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Planning of CO₂ Pipeline Networks under Uncertainty with Extended Scenario Analysis

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Abstract Carbon infrastructure will be indispensable to link the captured CO₂ sources with the storage sites. However, there are many uncertainties in terms of the potential emitters, pipeline routes and locations of carbon sinks which will have an impact on the associated costs. On the one hand, the various industries have different roadmaps on how and when to mitigate their CO₂ emissions, which are strongly impacted by the development of the carbon market and decarbonization costs. This means that they will connect at different times to the prospective CO₂ network and changes in policies, energy availability and technologies might deter them completely from joining it. Also, changes in capacities of carbon sinks as well as their prices might not allow the sinks to be available or economically feasible as expected.

On the other hand, pipeline infrastructure is not easily adaptable. Pipes cannot be upgraded to one with a bigger diameter later, without incurring extremely high costs. More likely parallel loops are built to increase capacity, which reduces the economy of scale. Thus, it might be advantageous to build bigger pipelines in an earlier period even if they are not fully utilized. However, building oversized pipelines leads to unnecessary costs in construction, operation and maintenance. Especially if potential emitters decide not to join the network at a later point.

Hence, this study presents an approach to model the future CO₂ backbone in Germany and investigate the impact of different scenarios on the route and costs. The developed model is based on extensive datasets and sophisticated optimization scheme to yield more realistic and optimally designed outcomes. Beside geographical features like nature reserves, terrain slope, waterways and lakes, the derived framework considers infrastructure like highways, railways, and already existing pipelines as well as population data. In total, the costs of the investigated scenarios range between 1.5 and 3 billion EUR. The results also demonstrate that the different scenarios have an impact on the configuration, total and specific transportation costs with different intensities.

Moreover, the contribution outlines a model extension that allows building the network in an incremental manner over multiple periods. It can account for these specific construction restrictions as well as allowing for each period to assume a set of scenar-

ios. The focus is that it then gives recommendations on what kind of network to build at the start of a period to reduce regret in a later period, considering all possible scenarios. Hence, the outcomes are important for academia, industry and policymaking for the ongoing discussions regarding the development of carbon infrastructure.