4 Results and discussion

This section presents the most relevant modeling results for answering this paper's three different research questions. Therefore, the result section is structured as follows. Subsection 4.1 explicitly addresses the first research question and presents the LNG supply and associated supply costs in Europe in 2040. It presents the quantitative results for the two main scenarios *Net Zero* and *Persisting Fossil Demand* in 4.1.1 and 4.1.2 respectively are shown. The two main scenarios are compared in 4.1.3. Subsection 4.2 then aims to answer research question two and explains the impact of geopolitical tensions on LNG importers and exporters by presenting the importers' share of the European demand in 4.2.1, the exporters' expected gasification capacity utilization rate in 4.2.2, and the use of the European domestic production with CCS in 4.2.3. The values are shown for the different branches in the two main scenarios. Finally, Subsection 4.3 aims to research question three and shows the global LNG market equilibrium without European demand.

4.1 LNG supply and associated supply costs in Europe 2040

4.1.1 Net Zero scenario

Figure 1 shows LNG import volumes from regions in billions of MMBtu and associated supply costs in \$/MMBtu. In this scenario, Algeria, Nigeria, Other Europe, and Qatar supply European demand, as Other Europe is the marginal supplier. Compared to the remaining three importers, Other Europe's share is small at 0.053 billions of MMBtu (4.3 % of total European LNG demand). For example, Algeria exporters 0.415 billions of MMBtu (33 %).

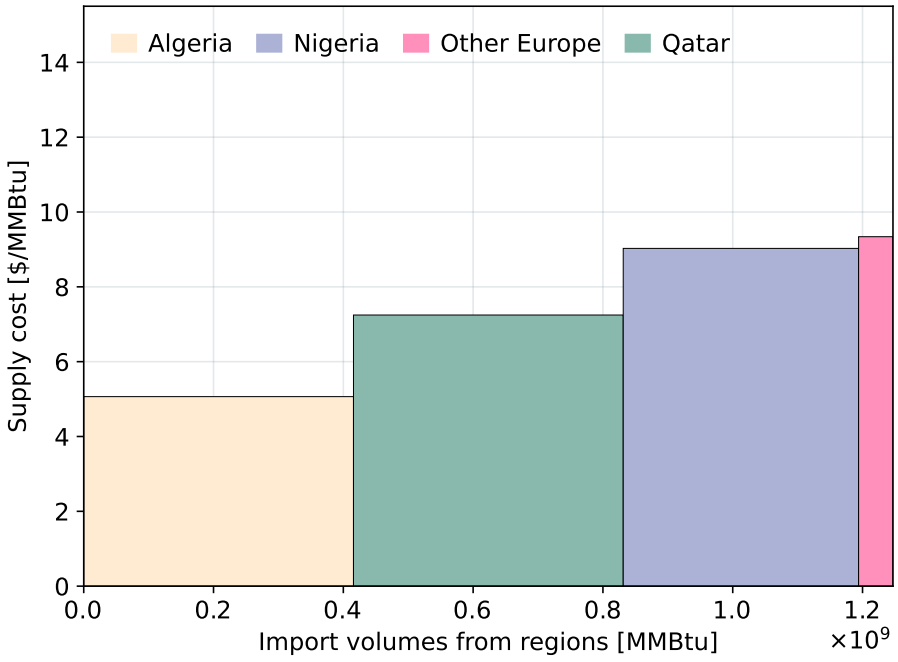


Figure 1: Import volumes from regions to meet the European demand in 2040 in billion MMBtu and associated supply costs per exporter in \$/MMBtu in the *Net Zero* scenario.

Based on the supply costs of the various exporters in Europe, Figure 2 shows the marginal (top, blue) and average (bottom, brown) supply costs in Europe in 2040. While the marginal supply cost determined by Other Europe as the marginal supplier is 9.3 \$/MMBtu, the average supply cost is 7.1 \$/MMBtu.

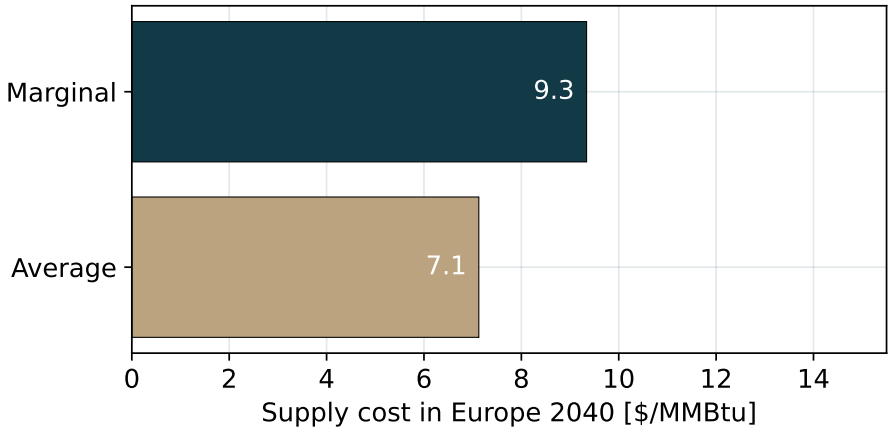


Figure 2: Marginal (top, blue) and average (bottom, brown) supply cost to meet the European demand in 2040 in $/MMBtu in the *Net Zero* scenario.

4.1.2 Persisting Fossil Demand

Figure 3 shows LNG import volumes from regions in billions of MMBtu and associated supply costs in $/MMBtu in the *Persisting Fossil Demand* scenario. The figure clearly shows that several exporters are needed to meet European LNG demand. The most important exporters in terms of import volumes to Europe are Nigeria, the USA, and Trinidad and Tobago. They reach a share of 76 % on the total European demand. In addition, fringe exporters (Other Americas, Other Europe, and Other Africa) supply the remaining demand. In particular, Other America, as one of the fringe exporters, serves as the marginal exporter to Europe.

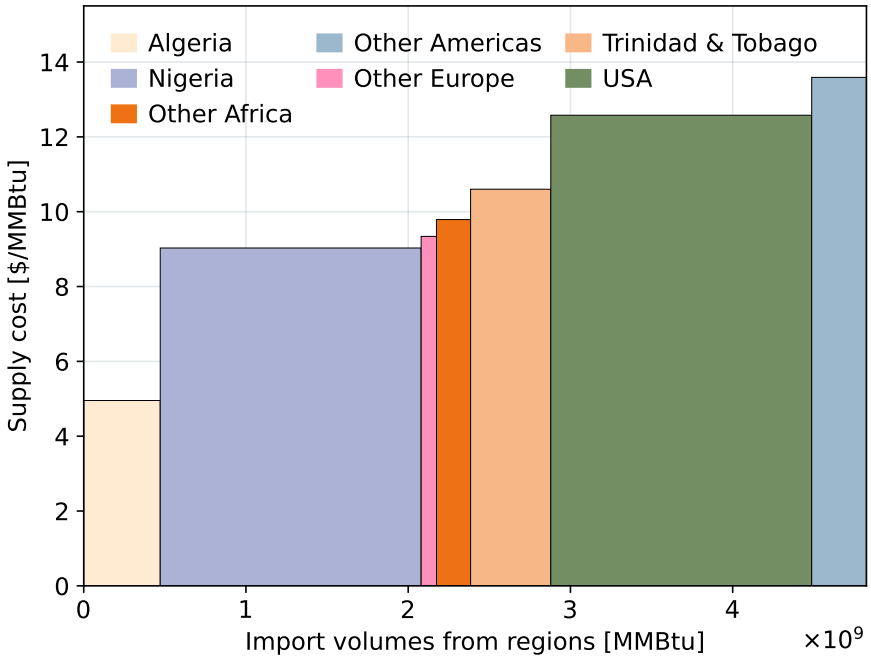


Figure 3: Import volumes from regions to meet the European demand in 2040 in billion MMBtu and associated supply costs per exporter in $/MMBtu in the *Persisting Fossil demand* scenario.

In analogy to the presentation of results in the previous subsection, Figure 2 shows the marginal

(top, blue) and average (bottom, brown) supply costs in Europe in 2040 in the *Persisting Fossil Demand* scenario. While the marginal supply cost determined by Other Americas as the marginal supplier is 13.6 $/MMBtu, the average supply cost is 10.3 $/MMBtu.

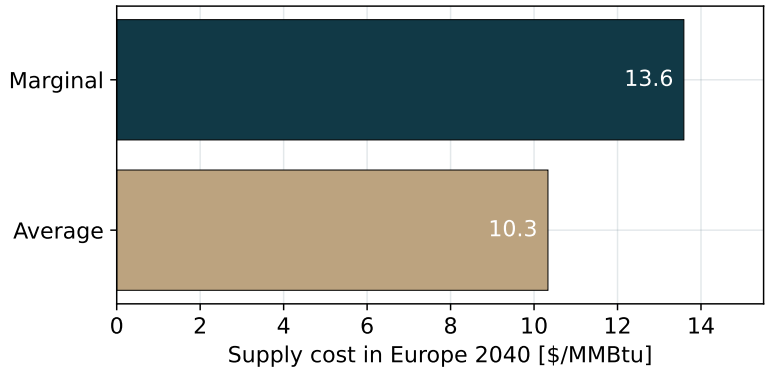


Figure 4: Marginal (top, blue) and average (bottom, brown) supply cost to meet the European demand in 2040 in $/MMBtu in the *Persisting Fossil Demand* scenario.

The differences in terms of the number of exporters meeting the European demand including their shares as well as associated supply costs become evident when examining the Figures 1 to 4. The following subsection provides a concise and clear comparison of the two scenarios regarding import volumes per region and associated supply costs.

4.1.3 Comparison of the two main scenarios

Figure 5 compares the results of the two main scenarios in terms of import volumes from regions (left) and associated supply costs (right) in Europe in 2040.

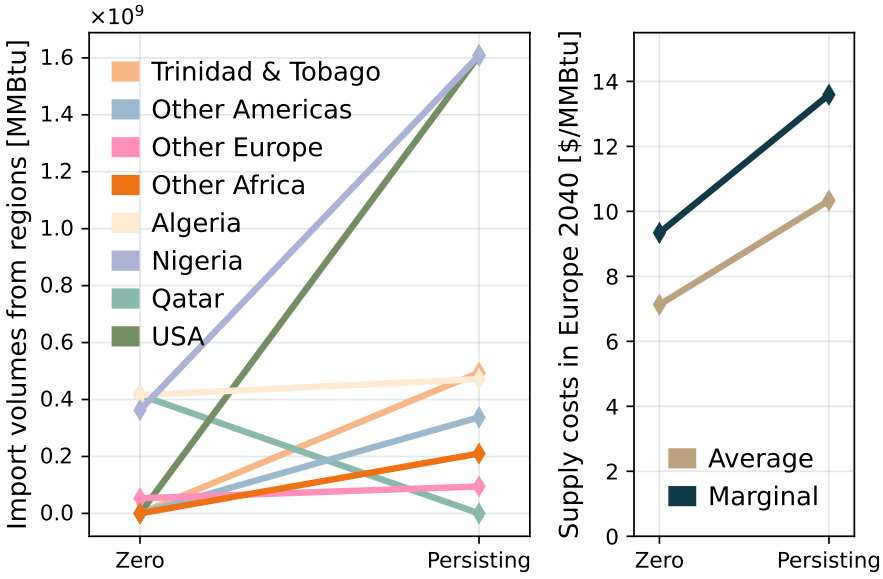


Figure 5: Comparison of the two main scenarios *Net Zero* (abbr. as Zero) and *Persisting Fossil Demand* (abbr. as Persisting) in terms of import volumes from regions (left) and associated supply costs (right).

Looking at Figure 5 (left and right subfigures), there are four interesting aspects to note:

- As far as exporters are concerned, the USA becomes the main exporter to Europe in the *Persisting Fossil Demand* scenario, while it does not import any LNG to Europe in the *Net Zero* scenario. The main reason for the latter is the available over-gasification capacity in the global LNG market.
- Another exporter, namely Nigeria, also significantly increases its import volumes to Europe in the *Persisting Fossil Demand* scenario. However, the increase (difference between the two main scenarios) is slightly lower than for the USA, as Nigeria is already importing to Europe in the *Net Zero* scenario.
- Qatar spielt nur im zero scenario eine rolle, nicht aber im persisiting. der hauptgrund ist dass der export nach europa weniger competitive ist als der export zu anderen abnehmern wie asia-pacific regions.
- In terms of supply costs, the marginal and average supply increase in the *Persisting Fossil Demand* scenario compared to the *Net Zero* scenario by 4.3 \$/MMBtu (+46 %) and 3.2 \$/MMBtu (+45 %).

4.2 Impact of geopolitical tension on LNG importers and exporters

The following gives the impact of geopolitical tension on LNG importers and exporters. Consequently, the results of the different branches derived from both main scenarios are in the foreground of this subsection. As a short reminder, the two main scenarios are the *Net Zero* and *Persisting Fossil Demand* scenarios. For both, the following branches are derived: *Diversify Importers*, *High Price the Middle East*, *No export from Africa*, *Panama Canal constricted*, and *Russia to Asia only*.

4.2.1 Supply share of importers on the European demand

Tables 2 and 3 show the import volumes from regions to Europe in the branches derived from the main scenarios in the *Net Zero* and *Persisting Fossil Demand* scenario, respectively.

Table 2: LNG import volumes from regions to Europe 2040 in the main scenario *Net Zero* and derived branches in billions of MMBtu. Symbols in the brackets qualitatively indicate the change compared to the main scenario. Legend: strong decrease (↓), slight decrease (↘), constant (∼), increase (↗), strong increase (↑) compared to the Net Zero scenario.

Exporter	Net zero	Diversify importers	High price Middle East	No export from Africa	Panama canal constricted	Russia to Asia only
Algeria	0.415	0.249 (↘)	0.415 (∼)	- (↓)	0.415 (∼)	0.415 (∼)
Nigeria	0.362	0.249 (↘)	0.415 (↗)	- (↓)	0.415 (↗)	0.285 (↘)
Other Africa	-	0.249 (↑)	- (∼)	- (∼)	- (∼)	- (∼)
Other Europe	0.053	0.249 (↑)	0.130 (↑)	0.130 (↑)	- (↓)	0.130 (↑)
Qatar	0.415	0.249 (↘)	0.285 (↘)	0.415 (∼)	0.415 (∼)	0.415 (∼)
Trinidad & Tobago	-	- (∼)	- (∼)	0.285 (↑)	- (∼)	- (∼)
USA	-	- (∼)	- (∼)	0.415 (↑)	- (∼)	- (∼)

Table 3: LNG import volumes from regions to Europe 2040 in the main scenario *Persisting Fossil Demand* and derived branches in billions of MMBtu. Symbols in the brackets qualitatively indicate the change compared to the main scenario. Legend: strong decrease (↓), slight decrease (↘), constant (∼), increase (↗), strong increase (↑) compared to the Net Zero scenario.

Exporter	Persisting fossil demand	Diversify importers	High price Middle East	No export from Africa	Panama canal constricted	Russia to Asia only
Algeria	0.472	0.472 (∼)	0.682 (↗)	- (↓)	0.472 (∼)	0.472 (∼)
Nigeria	1.608	0.965 (↘)	1.608 (∼)	- (↓)	0.897 (↘)	1.608 (∼)
Other Africa	0.210	0.756 (↗)	- (↓)	- (↓)	- (↓)	0.541 (↗)
Other Americas	0.337	0.707 (↗)	0.337 (∼)	1.348 (↗)	- (↓)	0.101 (↘)
Other Europe	0.094	0.310 (↗)	0.094 (∼)	0.125 (↗)	- (↓)	- (↓)
Qatar	-	- (∼)	- (∼)	0.260 (↑)	- (∼)	- (∼)
Trinidad & Tobago	0.494	0.494 (∼)	0.494 (∼)	0.184 (↘)	0.612 (↗)	0.494 (∼)
USA	1.608	0.965 (↘)	1.608 (∼)	1.608 (∼)	1.608 (∼)	1.608 (∼)

Looking at the LNG import volumes to Europe in 2040 in the *Net Zero* scenario, the following interesting results can be observed:

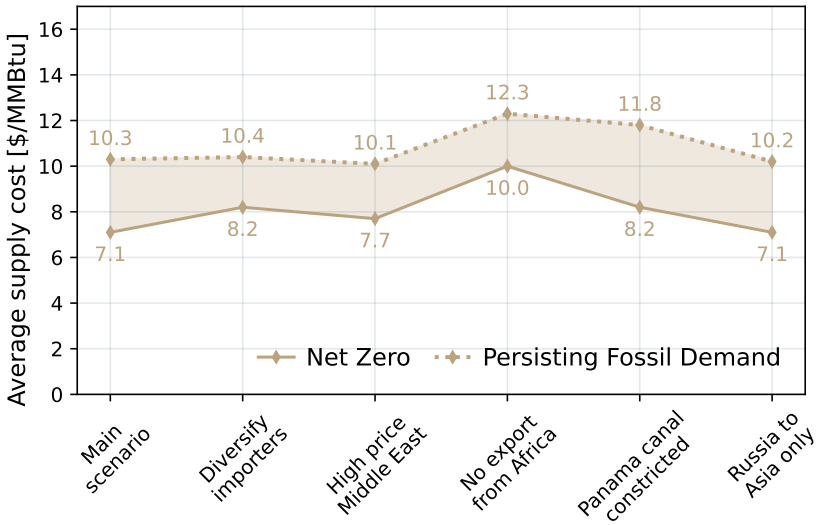
- LNG import volumes from regions such as Algeria, Nigeria, and Qatar remain largely constant in the different branches of the main scenario. Of course, this statement does not apply to cases such as the *No export from Africa* branch, where by definition no imports from African regions are allowed.
- Other exporting regions, such as Other Africa, Trinidad and Tobago, and the USA, are importers into Europe in 2040 in only a few branches. In other words, their import volumes in the different branches vary considerably.

In addition, the import volumes in the *Persisting Fossil Demand* scenario in Table 3 reveal, at least the following two interesting results that can be observed:

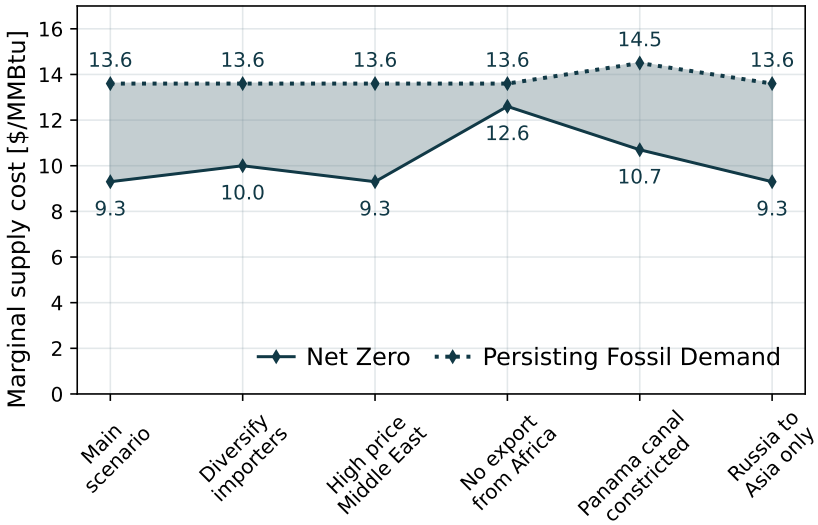
- In general, less clear trends can be identified with regard to the individual export regions. Import volumes fluctuate significantly more than in the *Net Zero* scenario and derived branches.
- Nevertheless, the picture is clearer at least for imports from the USA, which tend to be relatively constant across all branches in the *Persisting Fossil Demand* scenario.

An overview of the average and marginal supply costs in Europe in 2040 is given in Figure 6. There, the average supply costs for the two main scenarios and the derived branches are shown in Subfigure 6a, while the marginal supply costs are shown in Subfigure 6b. Note that the results of the *Net Zero* scenario are given by the solid lines and the results of the *Persisting Fossil Demand* scenario are given by the dashed lines. The largest increase in the average supply costs in Europe in 2040 is given in the *No export from Africa* branch for both main scenarios. There, the average supply cost reaches 12.3 $/MMBtu and

10.0 $/MMBtu in the *Persisting Fossil Demand* and *Net Zero* scenarios, respectively. Similar results are also obtained for the marginal supply costs. Again, in the *No export from Africa* case, the largest increase can be observed. However, the difference between the two main scenarios is smaller, and marginal supply cost in Europe in 2040 reaches 13.6 $/MMBtu and 12.6 $/MMBtu in the *Persisting Fossil Demand* and *Net Zero* scenarios, respectively.



(a) Average supply costs in Europe in 2040



(b) Marginal supply costs in Europe in 2040

Figure 6: Comparison of the average (a, top) and marginal (b, bottom) supply costs in the two main scenarios *Net Zero* (solid) and *Persisting Fossil Demand* (dashed) and derived branches in Europe in 2040 in $/MMBtu.

4.2.2 Gasification utilization rate of exporters

The previous subsection focused on import volumes from the regions to Europe. Differences have been shown in cases where political tensions affect the availability and price of LNG. Consequently, this sub-

section focuses on the gasification utilization rate of exporters. As an example, the European marginal supplier Other Europe in the *Net Zero* scenario (see Figure 1) and the USA (as one of the major suppliers) in the *Persisting Fossil Demand* scenario have been chosen to present the results. Figure 7 shows the case of the region Other Europe. In the main scenario *Net Zero*, the export volumes reach 17 % of the available gasification capacity. This share increases in all the derived branches, while it reaches full utilization of 100 % in the *High price Middle East*, *No export from Africa*, and *Russia to Asia only* case.

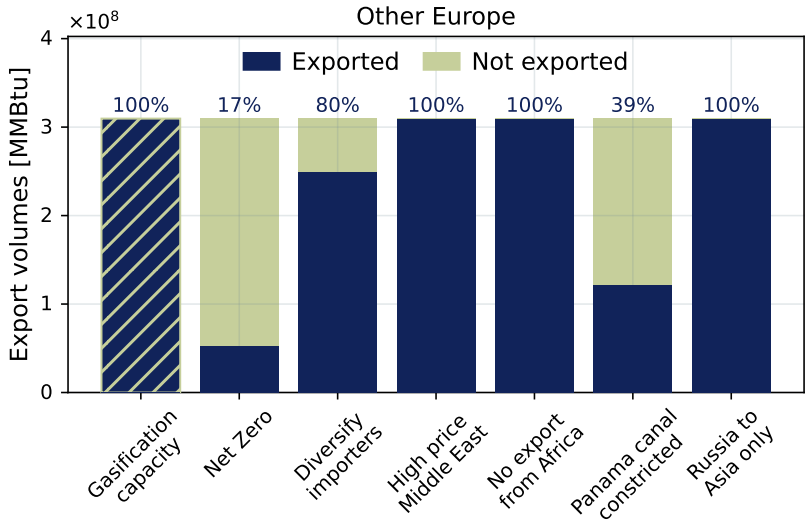


Figure 7: LNG export volumes in $MMBtu$ and gasification utilization rate in % of the region Other Europe in 2040.

Figure 8 shows the results for the US in the *Persisting Fossil Demand* scenario. It shows that LNG export volumes and thus gasification utilization are relatively constant. The latter is in most cases 78 %. However, without LNG exports from Africa, the utilization rate increases significantly and reaches its full capacity. Note that this is only the case here.

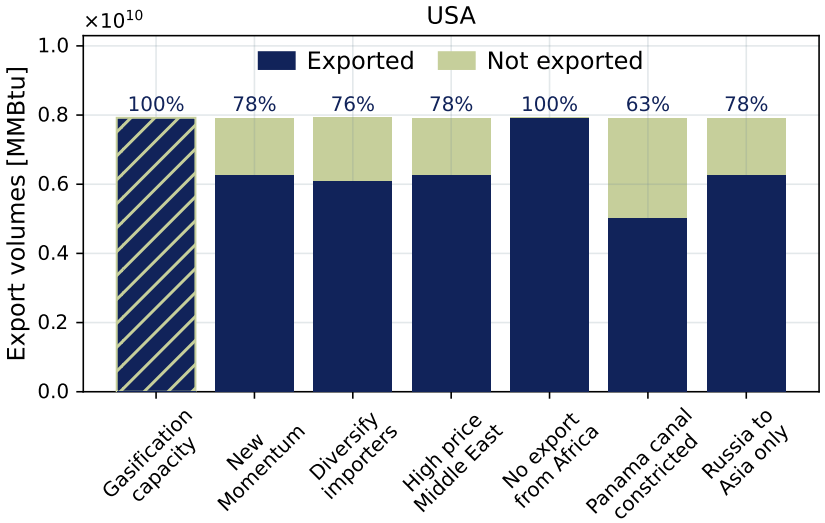
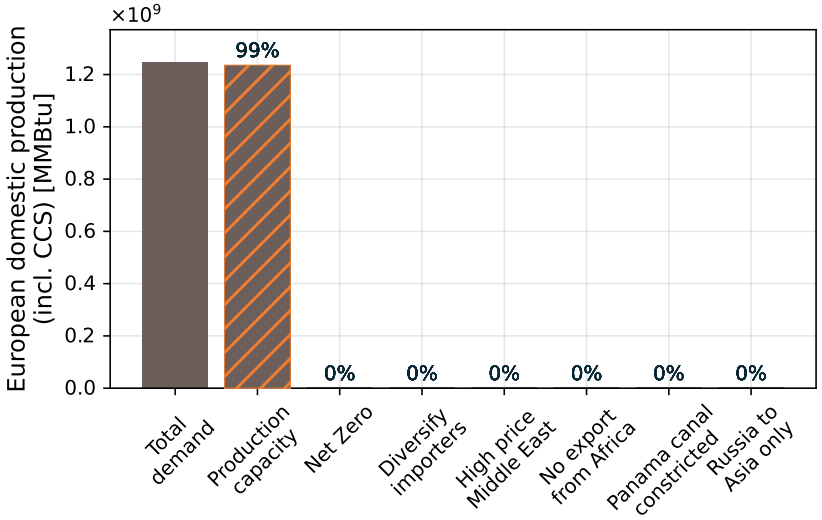


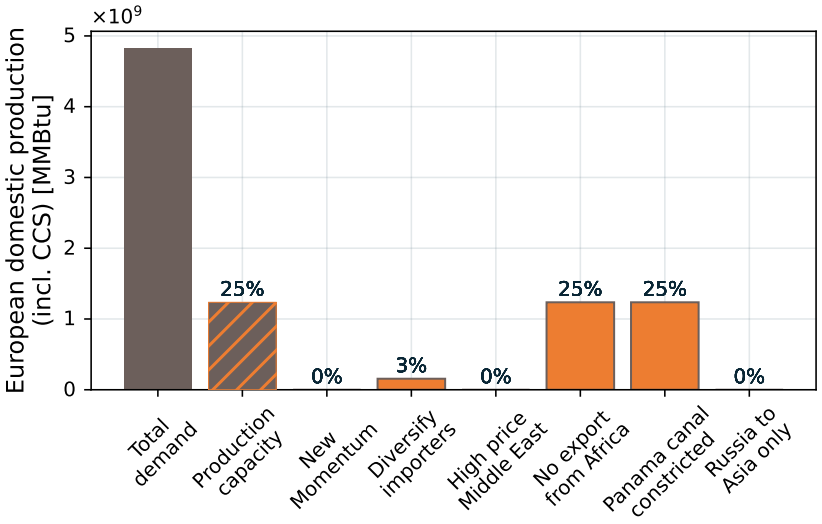
Figure 8: LNG export volumes in $MMBtu$ and gasification utilization rate in % of the USA in 2040.

4.2.3 European domestic production with CCS

Figures 9a and 9b for the *Net Zero* and *Persisting Fossil Demand* scenarios, respectively, show whether and to what extent European domestic production with CCS plays a role as an alternative to imports in meeting European LNG demand. In the *Net Zero* scenario, the European domestic production with CCS is not used in order to substitute LNG imports from other regions, not in the main scenario nor in one of the derived branches. In contrast, this alternative supply option is in fact used in the *Persisting Fossil Demand* scenario. In particular, in the two branches where no LNG exports from Africa take place and where the Panama Canal is constructed, the assumed production capacity (assumed to be equals



(a) Average supply costs in Europe in 2040



(b) Marginal supply costs in Europe in 2040

Figure 9