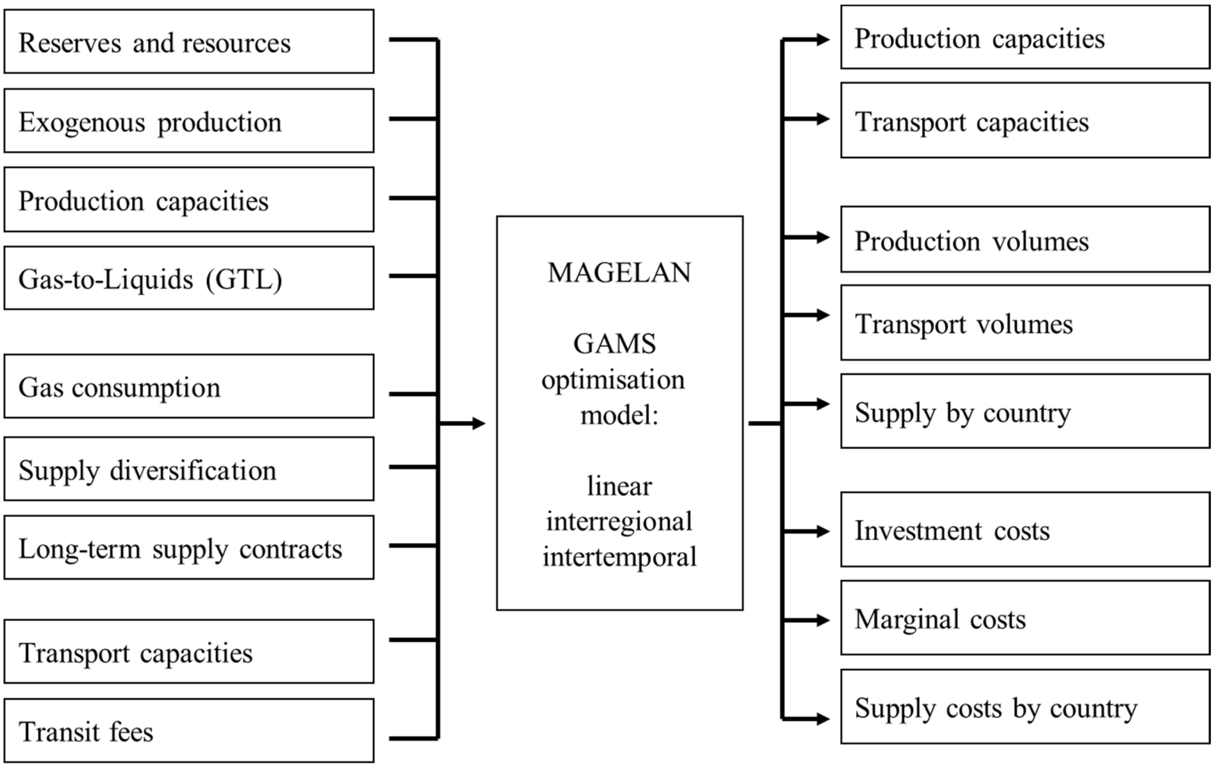
Section 2 gives a comprehensive overview of the model structure, followed by a reality check which compares actual data for 2020 with forecasted values for this year more than 15 years ago. The paper finish with a brief discussion of some of the differences between reality and model results. Finally, some thoughts are given, if some obvious mistakes are made in the modelling process and how some of the divergence could be avoided in future model versions.

2. Model Structure

MAGELAN is a long-term optimisation model for the global gas market (Seeliger 2006). It is designed as a supply-side model with exogenous given demand and is based on the assumptions of perfect competition. The forecast horizon covers five-years periods from 2005 to 2030. However, the model works with a significant longer timeframe to consider (a) investment cycles based on construction years in the past (starting 1970) and (b) to avoid the so-called “end effect” (Grinold 1983) which would bias the results especially in the last forecast periods (so the model has to calculate until 2055). MAGELAN consists of around 140 nodes, each representing a country or region, so that more or less the whole (gas-consuming) world is covered by the model. Those nodes could have various characteristics, such as gas consumption, gas production or LNG regasification respectively liquefaction. With respect to gas production, around 40 nodes (some major producing countries have more than one node with gas production, such as Norway (North Sea and Barents Sea)) are modelled endogenous, whereas for minor producers (such as Germany or Italy) gas production is covered by exogenous production assumptions based on individual forecasts. Concerning the programming, the code is written in GAMS (Brooke et al. 1998) and the used solver is CPLEX (GAMS 2005).

MAGELAN is based on a wide set of input parameters, which are summarised on the left side of Figure 1.

Figure 1: *Model structure of MAGELAN*



Source: Seeliger 2006, p. 32 (modified)

The main result categories are shown on the right side of Figure 1. The most relevant topics for forecasts are usually production volumes by country, capacity development of infrastructure projects or international trading flows. Beside gas volumes, also supply costs are a key output of MAGELAN.

3. Reality Check for Selected Model Results

Seeliger (2006) presented a reference case, which was designed to give a forecast based on at that time available data and assumptions (e.g. about resource development or technical progress) which seems to represent the highest probability of realisation. In this section, a reality check for some of the key model results will be conducted. All volumes are expressed in billion cubic meters per year (bcma), which might bear some statistical inaccuracies compared to other sources, as different sources using different energy units with partly not transparent declared assumed heating values per cubic meter.

3.1. Production by Country

Seeliger (2006, p. 97) provided production volumes by country for 2020. Table 1 compares the model results for the top 20 gas producing countries that are implanted by production nodes. The second column shows the model results for 2020 (by which the countries in the table are sorted), whereas the first column shows the status quo in 2004 (model input data) and the actual realised production volumes in 2020 (third column). The last column points out the difference between model results and reality: positive values means that the model results were too high and negative values indicates, that the model underestimated the production of the specific country.

Table 1: *Production volumes by country in bcma*

		Reality 2004	MAGELAN 2020	Reality 2020	Difference 2020
1	Russia	634	829	693	136
2	USA	533	513	948	-435
3	Canada	184	273	158	115
4	Iran	85	267	253	14
5	Qatar	39	234	185	49
6	Algeria	80	139	85	54
7	Turkmenistan	59	134	82	52
8	Indonesia	75	126	59	67
9	Norway	83	131	110	21
10	Venezuela	27	100	18	82
11	Saudi Arabia	66	96	103	-7
12	Malaysia	62	91	73	18
13	Nigeria	22	77	50	27
14	UK	96	63	40	23
15	Australia	35	65	154	-89
16	Netherlands	78	66	20	46
17	Egypt	33	67	62	5
18	Argentina	45	62	45	17
19	Uzbekistan	59	47	45	2
20	Kazakhstan	20	46	24	22
	Other	462	555	787	-232
	World	2777	3981	3994	-13

Source: Seeliger 2006, p. 97; BGR 2022, p. 83-87

In total, world gas production was 3981 bcma in the reference case, which comes quite close to the actual production volume of 3994 bcma in 2020 (BGR 2022, p. 87). This nearly perfect accordance is surprising (but pleasant, of course). This was not due to model calculations for production, but rather due to the exogenous demand forecast (Seeliger 2006, p. 59), which was based on a survey of various demand forecasts by IEA, EIA, EU, Shell and other sources.

When looking on individual countries, some forecasts hit the reality quite good (such as Uzbekistan, Iran or Saudi Arabia), but for some of the main producers, a wide gap between model and actual production has to be stated. The most distinguished divergence arises for the USA with an underestimation of more than 400 bcma. This could be explained by the so-called "shale gas revolution" (Joskow 2013). Even if the model input data already included an expansion of non-conventional gas resources in the USA, the extraordinary increase of gas production from shale gas fields was not foreseeable to full extent – at least not based on 2004 information basis (EIA 2004). The discrepancy of the US production, which accounts for more than 10 percent of global gas production in 2020, exuded to all other producers. As the USA don't rely on massive gas imports from all around the world (and in fact turned into one of the major gas exporters, as we will see in the next section), other producers had to reduce their production in this model world with given gas demand. In reality (or in a model with endogenous demand reactions) of course other effects as shrinking gas prices and increasing imports in other world regions could (and had in reality) arise. Despite this, actual production of producers like Russia, Canada, Qatar or Algeria lack behind the model results. Other producers had individual issues not covered by the model assumptions. The most prominent cases are Venezuela (massive economic and political crisis) and the Netherlands (earthquakes forced the Dutch government to abandon the giant gas field Groningen).

Another remarkable divergence between model results and real volumes in 2020 could be identified for the position "other". This includes on the one hand smaller producers implemented by a production node (such as Trinidad and Tobago, Angola or Denmark) and on the other hand consumption nodes with an exogenous given production (e.g. Germany, India or Brazil). Also included in the last group is China, which is responsible for the majority of the difference between model and reality. Most forecasts available in the early 2000s had been rather pessimistic about gas production increases in China. Therefore, China wasn't included in the list with an endogenous production node and only a, compared to the size of the country, minor indigenous production of 60 bcma was assumed. This was massively outnumbered by the developments in reality, which reached 205 bcma in 2020.

3.2. Net-Exports

The remainder of production and (potential) imports minus demand and (potential) GTL production accounts for the net-exports of a country. Table 2 summarises the top 10 net-export countries in MAGELAN's reference case for 2020.

Table 2: *Net-export volumes by country in bcma*

		Reality 2004	MAGELAN 2020	Reality 2020	Difference 2020
1	Russia	180	290	205	85
2	Canada	93	161	42	119
3	Qatar	24	147	155	-8
4	Norway	75	124	117	7
5	Turkmenistan	45	112	38	74
6	Iran	-2	106	21	85
7	Algeria	61	101	31	70
8	Indonesia	38	63	20	43
9	Venezuela	0	45	0	45
10	Nigeria	13	41	44	-3

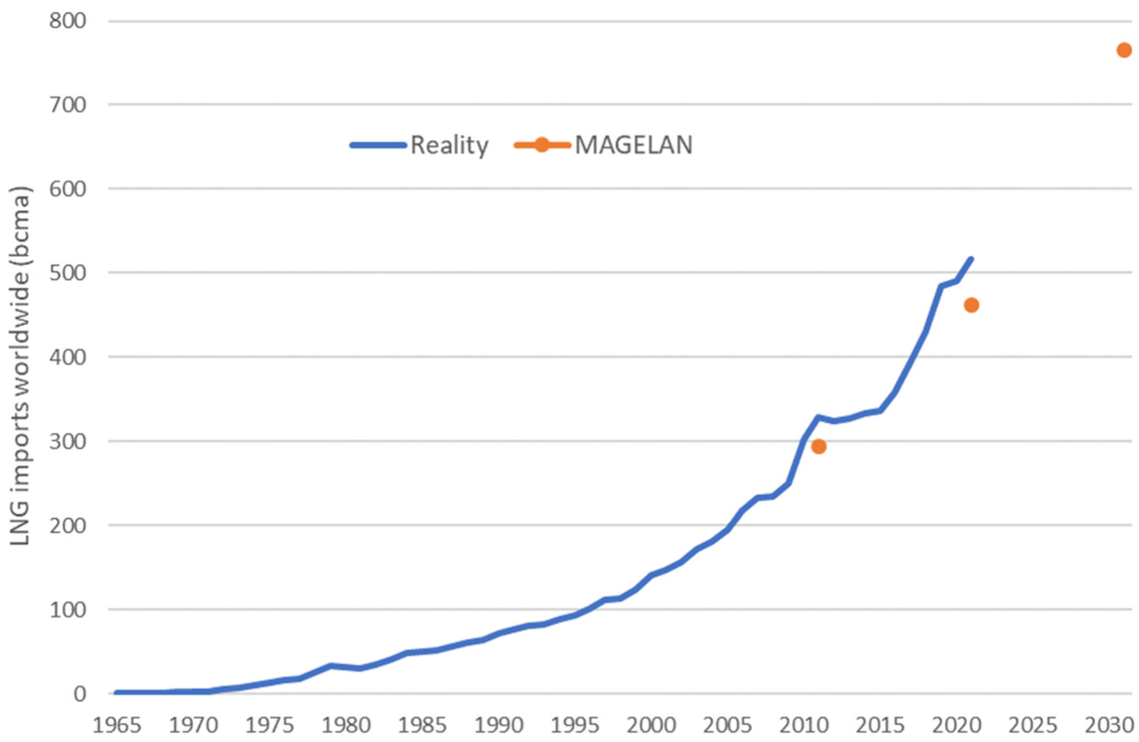
Source: Seeliger 2006, p. 118; BGR 2022, p. 83-87; BP 2022a, p. 31

Interestingly, all major exporters (except Qatar and Norway) had been highly overestimated. The reasons are individual for those countries. Some had much lower production in reality as forecasted, hence meaning a lower export potential (like Turkmenistan or Venezuela). Others met the modelled production level but had a higher domestic demand itself, which also lowers the export potential (e.g. Iran reaching an actual consumption of more than 230 bcma, which is more than double than assumed by reference case input data). The reason why Canada is so much below forecasts of the model, is because of the abovementioned shale gas revolution in the USA. Large amounts of the calculated exports of Canada had been dedicated for the USA, which were assumed to be the largest net-import country in the world. Thanks to shale gas production, the USA turned from net-imports (-263 bcma in 2020 in the model world) to net-exports (around 85 bcma in reality). This afflicts not only Canada, but also all other export countries, either direct or indirect.

3.3. LNG Trading

LNG was an important field of discussion in the time of development of MAGELAN - as it is still today. As could be seen in Figure 2, MAGELAN forecasted a massive expansion of LNG imports worldwide – which are even outnumbered by the actual development. Starting from a base of 180 bcma, the reference case foresaw an increase up to more than 460 bcma, meaning a factor of more than 2.5 compared to the starting point. The actual LNG imports in 2020 rose even higher, up to around 480 bcma, before reaching another all-time high in 2021 with more than 500 bcma (IGU 2022, p. 21). When looking at the trend, and also MAGELAN's forecast for 2030, it seems very likely, that LNG trading will reach new records in the coming decade.

Figure 2: *LNG imports worldwide – historical development and model forecasts*



Source: Seeliger 2006, p. 129; BP 2022b

As for the production figures, the forecast of the total LNG volumes looks quite accurate compared to reality. However, when looking more into detail, once again some remarkable discrepancies has to be stated. When looking at the LNG import nations (Table 3), obviously shale gas revolution demonstrates its power: the USA imported 118 bcma less than expected by the reference case. Given that this volume is around one quarter of the total LNG market, it is not surprising that market prices dropped remarkably in some years after 2007 and market participants labelled the LNG supply situation as a "LNG glut" (IEA 2010, p. I.4; Seeliger 2016, p. 7). On the other hand, the reference case dramatically underestimated the import needs of China and, to a much lesser extent, other Asian import nations.

Beside this, the model (or better: the author of the model) somehow missed a few new entrants to the market. Those are countries that entered the LNG market somewhere between 2005 and 2020 and are not implemented in MAGELAN with an option to import LNG. They are marked with an "-" in the column MAGELAN 2020 and include countries like Pakistan, Bangladesh or Poland as well as some minor gas consumers such as Panama which are summarised in the region specific group "others". With respect to LNG export nations (Table 4), only two new LNG supply countries are not implemented in MAGELAN: Cameroon and Papua New Guinea.

Table 3: *LNG imports by country in bcma*

	Reality 2004	MAGELAN 2020	Reality 2020	Difference 2020
Japan	77	86	100	-14
South Korea	30	48	55	-7
India	3	15	36	-21
Taiwan	9	14	24	-10
China	0	8	93	-85
New Zeeland	0	4	0	4
Philippines	0	2	0	2
Singapore	0	2	4	-2
Pakistan	0	-	10	-10
Thailand	0	-	8	-8
Bangladesh	0	-	6	-6
Other Asia-Pacific	0	-	7	-7
Kuwait	0	-	5	-5
Other Middle East	0	-	4	-4
Qatar	24	91	104	-13
Spain	18	32	21	11
UK	0	24	18	6
France	8	23	18	5
Italy	6	16	12	4
Netherlands	0	11	7	4
Belgium	3	8	4	4
Portugal	1	3	5	-2
Greece	1	2	3	-1
Turkey	4	0	14	-14
Germany	0	0	0	0
Poland	0	-	4	-4
Other Europe	0	-	3	-3
Brazil	0	5	3	2
Chile	0	2	4	-2
Argentina	0	0	2	-2
Other Latin America	1	2	3	-1
USA	19	120	2	118
Mexico	0	36	3	33
Canada	0	0	1	-1

Source: Seeliger 2006, p. 129; IGU 2021, p. 24; BP 2022; own calculations/estimations

As in the sections before, also for LNG exports the USA are one of the largest deviators. But the difference of 57 bcma (exports of 60 compared to 3 bcma in the reference case) didn’t mark the highest gap. This belongs actually to Australia, with 105 bcma the largest LNG exporter in reality, which only reached 19 bcma in the model run. On the other side, the model significantly overestimated the exports of Iran and Venezuela, as both did not enter the LNG export market until today but had a major role in the reference case.

Table 4: *LNG exports by country in bcma*

		Reality 2004	MAGELAN 2020	Reality 2020	Difference 2020
1	Qatar	24	91	104	-13
2	Iran	0	55	0	55
3	Indonesia	34	44	20	24
4	Venezuela	0	37	0	37
5	Nigeria	13	36	28	8
6	Algeria	26	29	14	15
7	Malaysia	28	29	32	-3
8	Australia	12	19	105	-86
9	Trinidad & Tobago	14	19	14	5
10	Egypt	0	17	2	15
11	United Arabic Emirates	7	16	8	8
12	Russia	0	12	40	-28
13	Oman	9	12	11	1
14	Brunei	10	9	8	1
15	Bolivia	0	8	0	8
16	Yemen	0	8	0	8
17	Libya	1	7	0	7
18	Norway	0	6	4	2
19	Equatorial Guinea	0	5	4	1
20	USA	2	3	60	-57
21	Peru	0	2	5	-3
22	Angola	0	0	6	-6
23	Cameroon	0	-	1	-1
24	Papua New Guinea	0	-	11	-11
	World	180	464	479	-15

Source: Seeliger (2006), p. 131; IGU 2021, p. 21; own calculations/estimations

3.4. Interregional Pipelines

In addition to LNG trades, MAGELAN also optimises the construction and utilisation of so-called interregional (meaning between continents or other geographic definitions (such as Middle East)) gas pipelines. This accounts mainly to Europe with its connections to Africa, Middle East and the states of the former Soviet Union. As of 2005 no interregional pipelines existed in Asia, but nevertheless MAGELAN offers some possible pipeline connections to other regions (Middle East and former Soviet states).

Concerning Europe, there are mainly three transport channels available (Seeliger 2006, p. 139; ENTSOG/GIE 2022): from Algeria and Libya via the Mediterranean, from Iran, Iraq and Azerbaijan via Turkey and from Russia (and as transits via Russia also from Turkmenistan, Kazakhstan and Uzbekistan) using a wide set of pipelines routes (via Turkey, Ukraine, Belarus and directly to Finland and the Baltic States). At the time MAGELAN was designed, some discussions arose about Nord Stream and its potential routes to Germany. There had been various ideas, either via Finland (with or without a loop to Sweden), the Baltic States or as a completely direct connection between Russia and Germany, which finally was realised in reality. In the model parametrisation, Nord Stream is mapped as a link from Russia to Finland and from there via the Baltic Sea to Germany. However, from cost perspective, this had no impact on the results.

On the Mediterranean pipelines, another pipeline between Algeria and Spain (Medgaz) was completed –in the model world as well as in real life. Another pipeline between Algeria and Italy via Sardinia (Galsi)), that was discussed in 2005, hasn't come on stream until now but was constructed by MAGELAN.

On the Russian side, MAGELAN showed not much investment activity. This is due to (already in 2005) more than sufficient transport capacities to Europe on the traditional transit route via Ukraine (Transgas System) and the second transit line via Belarus (Yamal). The model focussed on re-investments to keep the aging infrastructure alive or gradually increased some lines over time. Nevertheless, in 2020 MAGELAN opened one single pipeline via the Baltic Sea, but with much less capacity than the real double lined Nord Stream I (23 vs. 55 bcma). When looking ahead to 2030, MAGELAN keeps this capacity equal, whereas in reality another double lined Nord Stream II would have added further 55 bcma to this transport channel – if not Russia had begin to start the invasion of Ukraine in 2022, which in turn forced the German government to refuse to grant the operation licence for this pipeline.

On the supply route from the Middle East, something diametral to the Nord Stream issue happened. MAGELAN postulated the opening of another big supply channel for Europe, starting in Iran, passing Turkey to finally reach Central Europe. The pipeline capacity of this route was set to 30 bcma by MAGELAN in 2020, with an expansion up to 100 bcma when looking towards 2030! By this, Iran had become a major supplier for Europe and a potent competitor for incumbent Russia. When looking at the reality, this project (known under the name Nabucco) was aborted due to political conflicts with Iran around 10 years ago.

In Asia, only limited pipeline connections to other regions existed in 2005 and in fact this is still the case today. Despite various discussed projects in the last decades, only a limited number has been realised until now. Only two of them were operational in 2020 (O'Sullivan 2019): a pipeline between Russia's eastern Siberian fields to China (called Power of Siberia with 5 bcma in 2020 but plans to increase capacity up to 38 bcma and even more by a later second line) and a major transit channel from Turkmenistan, Kazakhstan and Uzbekistan to China (Central Asia-China with 55 bcma in total). MAGELAN also realised those two pipeline connections in the reference case with 5 respectively 26 bcma (Seeliger 2006, p. 142). In addition, the model forecasted the construction of two interregional pipelines to Pakistan: one from Iran (20 bcma) and one (7 bcma) from Oman (which would have been an extension of an existing pipeline between Qatar and Oman). Finally, a pipeline from Russian island Sakhalin to Japan with 20 bcma was realised by the model – a project that was planned since the 1970s but never has been started so far.

4. Discussion

Obviously, the most important difference between model forecast and the development in reality is the role of the USA in the world market. In the reference case, the USA could stabilise their production somehow with help of (from 2005 perspective) a large increase of non-conventional production, but this was completely outnumbered by actual development. A difference of more than 400 bcma, which equals around 10 percent of world gas production in 2020, has of course massive impacts on many model outputs. Given that the by far largest net-import nation turns into a major LNG exporter, import/export balances of nearly all countries are afflicted - starting with Canada as the natural main supplier of the USA and along to the LNG export players in the Middle East, Asia or Africa.

While the import needs of the USA shrank drastically (and finally turned into export potential) due to the shale gas revolution, the import needs of China rose in turn. This was driven by a heavy underestimation of gas demand. The gap between model and reality would have been even larger, if the reference case hasn't underestimated the domestic gas production in China (which had reduced the already low import volumes even further). However, both issues are not the "fault" of the model but of inadequate exogenous input parameters. The latter effect could be reduced, if China, in the meantime one of the main resource owners in the world (due to massive new discoveries), would be implemented as a production node in the model. But the demand effect remains a crucial problem for the model, not only with respect to China.

When looking at the total demand in the reference case, it is absolutely surprising, that the reference case met reality with more than 99 percent accordance. This is even more surprising, when considering the major events that had massive impact on gas demand: word finance crisis, economic and debt crisis, civil wars in the Middle East, changing energy policies due to climate crisis, Corona pandemic crisis (including lock-downs) – just to name the most important.

With respect to the transport section of the model, once again, overall figures came quite close to the reality, but some individual differences stick out. The most prominent case was the before discussed Nord Stream pipeline route. In reality, a total project volume of 110 bcma was planned (and one step before finalisation until the war in the Ukraine starts), whereas the model only saw a need for around 20 bcma. This divergence could have several explanations: one could be that the cost assumptions where too much in favour of LNG, so that pipeline projects get wrongful prevented. This actually isn't the case in this specific situation: MAGELAN didn't realise any LNG terminal in Germany until 2020 – the model simply used the existing pipeline capacities via Poland and Ukraine to import Russian gas. One more plausible reason is that diversification and security of supply is obviously a more binding condition in the model world than in German reality. The reference run implemented a diversification of supply constraint to avoid that an import country becomes fully dependent from one supplier (what could happen quite fast in pure cost-based model runs). This constraint is entered individually for each country and for Germany it was set to a maximum of 40 percent for the market share of the biggest supplier. Whereas this sounds somehow reasonable, not only from security of supply but also from competition perspective, Germany failed to consider this in reality – the market share of Russia raised to more than 55 percent of gas imports - in addition to 50 percent for coal and 34 percent for oil (AGEB 2022). Another aspect that could have prevented higher capacity for Nord Stream in the model is the fact that Iran (one of Russia's main competitor in the model) is due to political reasons a complete outage in reality and therefore the major export pipeline Nabucco has not been constructed until now.

To sum up, the reality check showed potential of improvement. It might increase forecast accuracy if more model regions will be implemented as a production node instead of consumption only nodes with a predefined exogenous production. Additionally, an expansion of potential LNG sites even if no terminal is under development at present could help to catch up further import trends. This applies mainly to import areas, where way more new LNG players established in the last decades than expected and implemented in the model. In principle and with no technical restrictions given (such as calculation time) nearly every country in the model should get the option to build LNG regasification plants in the future.

But: the key drivers for divergence between model results and reality wouldn't be avoided by such structural changes to the model. Political decisions (e.g. ambition of climate policy or diversification strategy), exogenous demand shocks (e.g. lock-downs during Corona pandemic or worldwide economic crises) or erratic technological progress (e.g. shale gas revolution) will always somehow undermine even the best designed model structure and limit reliability of model results.

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