Development options for the Dutch gas distribution grid in a changing gas market

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***Abstract*—The Dutch gas distribution grid faces several changes in the near future. Currently, the grid handles only one gas type, namely Groningen gas, however, the future gas distribution grid is expected to handle multiple gas types. First of all, the share of green gas in the gas supply is expected to increase from the current share of 0.1% to 8 - 12% in 2020. Furthermore, due to the decline of domestic gas production, the share of imported natural gas will increase. Therefore, the gas distribution grid, which currently is a mono-gas system, will transform into a multi-gas system. In addition, due to the increased share of Combined Heat and Power (CHP) installations, the gas distribution grid will increasingly interact with the electricity distribution grid and local heat distribution grids. The gas distribution grid, which currently is exclusevely composed of pipelines and supply stations, might be expanded with novel components, e.g. blending stations, gas storage sites, and gas compressor stations, to facilitate the aforementioned changes. Furthermore, the injection of green gas, the different foreign gas types, and the increased interaction with the electricity distribution grid and heat grid requires the passive gas distribution grid to become a smart gas grid, which monitors and controls the gas pressure, gas flow, and gas quality. Due to the multitude of development options for the gas distribution grid and the fact that the best solution is largely dependent on the local situation, the distribution service operators are in need of gaining insight about suitable development options for the current gas distribution grid. A tool is required that can generate situation specific advice by generating multiple solutions. The tool should show the advantages and disadvantages of each solution. This will provide insight in the available solutions and ease the decision making on investments of the gas distribution grid.**

I. Introduction

The Dutch gas distribution grid is facing a changing gas market. Up to now, the gas distribution grid has been a passive grid which is composed of passive pipelines that distribute only one type of natural gas to the customers. Due to the anticipated changes in the gas market, this situation will change in the near future. The new grid will have to be more flexible with regard to multiple types of gases that will flow through the grid. Furthermore, the gas distribution grid will have to be able to monitor and control the quality, the flow, and the pressure of the gas. Therefore, the grid becomes more intelligent compared to the current situation. The Dutch distribution service operators (DSOs), which are responsible for the distribution grids, will have to make investments to assure that the functionality of the gas distribution grid complies with the future requirements of the gas grid. At this moment, it is unclear what the future design of the distribution grid should look like. Therefore, research is required on the investments needed for the gas distribution grid. Since the desired solution will depend largely on the specific situation and on the preferences of the DSOs, a tool is required that can give situation specific advice, by showing possible solutions each with its own advantages and disadvantages.
The question arising is: how can the design and operational management of the future gas distribution system in the Netherlands be adapted, such that it can cope with the expected changes in the gas market?

This article is outlined as follows, section II describes the current Dutch gas grid and what changes the distribution grid is going to face in the near future. Since green gas, which is gas with burning properties similar to natural gas but is produced from renewable sources, will be a major factor for the required adaptations of the future gas distribution grid, section III elaborates on the green gas supply chain. In order to illustrate the possible development options of the gas distribution grid, in section IV the development options for the future gas distribution considering green gas are listed. Section V elaborates on the requirements for the tool that will give situation specific investment advice on the future gas distribution grid. Finally, in section VI, some concluding remarks are given on this research.

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II. The Dutch gas distribution grid

This section elaborates on the future changes of the gas distribution grid. To get a better grasp of the Dutch gas system, first, the gas grid supply chain, of which the distribution grid is part, is discussed. Then, the anticipated changes in the gas distribution grid are described.

A. *The present situation*

After the discovery of the Groningen gas field in 1959, with an initial volume of 2800 billion m^3 one of the largest gas fields in the world, the Dutch gas sector was shaped and the foundation of the current Dutch gas infrastructure was laid [1]. In Fig. 1, the gas supply chain in the Netherlands is schematically shown. The high-pressure transmission lines (HTL) grid transports the gas across the country. Two HTL-grids exist in the Netherlands; one HTL-grid transports low-calorific gas (Groningen gas) and the other transports high calorific-gas. Gas produced from the Dutch gas fields is injected into the HTL grids and the imported or exported gas also enters or leaves the country through the pipelines of these grids.

Furthermore, the Dutch gas storage sites are connected to the HTL grids. The HTL grids also supply gas to power plants and large industrial customers. The HTL grid that transports low-calorific gas delivers gas to the metering and regulating (M&R) stations, which reduce the gas pressure to 40 bar and supply gas to several regional transmission lines (RTL) grids. The RTL grids transport the gas further into the country with a finer mesh of pipelines. The RTL grid delivers the gas to gas receiving stations (GRS), which reduce the gas pressure to 8 bar and supply gas to the distribution grids. The distribution grids are composed of high pressure distribution grids and low pressure distribution grids. The high pressure distribution grids transport the gas over longer distances and feed the gas into the low pressure distribution grids via a supply station, which reduces the gas pressure to 100 (or 30) mbar. The low pressure distribution grid supplies gas to households and smaller industry. Transmission service operators (TSOs) are responsible for the RTL and HTL grid and the M&R stations and GRSs. The DSOs are responsible for the distribution grid and the supply stations.
During the past 50 years, the Dutch gas grid has proven to be a robust system and customers could rely on a reliable gas supply[1].
Recently, the Dutch gas market has been liberalized with the purpose of increasing the competition in the gas market. In this liberalized gas market, customers are given a free choice of gas supplier. Furthermore, the network activities were separated from other activities, in order to safeguard free non-discriminatory (third-party) access of suppliers to the network. Therefore, since January 2009, gas transport and distribution activities in the Netherlands are separated from production and supply activities. The network companies remained 100% publicly owned.
Besides the liberalization of the gas market, the distribution grid is facing more changes in the gas market, and at the same time the distribution grid is reaching the end of its economic and technical life. The expected changes are discussed in the next subsection.

B. Foreseen changes for the gas distribution grid

The anticipated changes in the gas market that will affect the gas distribution grid are listed in TABLE I. As can be seen, the current gas distribution system only supplies one type of gas, namely gas with Groningen gas (g-gas) quality. In the near future it is expected that multiple qualities of gas will flow through the gas distribution grid.
First of all, green gas will play a more important role in the Dutch gas supply. The Dutch government aims to reduce CO_2 emissions, to increase the amount of renewable energy produced, and to become less dependent on imported energy. Since green gas reduces CO_2 emissions by 70% in comparison with natural gas, is renewable, and can be produced domestically, its share in the Dutch gas supply is expected to increase.

[1]The yearly downtime of the gas supply for Dutch consumers was on average 23 seconds in the year 2008 [2]. In comparison, the average downtime for electricity was 22.1 minutes in the same period [3].

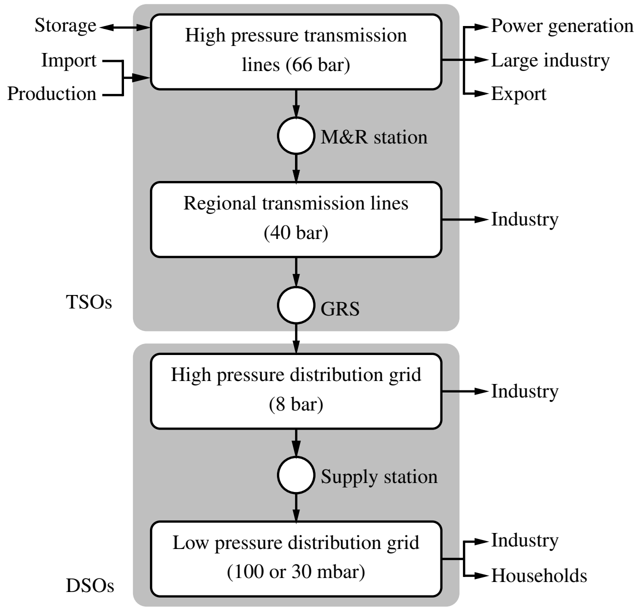

Fig. 1. Dutch gas grid supply chain

The New Gas Platform, an organisation initiated by several Dutch ministries to promote green gas among parties in the Dutch society, states the ambition of an 8 - 12% green gas share in the gas supply by 2020 and a share of 15 - 20% by 2030 [4]. Currently, the green gas share is only approximately 0.1% [5]. Since the introduction of green gas will have a large impact on the gas distribution grid, the production process of green gas and the issues concerning injection of green gas in the distribution grid are described in more detail in section III. With the injection of green gas in the distribution grid, the top-down gas supply chain will transform into a bi-directional gas supply chain. Gas will not only enter the distribution grid from the GRSs but also from green gas in-feed points connected to the high pressure or low pressure distribution grid.
Secondly, the Groningen gas field and other smaller Dutch gas fields are in decline and therefore the amount of imported natural gas will gradually increase. Increased volumes of gas will be imported from e.g. Norway, Russia, and Algeria by pipeline and by LNG-tanker and will flow through the Dutch gas distribution grid. These gases have a different quality than that of g-gas, which currently flows in the distribution grid, hence, the gas will not burn properly in the Dutch gas appliances, which are calibrated for g-gas. Therefore, the gas either has to be converted to g-gas quality or the gas requirements of the gas appliances have to be adjusted. Currently, gas with a different quality than that of g-gas is converted to the appropriate quality. However, with the Groningen field in decline and the increase in foreign gas, it might be economically beneficial to adjust the requirements for the gas quality to save conversion costs.
With the introduction of green gas and foreign gases, the gas distribution grid transforms from a mono-gas system into a

multi-gas system. This means that the distribution grid will have to handle more gas qualities. In practice, this could mean that the distribution grid should be able to take care of a wider Wobbe range[2], and also dedicated distribution grids that will distribute a specific gas quality are likely.

An other change that is at hand, is the increased interaction of the gas distribution grid with the electricity distribution grid and local heat grids, due to the rise of gas-fired (micro-) CHP installations which generate electricity and heat simultaneously. The increased interaction between the electricity and gas grids could change the role of the gas distribution grid. In contrast to electricity, gas is relatively easy to store, hence, local gas storage sites could provide a means to increase the robustness of the electricity distribution grid. For instance, solar PVs or windmills, which provide power to the electricity distribution grid, could be complemented by gas-fired CHP installations which will produce electricity when the intermittent power production of the solar PVs or windmills is too low. If the capacity of the gas distribution grid is too small to supply sufficient gas to the CHP installations in case of low power production, the gas distribution grid could be expanded by means of a gas storage site.

Due to these aforementioned changes, the gas distribution grid is expected to change from a passive grid to an actively controlled smart gas grid. We define a passive grid as a grid with no monitor or control options. We define a smart gas grid as a grid that monitors and controls the quality, pressure, and flow of the gas in the grid. Currently, the gas distribution grid is composed of passive pipelines and passive supply stations. With the introduction of multiple gas qualities, injection of green gas in the distribution grid, and the increased interaction with the electricity and heat grids, the gas distribution grid can no longer be passive. Since green gas is injected in the distribution grid, the pressure needs to be monitored, if local gas demand is insufficient for the gas supplied, the pressure will increase and appropriate measures are required, see section IV. Furthermore, the injection of green gas and the increased volume of foreign gases, requires the monitoring of the quality and, if necessary, control of the quality. Hence, the distribution grid requires monitoring and control of the quality, pressure, and flow of gas in order to maintain the service level. Therefore, the distribution grid is expected to change from a passive grid to a smart grid.

III. Green gas production

Since the introduction of green gas will have a great effect on the design and control of the gas distribution grid, this section describes the green gas supply chain and the corresponding issues into more detail. The effect of the green gas on the gas distribution grid is described in section IV, which discusses the potential development options for the gas distribution grid in regard of green gas.

[2]The main characteristic for the comparison of gas qualities is the Wobbe index, which is defined as: $W = \frac{V_C}{\sqrt{G_s}}$, with W the Wobbe index, V_c the calorific value of the gas, and G_s the relative density of the gas. G-gas has a Wobbe index that varies between 43.46 and 44.41 MJ/m^3(n)

TABLE I
Foreseeen changes in the gas distribution grid

Current situation	Future situation
Mono-gas distribution grid (only g-gas)	Multi-gas distribution grid (including green gases and foreign gases)
Top-down gas supply chain	Bi-directional gas supply chain
No interaction with other energy distribution grids	Increased interaction with electricity distribution grid and heat grids
Passive grid	Smart grid, which actively monitors and controls the quality, flow, and pressure of gas

Although, two possible options for the production of green gas can be distinguished, only the green gas from co-digestion process is considered in this paper. This because, the other production process, green gas from gasification, is not yet available for commercial application.

This section first describes the green gas from co-digestion supply chain, after which the corresponding difficulties with regard to the injection of the green gas in the distribution grid are discussed.

A. *Green gas from co-digestion supply chain*

Green gas is produced by digesting wet biomass. Commonly, manure is digested in combination with a co-substrate, e.g. agricultural crops, swill, or other waste products. This process is referred to as co-digestion. In Fig. 2, the supply chain for green gas from co-digestion is shown. The feedstock for the co-digestion process is manure and co-substrate. The digestion process produces biogas, consisting of 50 - 65% methane [6] (for comparison g-gas consist of 83% methane). The upgrading process, removes unwanted components, e.g. hydrogen sulphide, hydro carbons, and ammonia, from the biogas and increases the methane content in order to obtain gas with a Wobbe-index similar to that of g-gas. Once the gas is at the desired quality, the gas can be injected into the gas grid.

The digestion and upgrading processes are technically robust and commercially proven technologies.

B. *Green gas production difficulties*

Green gas installations using the digestion process to generate biogas are small-scale (the maximum capacity is

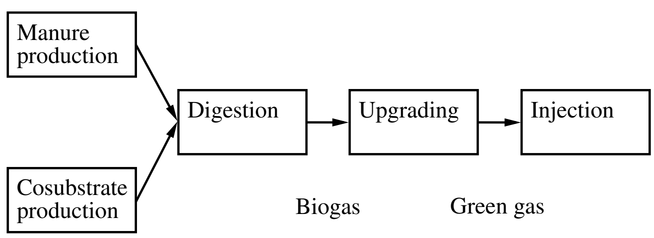

Fig. 2. Green gas supply chain [7]

approximately 1000 m^3/h), therefore, it is economically not feasible to inject the gas into the transportation grid, since the costs for the connection to the transportation pipeline and for compression are too high. Therefore, the green gas will be injected into the distribution grid. The cost for injection of green gas into the distribution grid are lower since the length of the connection will be smaller (the distribution grid has a finer mesh and therefore, needs probably a shorter connecting pipeline) and compression costs are lower since the distribution grid is operated at a lower pressure than the transportation grid.

However, injection of green gas into the distribution grid might lead to problems in balancing the gas demand and (green) gas supply, since the volume of the gas flow in the distribution grid is significantly lower than in the transportation grid and gas flow in the gas grid is unidirectional, i.e. gas can only flow from a grid with a higher operating pressure to a grid with a lower operating pressure (unless a gas compressor station is installed in the grid). Therefore, green gas can congest in the distribution grid. Furthermore, green gas production often takes place in rural areas, where gas demand is lower than in urban areas. Finally, due to seasonal fluctuations the gas demand in summer is lower than in winter. The difference between summer and winter demand is about a factor 10, if there are no industrial customers connected to that distribution grid. Since the green gas production process is very inflexible, and therefore, the volume of produced green gas can hardly be varied during the year, the gas demand in summer becomes the limiting factor. Therefore, it might occur that not all biomass potential can be used in a certain area.

Furthermore, the injection of green gas into the distribution grid requires active monitoring and control of the quality, pressure, and flow of the gas in the distribution grid. Hence, transforming the passive distribution grid into an actively controlled smart gas grid.

IV. Development options for the gas distribution grid

Currently, the gas distribution grid is exclusively composed of pipelines and supply stations. As mentioned in section II, this situation is likely to change, since the gas distribution grid will have to be adjusted to cope with the changes laying ahead in the gas market. To cope with these changes, the gas grid may be expanded with novel components, e.g. CHP installations in combination with a local heat grid, Micro-CHP installations, local gas storage sites, green gas/biogas plants, local biogas grids, gas compressor stations, and blending stations to deal with several types of gases. To illustrate the possible development options for the gas distribution grid, this section elaborates on various development options. Below, a number of these options are discussed in more detail. The focus will be on the development options when introducing green gas in the distribution grid. These options are summarized in TABLE II and are discussed in more detail in the remainder of this section.

1: The first choice is whether the available biomass is utilized. From an economic, energetic, or technical perspective it might be unattractive to exploit the biomass potential. The volume of the biomass might be too small to justify the investment in the appropriate equipment or the biomass is available at a too remote location.

2: If the biomass will be exploited, the question arises where the collection of manure and co-substrate and the digestion process takes place. In this respect, two options are possible:

- The collection of manure and co-substrate and the digestion process takes place at the farm site. The advantage of this option is that the manure and co-substrate do not have to be transported over long distances, which otherwise might result in a negative energy and environmental efficiency of the supply chain. The disadvantage is that the process will be small-scale and therefore the investment and operational cost will be relatively high for the digester installation.
- The collection of manure and co-substrate and the digestion process takes place at a central location. The manure and co-substrate have to be transported to this location by road transport, which costs energy and gives negative environmental effects. On the other hand, one large digester will have lower operational and investment costs than several smaller digesters. If the collection and digestion process is done centrally, a choice on the optimal size and location of the plant has to be made.

3: Once the manure and co-substrate have been collected and digested, according to Fig. 2, the next step would be to upgrade the biogas to g-gas quality. This is necessary, if the green gas is injected in the gas grid, since according to the current Dutch gas legislation, gas injected into the gas grid must be of g-gas quality.

However, other utilization options of biogas exist. These options might be more beneficial from an economical, technical,

TABLE II
Gas distribution grid development option regarding green gas

	Choice	Options
1	Use biomass?	-Yes, see 2 -No
2	Digestion location?	-Farm site -Central location
3	Upgrade to g-gas?	-Yes, see 4a -No, see 4b
4a	Location upgrading plant?	-Adjacent to digester location -Central location
4b	What alternatives?	-Use biogas as transport fuel -Dedicated biogas grid -Feed biogas to CHP -Mix biogas with natural gas

or energy efficiency point of view. The available options for upgraded biogas are discussed in paragraph *4a*, and the options for biogas that is not upgraded are listed in paragraph *4b*.

4a: If the biogas will be upgraded to natural gas specifications, a choice has to be made on where to locate the upgrading plant:

- The biogas can be upgraded at the same location as where the digestion process occurs. Advantage of this method is that no costs are incurred for the transport of biogas to a different location.
- The biogas can also be upgraded at a central location. The biogas of several biogas producers is collected by means of a pipeline, which transports the biogas to the central location. At the central location the biogas is upgraded. The advantage of this is that only one upgrading plant has to be built and operated, and due to advantages of scale this will be cheaper than building and operating several smaller upgrading plants. On the other hand, extra costs are incurred due to the required biogas pipeline. Furthermore, due to the larger scale of the upgrading plant, it becomes economically more feasible to inject the green gas into gas grids that operate at higher pressures. And therefore, more gas offtake capacity is available, which is not only caused by larger volumes of gas flow, but also by the reduced fluctuation in gas demand, due to the increased amount of industrial customers connected to these gas grids.

Once the location of the upgrading plant is known, a choice has to be made on where to inject the green gas into the gas grid. First of all, one can inject the green gas into the gas grid laying close to the upgrading plant. However, the gas demand of that grid might be too low, and therefore, it might be beneficial to lay a gas pipeline that transports the gas to a location in the gas grid where gas demand is higher, consequently the investment costs of these options are higher due to the required pipeline to be built.

4b: If the biogas will not be upgraded to natural gas quality, the following options, among others, are available:

- Instead of injecting the gas into the gas grid, the biogas can be used as transport fuel [8].
- Injection of biogas into a dedicated biogas grid. One or more customers are connected to this grid. These customers use gas equipment that is adjusted to the specific gas quality of the biogas.
- The biogas can be used to fuel a CHP installation, in order to produce electricity and heat. The produced electricity can be utilized locally or be fed to the electricity distribution grid.
- The biogas could be mixed with natural gas and then injected into the gas grid. If the ratio biogas and natural gas is sufficiently small the value of the Wobbe index, falls within the allowable Wobbe range. For this option, relatively large natural gas flow volumes should be available at the point where the biogas is injected into the grid.

As mentioned in section III, balancing issues can occur when the green gas is injected into the gas grid. This imbalance, caused by a surplus of injected green gas, can be solved in several ways:

- A gas storage site is connected to the distribution grid in order to flatten out fluctuations in the gas demand. In times of green gas surplus, the gas storage site withdraws gas. When green gas production is insufficient to meet the local gas demand, the gas supply can be complemented by natural gas from the transport grid or green gas stored in the local gas storage site.
- By means of a gas compressor station, the green gas can be compressed and fed to a gas grid with a higher operating pressure, which also has a higher gas flow.
- By means of a CHP installation the surplus of green gas can be converted to electricity and fed to the electricity grid.
- The surplus of green gas can be flared off. Although this way, the surplus gas is not utilized, a congestion of gas in the local grid is prevented.

The injection of green gas in the gas distribution grid requires increased intelligence of the distribution grid, e.g: only by monitoring the pressure, a surplus of gas can be noticed; intelligence is required to give priority to green gas over natural gas; the gas storage site requires a storage policy, which again needs monitoring and control; and the quality of the injected green gas should be monitored according to Dutch legislation. Thus, the injection of green gas into the gas distribution grid, transforms the gas distribution grid into a smart grid.

As can be concluded, many development options for the gas distribution grid exist. It should be investigated which of these options is (economically, environmentally, etcetera) the best for a given situation. Since the solution depends on the specific situation, a decision support tool should be developed. This tool will provide suitable development options for the distribution grid. The next section proposes the development of such a decision support tool.

V. Development of a Decision Support Tool

A. *Decision Support Tool (DST)*

For the development of the gas grid of the future, most of the available options are known and are already partly listed in section IV. However, the desired solution for the gas distribution grid depends to a great extent on the specific situation. Therefore, we propose the development of a DST, which will generate for each specific situation several solutions. Each solution has its own advantages and disadvantages, which are denoted by performance indicators - for instance costs, CO_2 emissions, and reliability. Showing the performance indicators of each solution, provides the engineer insight in the available solutions and eases the decision making for new investments. The starting configuration is defined by e.g. the current gas distribution grid and biomass availability. Furthermore several pre-conditions are defined which have to be taken into account,

e.g. the gas demand of each consumer should be sufficed at any time; spatial restrictions; Dutch legislation; and gas quality requirements. The solutions generated by the DST have to comply with the pre-conditions. These pre-conditions are incorporated in the DST and have to be put in the DST by the engineer.
The solutions generated by the DST will be adjustments and additions to the starting configuration. The variables for the DST are for instance, the addition of a gas storage site, its size, and type. Also, the way to exploit biomass, as listed in section IV, is a variable for the DST. Other variables are, among others, increase of pipeline capacity; addition of CHP installations; and the addition, size, and type of a gas compressor station.

B. Aspects to be covered

In order to determine the relevant performance indicators, the requirements of the gas grid of the future should be determined. In this respect, Wolters [9] provides a good starting point. He states that the current functionality of the gas distribution grid is insufficient to comply with future requirements from a technical, economic, and regulative point of view. Among the most important and urgent requirements mentioned by Wolters are: decreased vulnerability to damage, increased economic efficiency, more intelligence built into the networks in order, for example, to achieve optimum economic results for the end user, and flexibility of the distribution infrastructure with regard to the use of various gases.
Furthermore, information on relevant parameters has to be collected and implemented in the DST. Parameters are needed to quantify the performance indicators for each generated solution. Relevant parameters are for instance, cost of laying a pipeline, investment costs of the gas grid components, energy usage of components, and downtime information on the components. Since this information is likely to change over the years, this information should preferably be easy to update in the DST.
Since the available solutions depend to a great extent on the institutional aspects (e.g. subsidies and DSO responsibilities), the DST should be able to incorporate these institutional aspects.

VI. Conclusions

Due to the changing gas market, the gas distribution grid will undergo many significant changes in the near future. Hence, the question arises how the design and operational management of the gas distribution grid can be adapted in order to cope with the changes in the gas market.
The gas distribution grid is expected to transform from a mono-gas system into a multi-gas system; to increasingly interact with the electricity grid and with local heat grids; and to transform from an uni-directional gas supply chain into a bi-directional one, due to the injection of green gas. Therefore, the passive gas distribution grid is expected to transform into a smart gas grid, which monitors and controls the gas pressure, the gas flow, and the gas quality.
Investments in the gas distribution grid are required to facilitate the aforementioned changes. As was shown many options exist to facilitate this, including expanding the gas distribution grid with novel components, like gas compressor stations and gas storages sites. So far, it is unclear what configuration of investment provides the best solution. In addition, the solution is largely dependent on the local situation. Hence, research is required on the suitability of several development options for the gas distribution grid. Furthermore, it should be investigated what the relevant performance indicators are and how each development option affects these performance indicators.
The proposed DST should provide insight in the available development options by showing the advantages and disadvantages of these development options. This not only provides insight but will also ease the decision making of the DSOs on investments of the gas distribution grid.
The DST will provide a means in determining the future design of the gas distribution grid. Consequently, the future design will determine to a large extent the operational management of the gas distribution grid.

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