SciGRID_gas: The combined IGG gas transmission network data set

Release 1.2

J.C. Diettrich & A. Pluta & W. Medjroubi

Sep 15, 2020

CONTENTS

How to cite

J.C. Diettrich, A. Pluta, W. Medrjoubi
SciGRID_gas: The combined IGG gas transmission network data set
DLR Institute for Networked Energy Systems
Germany
doi: 10.5281/zenodo.4009128

Impressum

DLR Institute for Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg
Germany
Tel.: +49 (441) 999 060

LIST OF FIGURES

LIST OF TABLES

Summary

Here, this document describes the resulting data set "IGG", where all missing values have been estimated using heuristic processes, and was generated by combining the following data sources:

- InternetDaten data set (INET) [DPM20d]
- Gas Infrastructure Europe data set (GIE) [GasIEurop20]
- Gas Storages Europe data set (GSE) [GasSEurop20]

The goal of SciGRID_gas is to develop methods to create an automated process that can generate a gas transmission network data set for Europe. Gas transmission networks are fundamental for simulations by the gas transmission modelling community, to derive major dynamic characteristics. Such simulations have a large scope of application, for example, they can be used to perform case scenarios, to model the gas consumption, to minimize leakages and to optimize overall gas distribution strategies. The focus of SciGRID_gas will be on the European transmission gas network, but the principal methods will also be applicable to other geographic regions.

Data required for such models are the gas facilities, such as compressor stations, LNG terminals, pipelines, etc. One needs to know their locations, in addition to a large range of attributes, such as pipeline diameter and capacity, compressor capacity, configuration, etc. Most of this data is not freely available. However throughout the SciGRID_gas project it was determined, that data can be found and grouped into two fundamental different groups: a) OSM data, and b) non-OSM data. The OSM data consists of geo-referenced facility data that is stored in the OpenStreetMap (OSM) data base, and is freely available. However, the OSM data set currently contains hardly any other information than the location of the facilities. The Non-OSM data set can fill some of those gaps, by supplying information such as pipeline diameter, compressor capacity and more. Part of the SciGRID_gas project is to mine and collate such data, and combine it with the OSM data set. In addition heuristic tools are required to fill data gaps, so that a complete gas network data set can be generated.

In this document, the chapter "Introduction" will supply some background information on the SciGRID_gas project, followed by the chapter "Data structure" that gives a detailed description of the data structure that is being used in the SciGRID_gas project. Chapter "Data sources" describes the INET, GIE and GSE data sets. To remove any missing data, the chapter "Heuristic methods" describes in detail, how missing attribute values (e.g. pipeline diameter) were generated. This is followed by the chapter "Final data set", which gives a brief overview on each set of components and in addition summarizes the changes to a previously published SciGIRD_gas data set.

The appendix contains a glossary, references, location name alterations convention and finishes with the table of country abbreviation.

CHAPTER

ONE

INTRODUCTION

SciGRID_gas is a three-year project funded by the German Federal Ministry for Economic Affairs and Energy [BMWi20] within the funding of the 6. Energieforschungsprogramm der Bundesregierung [BMWi11].

The goal of SciGRID_gas is to develop methods to generate and provide an open-source gas network data set and code. Gas transmission network data sets are fundamental for the simulations of the gas transmission within a network. Such simulations have a large scope of application, for example, they can be used to preform case scenarios, to model the gas consumption, to detect leaks and to optimize overall gas distribution strategies. The focus of SciGRID_gas will be the generation of a data set for the European Gas Transmission Network, but the principal methods will also be applicable to other geographic regions.

Both the resulting method code and the derived data will be published free of charge under appropriate open-source licenses in the course of the project. This transparent data policy shall also help new potential actors in gas transmission modelling, which currently do not possess reliable data of the European Gas Transmission Network. It is further planned to create an interface to [MMK16] or heat transmission networks. Simulations on coupled networks are of major importance to the realization of the German *Energiewende*. They will help to understand mutual influences between energy networks, increase their general performance and minimize possible outages to name just a few applications.

This project was initiated, and is managed and conducted by DLR Institute for Networked Energy Systems.

1.1 Project information

- **Project title**: Open Source Reference Model of European Gas Transport Networks for Scientific Studies on Sector Coupling (*Offenes Referenzmodell europäischer Gastransportnetze für wissenschaftliche Untersuchungen zur Sektorkopplung*)
- **Acronym**: SciGRID_gas (Scientific GRID gas)
- **Funding period**: January 2018 - December 2020
- **Funding agency**: Federal Ministry for Economic Affairs and Energy (*Bundesministerium für Wirtschaft und Energie*), Germany
- **Funding code**: Funding Code: 03ET4063
- **Project partner**: DLR Institute for Networked Energy Systems

Gefördert durch:

aufgrund eines Beschlusses
des Deutschen Bundestages

1.2 Background

As of today, only limited data of the facilities of the European Gas Transmission Networks is publicly available, even for non-commercial research and related purposes. The lack of such data renders attempts to verify, compare and validate high resolution energy system models difficult, if not impossible. The main reason for such sparse gas facility data is often the unwillingness of transmission system operators (TSOs) to release such commercially sensitive data. Regulations by EU and other lawmakers are forcing the TSOs to release some data. However, such data is sparse, and too often not clearly understandable for non-commercial operators, such as scientists.

Hence, details of the gas transmission network facilities and their properties are currently only integrated in in-house gas transmission models which are not publicly available. Thus, assumptions, simplifications and the degree of abstraction involved in such models are unknown and often undocumented. However, for scientific research those data sets and assumptions are needed, and consequently the learning curve in the construction of public available network models is rather low. In addition, the commercially sensitivity also hampers any (scientific) discussion on the underlying modelling approaches, procedures and simulation optimization results. At the same time, the outputs of energy system models take an important role in the decision making process concerning future sustainable technologies and energy strategies. Recent examples of such strategies are the ones under debate and discussion for the Energiewende [BundesregierungDeutschland20] in Germany.

In this framework, the SciGRID_gas project initiated by the research centre DLR Institute of Networked Energy Systems in Oldenburg aims at building an open source model of the European Gas Transmission network. Releasing SciGRID_gas as open-source is an attempt to make reliable data on the gas transmission network available. Appropriate (open) licenses attached to gas transmission network data ensures that established models and their assumptions can be published, discussed and validated in a well-defined and self-consistent manner. In addition to the gas transmission network data, the Python software developed for building the model SciGRID_gas are published under the GPLv3 license.

The main purpose of the SciGRID_gas project is to provide freely available and well-documented data on the European gas transmission network. Further with the documentation, and the Python code, users should be able to generate the data on their own computers.

The input data itself is based on data available from openstreetmap.org (OSM) under the Open Database License (ODbL) as well as Non-OSM data gathered from different sources, such as Wikipedia pages, fact sheets from TSOs or even newspaper articles.

The main workload of this project is to:

- retrieve the OSM and Non-OSM data sets for the gas infrastructure
- merge all available data sets

- build a gas transmission component data set
- generate missing data using heuristic methods
- remove all gas facilities that are not connected to pipelines.

The first step of the project was to collate a Non-OSM data set by searching the web for metadata that will be useful for the project. This included information, such as pipelines, compressors, LNG terminals, and their attributes, such as diameters, capacities, etc.

This data set is called the **InternetDaten** data set (INET). The raw data set has been published previously. However, here the missing values have been determined using heuristic processes. At later stages, descriptions of other data sources will follow, and will be made available on the project webpage.

This multi-stage release will allow us to easily and effectively incorporate feedback from potential users during the lifetime of the project. Those releases can be downloaded from the SciGRID_gas webpage with documentation, and can be seen as a snapshot of the current research project state.

Further information on the project can be found on the SciGRID_gas web page: https://www.gas.scigrid.de/pages/imprint.html.

The web page is maintained throughout the project lifetime, and will contain information on:

- General project information
- Contact details
- Presentations
- Bug/data fixes
- Data, code and documentation releases
- Publications.

As part of the SciGRID_gas webpage, one can also sign up to the SciGRID_gas newsletter by sending an email to

news.gas-subscribe@scigrid.de

1.3 Project goal

The overall goals of the SciGRID_gas project are:

- **Data output**: Creation of customisable gas transmission network data sets.
- **Open source**: Any one can download the data, make changes to it, pass it on to others, or even use it in commercial projects, as long as the SciGRID_gas project is mentioned as the original source of the data (CC by).
- **Application**: The outcome of the project can be used for a variety of scientific applications (e.g. sector coupling, entry-exit models, etc.).
- **Transparency**: The Python code, the documentation and the data (that can be passed on under copyright licences) is supplied.
- **Extendability**: Every user can extend the software code to their needs. However, we would encourage users to update and maintain the original git-repository and documentation for others.
- **Feedback**: Through constant data releases, it is hoped that the output data set will improve in quality and quantity by constantly incorporating feedback from the research community.

1.4 Document overview

This is an overview of this SciGRID_gas documentation, as this will help the user to better understand the overall project, its aims and the steps that were taken to obtain/model the resulting data set.

SciGRID_gas has been coded in Python, and hence, with that came the overall data structure that was selected for the project. As this is the most fundamental aspect for anyone wanting to use the data and the code, it is described first. In the chapter **Data Structure** we define the terms *Components*, *Elements*, and *Attributes*. We also give an overview on the internal workings of the SciGRID_gas source code.

A fundamental building block for the SciGRID_gas project is the data itself. Overall, we have classified the data into two groups: OSM and non-OSM data. The chapter **Data Sources** contains background information on the InterDaten (INET) data set only. Information is supplied on how the data was collated and how it was implemented into the SciGRID_gas data sets structure. In addition, an overview of the extent of the data will also be given for the data, e.g. the number of elements or the list of attributes that the data contains.

The raw INET data is "incomplete", as not all attribute values could be found for all elements. This results in missing elements and missing attribute values. Hence, the chapter **Heuristic Methods** will describe the different methods that have been implemented to estimate the missing attribute values.

The document also contains the chapter **Appendix** that contains sub-sections, such as *Glossary*, *References*, etc.

1.5 Formatting style

Throughout this document certain editing format styles have been applied, to make it easier for the user to read the document.

Key SciGRID_gas component labels are written in italic, such as *PipeLines*, *Storages* etc.

Component attributes are also written in italic, such as *length_km*, *pressure_bar*.

Function names are written in bold, e.g. **M_CSV.read()**. This also includes build in statistical function, such as **mean** or **median**.

Directory names and file names are surrounded by double quotes, e.g. "StatsMethodsSettings.csv".

CHAPTER

TWO

DATA STRUCTURE

A well designed and documented data structure is fundamental in any large scale project. Good data structure in combination with tools, based on algorithms, improve the performance of any project output.

This structure needs to represent the gas flow facilities as good as possible, Hence, it needs to include components, such as pipelines, compressors, etc. A finite number of components have been identified, that are required as building blocks of a gas network. In addition each component will contain attributes, such as pipeline diameter, maximal operating pressure, maximal capacity, number of turbines etc.

It is anticipated, that the adopted data structure can be implemented in different types of gas flow models and will be used by the research community for topics, such as sector coupling or identifying gas transmission bottlenecks.

Within the SciGRID_gas project, the structure of the data model is part of classes defined within the Python code. Alterations may occur over the duration of the project, but it is envisaged, that those will be small, and that compatibility will be assured.

The goal of this section is to describe in details the data structure that has been adopted and implemented into the Python code. This will be important in understanding other aspects of this document, such as exporting the data into CSV files or generating missing values.

Prior to the description of the data structure, the overall pathway of the data flow within the SciGRID_gas project will be explained, as it is believed, that such overview will help the reader.

2.1 Data structure description

This section contains information about the SciGRID_gas data structure, the format, and the code that can be used to import publicly available data into the project, so that it can be used in subsequent steps. Paramount for an understanding of the data structure is a good understanding of the terminology used throughout this section and the document in general. Hence, terminology will be introduced in the following sub-section.

2.1.1 Terminology

Throughout this document certain terms will be used, which will be described below and summarized as a picture in Figure 2.1.

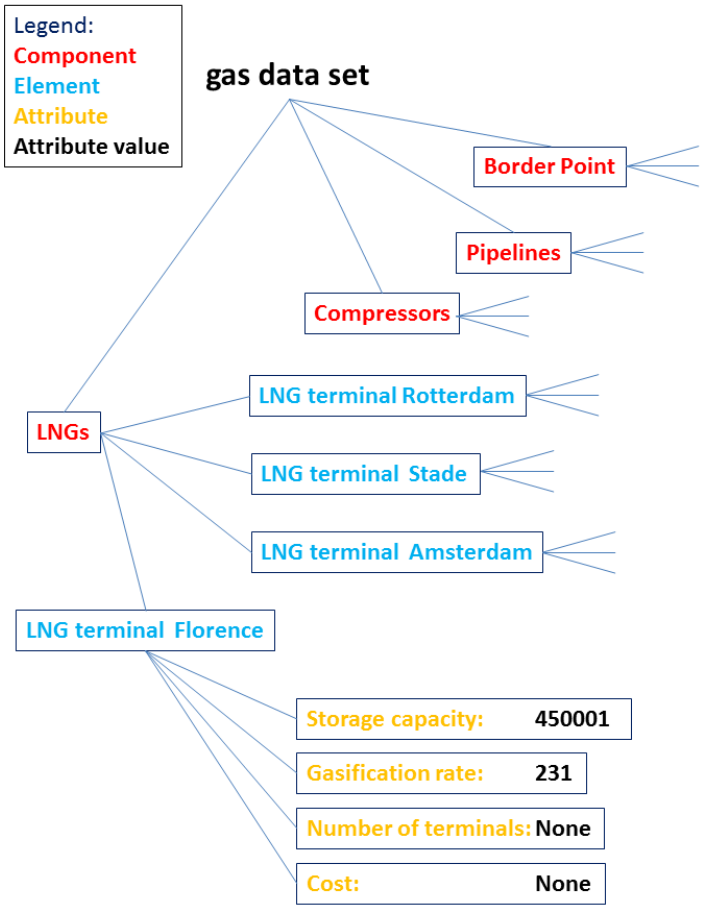


Figure 2.1: Data structure for the SciGRID_gas data set

Gas transmission network

The term "gas transmission network" describes the physical gas transmission grid. This does not include the distribution of gas through gas distribution companies, but includes the long distance transmission of gas from producer countries to consumer countries, as carried out by the Transmission System Operators (TSO) [Wik20g]. In addition, throughout this document, the terms "transportation" and "transmission" are seen as interchangeable, and hence will both be used describing the same.

Gas component data set

The term "gas component data set" is used for all raw data of objects/facilities that have been loaded using SciGRID_gas tools into a Python environment. Gas component data sets are used as input into our SciGRID_gas project. Several data sources can be loaded as gas component data sets, and then combined into a single gas component data set. However, not all elements (e.g. compressors) must be connected to pipelines. Hence, such a data set is referred to as a "gas component data set".

Gas network data set

A "gas component data set" can be converted into a "gas network data set", by connecting all non-pipeline elements to nodes and all nodes are connected to pipelines, and as part of the process all network islands have been connected or removed, resulting in a single network. Therefore the network contains nodes and edges which are coherently connected, and all objects with the exception of pipelines are associated with nodes in this network, whereas pipelines are associated with edges.

Component

There are several component types in a gas transmission network, such as compressors, LNG terminals, or pipelines. In Figure 2.1 they are coloured red. Hence, whenever the word "component" is mentioned, it refers to one of these components. There are roughly a dozen different components that will form a gas network data set. They will be briefly explained below.

Element

The term "element" refers to individual facilities, e.g. the LNG Terminal in Rotterdam, or the compressor in Radeland. In Figure 2.1 they are coloured blue. The first one is an element of the component LNG terminals, whereas the second one is an element of the component compressors. Hence, many elements make up a component. However, all elements are referring to different facilities by default. This means in a single network, one cannot have two elements of a component describing the same facility. The structure of elements is described below.

Attribute

"Attribute" is a term that is being used for the individual labels of the values that are associated with the elements. Examples for this term are gas "pipeline diameter", "maximum capacity", "max gas pipeline pressure", to name just a few and in Figure 2.1 they are coloured yellow. Overall there will be several hundred attributes in the SciGRID_gas project. However, the same attributes can occur in more than one component, e.g. "max flow capacity" exist for pipelines and also for compressors. Throughout the project, we have tried to keep the units of such attributes the same, so that there is no unit conversion required.

Attribute value

Each attribute has a value, most likely a number or a string. In Figure 2.1 they are coloured black. While booleans (*True*/*False*) are also allowed, more likely a "1" will stand for *True* and "0" for *False*. However, not all attribute values are given. Therefore a no value attribute value needs to be specified. In the SciGRID_gas Python code it is *None*.

The Figure 2.1 depicts the relationships between the terms "gas data set", "component", "element", "attribute", and "attribute value". As can be seen, a single gas data set consists of several components. On the next level, each component contains several elements. Further, each element has several attributes, where each attribute has a value,. Here, "None" stands for unknown value. The heuristic processes described in this document at a later stage will fill those "None" values with generated values.

Gas component types

A gas transmission network consists of different components, such as pipelines, compressors, etc. For the SciGRID_gas project a hand-full of components have been implemented, and will be described here briefly:

- *Nodes*: In a gas network, gas flows from one point to another point, which are given through their coordinates. All elements of all other components (such as compressor stations and power plants) have an associated node, which allows for the geo-referencing of each element. Overall the term "nodes" will be used throughout this document, as it aligns with graph theory aspects.
- *PipeLines*: *PipeLines* allow for the transmission of the gas from one node to another. *PipeLines* are georeferenced by an ordered list of nodes.
- *PipeSegments*: *PipeSegments* are almost identical to *PipeLines*, However, are only allowed to connect two nodes. Hence, any pipeline can easily be converted to multiple pipe-segments.
- *Compressors*: *Compressor* represent compressor stations, which increases the pressure of the gas, and hence, allows the gas to flow from one node to another node. A gas compressor station contains several gas compressors units (turbines).
- *LNGs*: *LNGs* is the acronyme for the LNG terminals and LNG storages, which there are several in Europe, as some gas gets transported to Europe via ships.
- *Storages*: *Storages* are a further network component. Gas storages are being used as gas pipeline capacities or gas production capacities might not be able to cover high demand periods, such as during the winter. Hence, large gas storage units are being filled during the summer periods, and released during winter periods.
- *Consumers*: *Consumers* is the term used for gas users, which can be households, industry, power plants or others.
- *Production*: These can be wells inside a country where gas is pumped out of the ground. Most of the gas used in Europe comes from outside of the EU, However, there are several smaller gas production sites scattered through Europe.
- *BorderPoints*: *BorderPoints* are facilities at borders between countries, which are mainly used to meter the gas flow from one country to another.
- *EntryPoints*: These are special border points at the borders of the European Union.
- *InterConnectionPoints*: These are connection points between gas transmission operators, and will be found mainly within Europe, in particular at country borders.

Element structure

As described above, elements are describing individual facilities, such as compressors or LNG terminals. However, the overall structure of those elements is the same for all elements of all components. The overall structure of those elements is described in the following part:

- *id*: A string that is the ID of the element, and must be unique.
- *name*: A string that is the name of the facility, such as "Compressor Radeland".
- *source_id*: A list of strings that are the data sources of the element. As several elements from different sources could have been combined in a single element, one might need to know which the original data sources are.
- *node_id*: This is the ID of a geo-referenced node to which an element of the network is associated to. For a compressor, this will be just a single *node_id*. However, for a gas pipeline this entry would be a list of at least two *node_id* values: the starts node id and the end node id.
- *lat*: This is the latitude value of an element. For pipelines *lat* is a list of latitude values. Throughout the SciGRID_gas project the projection World Geodetic system 1984 (epsg:4326) will be used.
- *long*: The longitude, analogue to lat.
- *country_code*: This is a string indicating the 2-digit ISO country code (Alpha-2 code, see Chapter 8.6 for list of countries and their code) of the associated node of elements or list of nodes in case of *PipeLines* or *PipeSegments*.
- *comment*: This is an arbitrary comment that is associated with the element.
- *tags*: This dictionary is reserved for OpenStreetMap data. It contains all associated key:value-pairs of an OpenStreetMap item.

In addition, there are three further groups of attributes to each element, which have been coded as "dictionaries", namely:

- *param*
- *method*
- *uncertainty*.

The structure within each dictionary is the same. The dictionary *param* (short for "parameter") contains a list of attributes and their values. This list of attributes will be different for each component. For the component *PipeLines* they might be pipeline diameter, max pipeline pressure, and max pipeline capacity. For the component *Compressors* they might be , such as number of turbines, overall turbine power, energy source of turbine and more.

So the other two attribute dictionaries are *method* and *uncertainty*. Each of those two dictionaries contains exactly the same list of attributes as the *param* dictionary. However, their attribute values reflect the name of the dictionary. E.g. the attributes in the dictionary *method* contain the information on the method used to derive the attribute value that is stored in the*param* dictionary. Here methods of value generation can include heuristic methods names (in form of strings) that have been implemented in the SciGRID_gas project. However, if attribute values are not being generated by the SciGRID_gas project, but originate from one of the input data sources, then the attribute values in the *method* dictionary is set to "raw".

Similar is the content of the *uncertainty* dictionary. It contains information on the uncertainty of the attributes from the *param* dictionary of that component. Again all attributes listed in the *param* dictionary are also present in the *uncertainty* dictionary. The attribute values here reflect the uncertainty of the attribute. Here, it is assumed, that attributes with a method of "raw" have an uncertainty of zero. Only for those attributes, which were generated during heuristic SciGRID_gas methods an uncertainty larger than zero will be specified.

2.2 Summary

The SciGRID_gas software is designed to construct a gas transmission network data set form different open source gas component data sets. The gas transmission data set needs to be available and stored in a precise and predefined way, which was described in this section. We have identified several *component*-types of a gas transmission network grid, like pipelines, compressor stations, LNG-terminals, etc. Each specific facility that falls under such a component is considered an *element* of that component. Each element is described by a list of *attributes* and correspondent *attribute values*.

CHAPTER

THREE

DATA SOURCES

Data sets describing gas transmission networks are the property of the transmission system operators (TSOs) and are generally not freely available in the form and depth that is required for modelling purposes. The major reason for the difficulty of obtaining of such data is that most of the gas network infrastructure, namely pipelines, is buried underground. Thus a pipeline diameter is hard to estimate locally. In addition, almost all of the data is commercially sensitive.

Nevertheless, some data is made available by gas transmission network operators, through different channels. E.g. information on the size and number of compressors could be made public through a press release, as part of a refurbishment. An example is given below (https://www.maz-online.de/Lokales/Teltow-Flaeming/Neue-Verdichterstation-entsteht-in-Radeland):

> "Die Eugal-Pipeline dient dazu, Gas aus der neuen Ostseepipeline Nord Stream 2 bis zur tschechischen Grenze zu leiten. 275 Kilometer von ihr verlaufen in Brandenburg. Grundsätzlich soll die neue Leitung parallel zur bestehenden Opal-Pipeline gebaut werden."

In addition some information can be found on company web pages, (https://www.open-grid-europe.com/cps/rde/SID-752BB6B5-E0A975F2/oge-internet-preview/hs.xsl/NewsDetail.htm?rdeLocaleAttr=en&newsId=50190C3B-E14F-4685-9E64-E40EEAB57A28):

> Open Grid Europe (OGE) is investing roughly EUR 150 million at its compressor station in Werne to improve the security and flexibility of energy supply for North Rhine-Westphalia and Germany. The upgrade of the station, which is one of the hubs of the pipeline network, will allow gas flows to be switched (reversed) from north to south and south to north. In addition, OGE is preparing the station for the upcoming transition from L- to H-gas. Through this fitness programme, the station's transmission capacity will increase by about 500,000 to 6.5 million m^3/h, which is equivalent to the annual consumption of more than 2,100 single-family homes. The project, which is due for completion at the end of 2018, is fully on track."

However, there is a public drive to gather such data and subsequently make it available. The major platform through which this is occurring is the Open Street Map database [Hel18]. OSM is a geo-referenced database through which people can supply geo-referenced information on all man-made and natural structures, ranging from mountains to buildings. To achieve this, people throughout the world wander the globe and geo-reference everything that they can find. This also includes gas-pipeline markers, compressor stations or LNG terminals. However, the major problem remains that one cannot measure or estimate the diameter of the underground pipelines, or the number and size of the compressor turbines, as compressors are within buildings, which are fenced off. Hence, such information is hardly supplied to the OSM platform.

For the reasons mentioned above, the available data can be separated into two different groups:

- OSM data: Data can be found in the OSM data base. OSM data is well geo-referenced, but contains little meta-information (information on the facility attributes, such as pipeline diameter or pipeline capacity). OSM data is very helpful to obtain accurate routes of pipelines.
- Non-OSM data: Non-OSM data have in general lower geographical accuracy but contain a lot of meta-information. Unfortunately, such information is only known for a few facilities. One exception to this rule

are shapefiles from TSOs. They are rare, but well geo-referenced. However, the resolution of the meta information can vary from TSO to TSO.

The following section will introduce non-OSM data sets, and at a later stage, this will be followed by a section on the OSM data set.

3.1 Non-OSM data

Non-OSM data includes data from internet research, TSO press releases, TSO transparency platform, TSO public data, national open-source gas network data sets[1], etc.

Some of the TSO information had to be made available due to EU-regulations. Other information has been made public as part of a company's self presentation and advertisement. The information used by the SciGRID_gas project focuses on:

- the quality of the data
- the format of the data
- the level of representation of the data
- and the copyright restrictions on the data.

In addition, each data source is unique. Source specific tools need to be developed, so that all data sources can be made accessible for the SciGRID_gas project in the format as described in later chapter releases.

A significant portion of the project was spent on finding non-OSM data sets . Further data sources might be available, but unknown to the authors. If the authors are made aware of additional sources, the project will try to incorporate those, as this would only increase the depth of the data available and increase the applicability of the gas network data set and model.

Non-OSM data sources are very specific, addressing only certain aspects of the entire gas infrastructure. E.g. the GIE [GasIEurop20] data set supplies information on the daily gas flow in and out of gas storages in LNG terminals. However, they fall short on specifying the fundamental information of the actual physical location. Other data sets, such as the LKD [FMWP+17] data set is quite detailed in respect of pipelines, compressors and consumptions, however, only available for Germany.

Hence, the main task is to look closely at each data source, distil which data attribute values can be used, how it can be downloaded and incorporated into our SciGRID_gas model, and identify the copyright restrictions on the data source.

Due to copyright regulations, there are roughly two groups of data:

- Non copyright restrictive data (N-CRRD): here the copyright does not restrict the download, use and distribution of the data.
- Copyright restrictive data (CRRD): here the data can be downloaded and used internally, but not re-distributed to others.

The following is a list of the data sources that will be used throughout the project and an indication into which group of copyright restriction they fall:

- **OSM** (https://www.openstreetmap.org) (N-CRRD)
- **GB** (https://www.nationalgridgas.com/land-and-assets/network-route-maps) (CRRD)
- **NO** (https://www.npd.no/en/about-us/information-services/available-data/map-services/) (N-CRRD)
- **LKD** (https://tu-dresden.de/bu/wirtschaft/ee2/forschung/projekte/lkd-eu) (N-CRRD)
- **ENTSOG** (https://transparency.entsog.eu/) (CRRD)

[1] An entire gas network data set is only available from the UK, see https://www.nationalgridgas.com/land-and-assets/network-route-maps'.

- **EMap** (https://www.entsog.eu/sites/default/files/2020-01/ENTSOG_CAP_2019_A0_1189x841_FULL_401.pdf) (CRRD)
- **GIE** (https://www.gie.eu/) (N-CRRD)
- **GSE** (https://www.gie.eu/index.php/gie-publications/databases/storage-database) (N-CRRD)
- **IGU** (https://www.igu.org/) (CRRD)
- **GasLib** (http://gaslib.zib.de/) (N-CRRD)
- **INET** (see `Refs_InternetData`) (N-CRRD).

Each data set and source comes with a different copyright regulation. The copyright can be rather non-restrictive (e.g. INET) or can be restrictive (IGU). It is attempted to use only freely available data, so that such data can be re-distributed. In more restrictive data cases (IGU, GB), it is not allowed to download the data and distribute it to others. However, it is allowed to let other potential users know of the location of such data and supply them with tools, that allow them to carry out the same data download and subsequent incorporation of the data into a gas network data set.

Note:

In case that other users are aware of other data sources, that might be useful to this project, please get in touch and supply us with a brief description of the data and the location of such data, so that additional tools can be developed to incorporate the data in this project. Please use the following email address: developers.gas(at)scigrid.de

3.2 The InternetDaten (INET) data set

This section contains information on the generated, content and nature of the so called **InternetDaten** data set (**INET**).

The INET data set is a special data set, as it was collated from many www sources and the information has been collated into CSV files. Please note, that throughout the project, the separator within CSV files will need to be ";". This section here will give an overview on the INET, its components and how the data is stored in INET specific CSV files. Further the processing of the data into Python will be described.

Prior to the description of those processes, a general overview of the INET data set is given first, so that the reader gets a better understanding of the size and depth of the data.

3.2.1 Overview of the INET data set

The INET data set contains geographical and meta information on gas facilities that were found through Internet searches. The data originated from www pages, such as Wikipedia, gas transmission system operators, fact sheets and press releases and more. Hence, most of the data had to be extracted manually out of text pages. To make this data available throughout the project, the data is being stored in CSV files. This also allows others to add additional properties and values to the INET data set at any stage. Tools have been written to load the INET from those CSV files and make them accessible throughout the project[1].

The Table 3.1 summarises the number of elements for each component that has been found so far. However, this does not imply that there is no missing data. In contrary, this data set comes with a lot of missing data:

Table 3.1: INET component summary.

Component Name	Count
BorderPoints	119
Compressors	249
ConnectionPoints	0
Consumers	0
EntryPoints	37
InterConnectionPoints	118
LNGs	32
Nodes	907
PipeSegments	920
Production	0
Storages	199

In addition, a map (see Figure 3.1) visualizes these components for Europe in the figure below.

3.2.2 Origin of the data

As has been stated before, the resulting INET data set originated from text sources found on the www. Here, for the pipeline JAGAL [Wik20h] an example from a Wikipedia page is given (https://en.wikipedia.org/wiki/JAGAL):

As one can see, some information is given, such as location name of the compressor (Mallnow), total pipeline length (338 km), pipeline diameter (1200 mm) and maximum pipeline capacity (24 billion $\mathrm{m}^3\mathrm{a}^{-1}$). This is the information that is manually extracted from such pages and put into the CSV files. Other sources of such data are: gas facility operator press releases, fact sheets and other documents, newspaper articles, federal departmental web pages etc.

To collate the data in an orderly manner, a system of CSV files has been created and will be described below.

[1] These tools will be made available during an upcoming release, where the INET data set will be jointly released with the GIE data set most likely through our project web page.

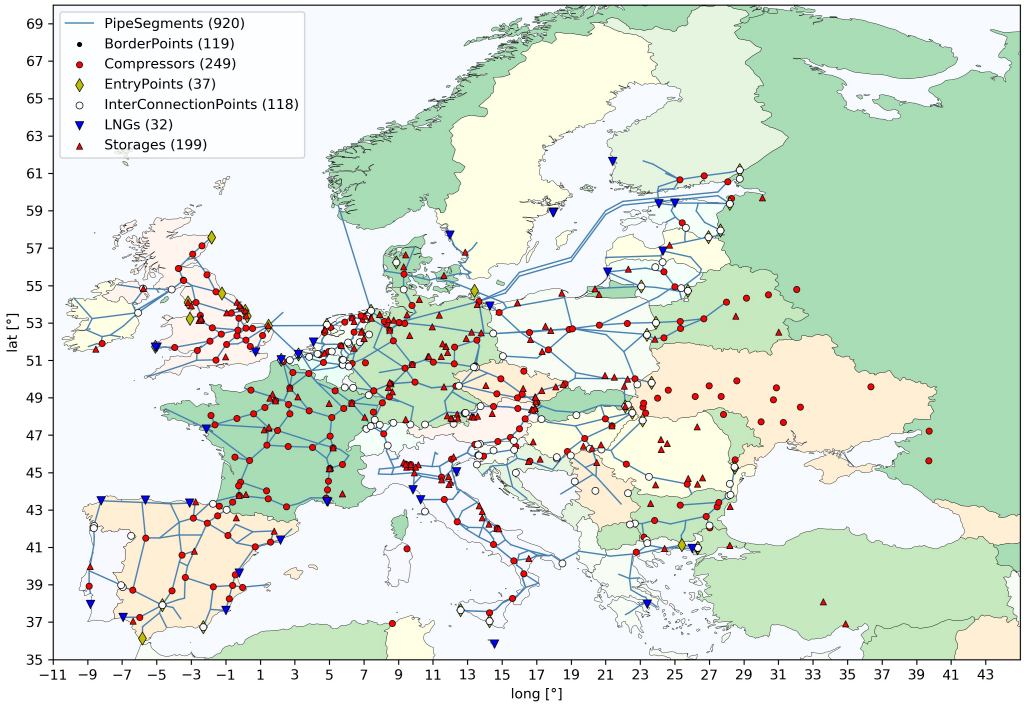


Figure 3.1: Map of the INET data set. The legend contains the number of elements for each component.

Commissioned	1999
Technical information	
Length	338 km (210 mi)
Maximum discharge	24 billion cubic meters per year
Diameter	1,200 mm (47 in)
No. of compressor stations	1
Compressor stations	Mallnow

Figure 3.2: Screenshot of part of the Wikipedia page for the pipeline JAGAL.

3.2.3 INET CSV file description

Each component of the INET data set is represented by a single CSV file. Each of those files has a single header line, and it is very important to know, that entries in the first line should only be changed if one knows, what one is doing, as the first row labels (the actual words) are imported and used as variable names in the SciGRID_gas project Python programs. Hence, if certain labels would be missing, the program would fail. In addition, each label needs to be unique within each file. It is advised to incorporate the units of the attributes into the label name, where possible.

Nodes.csv file

This is a unique file, and contains information on the nodes of the INET data set. Nodes are such entities, to which and from where pipelines can run, or to which other facilities can be associated to. Nodes supply information on a location including its name, its latitude and longitude, and the country in which it is located. Additionally, they supply information on how exact is the location of the node could be determined. The nodes component data is supplied to the SciGRID_gas data model only via a single CSV file.

- *id*: This is a unique id of a node of type string. Most likely this will be the name of an element. White spaces are allowed in this string.
- *comment*: Here the user can place additional information on the location node.
- *country*: Here the user needs to write the 2 letter abbreviation of the country, in which this node is located (see Table 8.4 for a list of country codes used).
- *lat*: This is a number of the best estimate of the latitude of the location. Best latitude value (and long value) were attempted to be generated by using metadata of the facility node and satellite maps. Using the satellite data, address information etc., it was tried to visually find the facility of the node.
- *long*: This is the corresponding best estimate of the longitude of the location derived during the same process as described under **Lat**.
- *node_id*: This is an identifier of a node.
- *source_id*: This is a unique identifier describing the source of the element. Here **INET** is the abbreviation for **InternetDaten**. Hence, all elements originating from the INET data set starts with the letters **INET**.
- *name*: A string containing the name of the location. It is allowed to contain white spaces.
- *exact*: This is a number in the range of 1 to 5, indicating how accurate the lat/longs were supplied for each node. Options are as follow:
  - "1": The exact location of this node is known, as one was able to verify the facility through satellite data.
  - "2": Here the lat/long is not known exactly, however one assumes that the location is within a small region (e.g. Krummhörn), Hence, not being much larger than 10 km.
  - "3": Here so little is known about the exact location, and one only knows, that the location is within a large region (e.g. Hamburg). Hence, the actual location could be out by 10 km or more but less than 100 km.
  - "4": Here so little is known about the exact location, and one only knows, that the location is within a state (e.g. Niedersachsen). Hence, the actual location could be out by 100 km or more but less than 1000 km.
  - "5": Here so little is known about the exact location, and one only knows, that the location is within a country (e.g. Ukraine). Hence, the actual location could be out by 1000 km or more.

All other components need two files, the location file and the metadata file, which will be described next.

Compressor CSV meta file

The compressor file ("Compressors.CSV") contains all the metadata for all known compressor stations.

In addition to the seven mandatory columns introduced above, the following columns are currently implemented, and contain the following data:

- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", than it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known.
- *operator_name*: This is a string, containing the name of the operator of the compressor station.
- *pipe_name*: This is a string containing the label of the pipeline that the compressor is connected to.
- *source*: Information on where the information of this element originated from.
- *is_H_gas*: This is a boolean, indicating if the gas is of high calorific gas type ("1") or of low calorific gas ("0").
- *max_cap_M_m3_per_h*: This is a number, which is the overall capacity of gas that can be compressed by the compressor station. Values need to be supplied in units of $[\mathrm{Mm}^3/\mathrm{h}]$.
- *max_pressure_bar*: This is a number, which is the maximum pressure that the gas can be compressed to. Values need to be supplied in units of [bar].
- *max_power_MW*: This is a number, which is the sum of the power of all compressor units that are installed at the compressor station. Values need to be supplied in units of [MW].
- *num_turb*: This is the number of compressor turbines installed at the compressor facility. This number is including the reserve turbine unit.
- *turbine_fuel_isGas_1*: This is a boolean, indicating if the turbine is powered by gas ("1"), or by electric ("0").
- *turbine_type_1*: This is a string containing additional information on the type of turbine unit, e.g. name of the turbine.
- *turbine_power_1*: This is a number, indicating the power of the turbine unit. The value needs to be supplied in units of [MW].
- *turbine_fuel_isGas_2*: This is the information for the second turbine unit. Same as for *turbine_fuel_isGas_1* applies. Currently up to 6 individual units can be stored in the database, Hence, the last digit in the identifier can be as large as 6.
- *turbine_type_2*: This is the information for the second turbine unit. Same as for *turbine_type_1* applies. Currently up to 6 individual units can be stored in the database, Hence, the last digit in the identifier can be as large as 6.
- *turbine_power_2*: This is the information for the second turbine unit. Same as for *turbine_power_1* applies.
- ...
- *turbine_power_6*: This is a number, indicating the power of the sixth turbine unit. The value needs to be supplied in units of [MW].

LNG CSV meta file

The LNG terminal metafile ("LNGs.CSV") contains all the metadata for the LNG terminals.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known.
- *source*: Information on where the information of this element originated from.
- *max_workingGas_M_m3*: This is a number, indicating the maximum amount of liquid gas that can be stored, after having been brought in by ship. Values need to be supplied in units of $[\mathrm{Mm}^3]$
- *max_cap_store2pipe_M_m3_per_a*: This is a number, indicating the maximum amount of gas that can leave the LNG terminal. This gas is in gas phase. Values need to be supplied in units of $[\mathrm{Mm}^3/\mathrm{a}]$

BorderPoints CSV meta file

The metafile for * BorderPoints * elements ("BorderPoints.CSV") contains all the metadata for each border point.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *pipe_name*: This is a string, the name of the pipe that is passing the border point.
- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known.
- *source*: Information on where the information of this element originated from.

EntryPoints CSV meta file

The metafile for *EntryPoints* elements ("EntryPoints.CSV") contains all the metadata for entry points of gas pipelines into Europe.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known.
- *source*: Information on where the information of this element originated from.

InterConnectionPoints CSV meta file

The *InterConnectionPoints* metafile ("InterConnectionPoints.CSV") contains all the metadata for interconnection points between the different operators within Europe.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known.
- *source*: Information on where the information of this element originated from.
- *pipe_name*: This is a string, the name of the pipe that is passing the border point.

Storages CSV meta file

The metafile "Storages.CSV" contains all the metadata for gas storage within Europe.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *access_regime*: String indicating the access of the storage facility, TPA or not TPA (nTPA), and could be used for heuristic processes at a later stage.
- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *start_year*: Integer number of the year, when the operation of this element started. If it contains a value of "None", then this year is not known. A value of 2050 was selected, if the site is in planung/construction, but not yet in operation.
- *store_type*: This is a string, indicating the type of storage, such as "Leeres Gas Feld" (empty gas field), "Salz Kaverne" (salt cavern) etc.
- *source*: Information on where the information of this element originated from.
- *is_H_gas*: This is a boolean, that indicates if the gas is of high calorific nature ("1") or of low calorific nature ("0").
- *is_onShore*: this is a number, indicating if this gas store is on land or not. Options are "1" and the gas store is on land, whereas the second option "0" indicates, that the gas store is not on land, Hence, will be off shore.
- *operator_name*": String, containing the name of the operator.
- *max_workingGas_M_m3*: A number indicating the maximum amount of gas that can be stored and worked with in that gas field. Values need to be supplied in units of $[\mathrm{Mm}^3]$.
- *max_cap_store2pipe_M_m3_per_d*: A number indicating the maximum amount of gas that can move from the gas store into a gas pipe. Values need to be supplied in units of $[\mathrm{Mm}^3\mathrm{d}^{-1}]$.
- *max_cap_pipe2store_M_m3_per_d*: A number indicating the maximum amount of gas that can move from the gas pipeline into a gas store. Values need to be supplied in units of $[\mathrm{Mm}^3\mathrm{d}^{-1}]$.

PipeSegments CSV meta file

The metafile "PipeSegments.CSV" contains all the metadata for gas pipe lines within Europe.

Next to the above described first seven columns the following columns are currently implemented, and contain the following data:

- *is_bothDirection*: This is a boolean with value of '1' or '0'. If set to '1', then the gas pipeline can be operated in both directions, whereas if set to '0', then the gas can only flow from the start point to the end point. Hence, here the order of the *point_lables* in the pipes file is important.
- *length_km*: This is the overall length of the pipeline, and NOT of the segment. The value needs to be supplied in units of [km].
- *diameter_mm*: This is the diameter of the pipe in units of [mm].
- *max_pressure_bar*: This is the maximum pressure of the gas within the gas pipeline in units of [bar].
- *max_cap_M_m3_per_d*: This is the maximum annual gas volume that the pipe can transmit in units of $[\mathrm{Gm3/d}]$.
- *num_compressor*: This is the number of compressors along the pipeline.
- *end_year*: Integer number of the year, when the operation of this element stopped. If it contains a value of "None", then it is still operational.
- *is_H_gas*: This is a boolean, that indicates if the gas is of high calorific nature ("1") or of low calorific nature ("0").
- *source*: Information on where the information of this element originated from.
- *lat_mean*: Average mean latitude value of the pipe-segment.
- *lat_mean*: Average mean longitude value of the pipe-segment.

3.2.4 INET data density

Now that the structure of the INET has been described in detail above, the "data density" of data will be presented. Here "data density" is defined as follow: it is the ratio of the number of usable (not missing, e.g. filled or raw values) attribute values over the number of all elements of the component. Supposedly the INET would have two LNG terminals. One of the facilities has a storage volume, whereas the other one does not. Hence, the data density would be 50% for the attribute storage volume. Here, the data density for the most relevant attributes will be given next for all components. At a later stage, missing values might be estimated through heuristic processes, to complete the data set.

PipeSegments

Overall there are 920 *PipeSegments* elements in the INET data set.

Table 3.2 summarizes the data densities for the most important pipe-segment attributes:

Table 3.2: INET *PipeSegments* data density

Attribute name	Data density [%]
diameter_mm	43
is_H_gas	94
is_bothDirection	9
length_km	100
max_cap_M_m3_per_d	16
max_pressure_bar	31
num_compressor	3

Compressors

Overall there are 249 *Compressors* elements in the INET data set. The data densities for the most important attributes is given in Table 3.3 below:

Table 3.3: INET *Compressors* data density

Attribute name	Data density [%]
is_H_gas	99
max_cap_M_m3_per_d	7
max_power_MW	16
max_pressure_bar	7
num_turb	15
operator_name	11
pipe_name	10
turbine_power_1_MW	15
turbine_power_2_MW	147
turbine_power_3_MW	9
turbine_power_4_MW	3
turbine_power_5_MW	1
turbine_power_6_MW	0
turbine_fuel_isGas_1	14
turbine_fuel_isGas_2	14
turbine_fuel_isGas_3	10
turbine_fuel_isGas_4	7
turbine_fuel_isGas_5	1
turbine_fuel_isGas_6	0
turbine_type_1	9
turbine_type_2	9
turbine_type_3	6
turbine_type_4	3
turbine_type_5	1
turbine_type_6	0

Nodes

Overall there are 907 nodes. As described above, the information supplied is an "id", latitude and longitude values, the country code and a value indicating the accuracy of the node location. Hence, Table 3.4 summarizes the relative number of nodes within the possible value range of 1 to 5:

Table 3.4: Summary for the attribute "exact" of component *Nodes* of the INET data set.

Exact value	ration of data with exact value [%]
1	20
2	45
3	9
4	12
5	14

Storages

Overall there are 199 storage elements in the INET data set. The data densities for the most important attributes is given in Table 3.5 below:

Table 3.5: INET *Nodes* data density

Attribute name	Data density [%]
access_regime	90
is_H_gas	12
is_onShore	22
max_cap_pipe2store_M_m3_per_d	77
max_cap_store2pipe_M_m3_per_d	77
max_workingGas_M_m3	80
operator_name	99
source	95
store_type	94

BorderPoints

Overall there are 119 *BorderPoints* elements in the INET data set. The data densities for the most important attributes are given in Table 3.6 below:

Table 3.6: INET *BorderPoints* data density

Attribute name	Data density [%]
pipe_name	9

EntryPoints

Overall there are 37 *EntryPoints* elements in the INET data set. This component does not contain any further major attribute of interest.

InterConnectionPoints

Overall there are 118 *InterConnectionPoints* elements in the INET data set. The data density for the most important attributes is given in Table 3.7 below:

Table 3.7: INET *InterConnectionPoints* data summary

Attribute name	Data density [%]
pipe_name	15

LNGs

Overall there are 32 *LNGs* elements in the INET data set. The data densities for the most important attributes is given in Table 3.8 below:

Table 3.8: INET *LNGs* data density

Attribute name	Data density [%]
max_cap_store2pipe_M_m3_per_d	90
max_workingGas_M_m3	97

Overall one can see that a lot of data has been collated and is made available through the INET data set. However, as presented in the data density tables, a lot of attributes have low data density. Chapters later in this documentation will demonstrate how missing values can be estimated, so that the generated SciGRID_gas data set has a data density of 100 % for each attribute.

3.2.5 Copyright and disclaimer for the INET data set

Copyright

A list of the sources used for the generation of the INET data set can be found in Chapter 8.3.

Disclaimer

The INET data set is supplied on a best-effort basis only, using available information as documented gathered from the Internet. While every effort is made to make sure the information is accurate and up-to-date, we do not accept any liability for any direct, indirect, or consequential loss or damage of any nature–however caused–which may be sustained as a result of reliance upon such information.

3.3 Gas Infrastructure Europe (GIE) data set

Gas Infrastructure Europe (**GIE**) is a data set with vital meta-data within the SciGRID_gas project, where GIE stands for Gas Infrastructure Europe.

'Gas Infrastructure Europe (GIE) is an association representing the sole interest of the infrastructure industry in the natural gas business, such as Transmission System Operators, Storage System Operators and LNG Terminal Operators. GIE has currently 68 members in 25 European countries.' (https://www.gie.eu/).

GIE is the umbrella organisation for the following three gas components:

- **Storage**: GSE - Gas Storage Europe representing the Storage System Operators (SSO)
- **LNG**: GLE - Gas LNG Europe representing the LNG Terminal Operators (TO)
- **Transmission**: GTE - Gas Transmission Europe representing the Transmission System Operators (TSO)

The storage and the LNG information can be retrieved through an API supplied by GIE. However, there is no further information on the gas transmission part.

The APIs for the gas storage and the LNG terminals are:

- Aggregated LNG Storage Inventory (ALSI) (https://alsi.gie.eu/api/data/)
- AGSI+ AGGREGATED GAS STORAGE INVENTORY (https://agsi.gie.eu/api/data/)

Documentation for the APIs can be found on the web under: https://agsi.gie.eu/GIE_API_documentation_v001.pdf.

3.3.1 Pre requirements for accessing the GIE data set

A private key is required for the GIE data set so that one can download data from the GIE API.

As stated in the documentation for the GIE_API:

> The API service is available to the public free of charge. Registration on the AGSI+ or ALSI website is mandatory for non-data providers to be able to use the API. Registration will result in a personal API key that is required within the API URL. The only purpose of this registration is to enable us to assess and improve the performance of our systems where and if required (user count, user activity, most popular data set types). Your account information and settings can be updated (and cancelled) at any time after signing in. Your data will be stored and securely handles as long as your account remains active.

For this you will need to go to the following link: https://agsi.gie.eu/#/login where on the right hand side you will need to fill in the registration details.

Under "Access to:" please select "Both AGSI+ and ALSI"

After registration you will have access to your private key. Copy the key and past it into the following file:

/SciGRID_gas/Eingabe/GIE/GIE_PrivateKey.txt

This is your private key, Hence, do not share it with others.

3.3.2 Data processing of the GIE data set

Gas infrastructure providers are requested to publish certain gas flow information. This data is accessible via the GIE URLs, and contains a vast amount of meta-data for storages and LNG terminals throughout Europe. Whenever the data is downloaded from the GIE API, the data needs modification, so that it is conform to the SciGRID_gas data model. Several tools have been written to achieve this. The GIE specific tools are described below for **Storages** and **LNGs**.

Processes for retrieving the data from the GIE API

First of all, one could access some meta-data on the storages and LNG terminals through the following internet links:

- LNG: https://www.gie.eu/index.php/gie-publications/databases/lng-database
- Storages: https://www.gie.eu/index.php/gie-publications/databases/storage-database

These data sets come as Excel books and contain information, such as name of facility, country, type of facility, and eic_code. Other information, such as max hourly capacity or LNG storage capacity, is also given, however, discarded due to copyright reasons.

LNG terminals The following information are used from the LNG table above:

- country
- type
- eic_code
- short_name
- name
- nameShort

This information (column heading and column data) needs to be placed into a CSV document. This file needs to be named "GIE_LNG.csv" and needs to be stored in the folder "/SciGRID_gas/Eingabe/GIE/".

Other additional fields from this table are:

- Region
- Status
- Investment
- Start-up year
- Type
- Operator short name
- Max. Hourly Cap. $[\mathrm{m}^3(\mathrm{N})/\mathrm{h}]$
- Nom. Annual Cap. billion $[\mathrm{m}^3(\mathrm{N})/\mathrm{a}]$
- Possible additional Nom. Annual Cap. billion $[\mathrm{m}^3(\mathrm{N})/\mathrm{a}]$
- LNG storage capacity $[\mathrm{m}^3\mathrm{LNG}]$
- Number of tanks
- Max. ship class size receivable $[\mathrm{m}^3\mathrm{LNG}]$
- Number of jetties
- Min. sea depth alongside [m]
- Max. send out pressure [bar]

- TPA regime
- PCI list
- Operator long name

This list can change during the runtime of the project.

The EIC-code, facility code and country code is subsequently used to request time series information for each location from the GIE API.

The retrieved time series contain two useful values:

- the working LNG volume in the LNG storage tank
- the gas flow amount from the storage to the gas-pipeline, in units of GWh/d (see Table 3.9)

From the so created time series, one can determine the maximum working gas volume in the LNG storage tank in units of million LNG cubic meters. Also the maximum and medium gas flow from the storage to the gas pipeline is determined, in units of GWh per day.

Prior to estimating the maximum and median value from the retrieved time series, the time series was quality assured. This was done by removing any outliers/spikes.

Table 3.9: GIE incorporated attributes

Field identifier	Description	Units	Example
status	E (estimated) C (confirmed) N (no data)	E / C / N	C
gasDayStartedOn	The start of the gas day reported upon	YYYY-MMDD	2015-11-02
lngInventory	The aggregated amount of LNG in the LNG tanks at end of the previous gas day	$1000\mathrm{m}^3\mathrm{LNG}$ (2 digits behind decimal point)	5373.25
sendOut	The aggregated gas flow out of the LNG facility within the gas day	GWh/d (1 digit behind decimal point)	976.5
dtmi	Declared Total Maximum Inventory	$1000\mathrm{m}^3$ LNG (2 digits behind decimal point)	8898.99
dtrs	Declared Total Reference SendOut	GWh/d (1 digit behind decimal point)	6650.0
info	Service Announcement (if applicable)	url	https://alsi.gie.eu/#/news/184

The following information is incorporated into the SciGRID_gas data structure: name, max storage volume, max and medium gas flow volumes, facility code, country code, and EIC-code.

Subsequently, the LNG storage volume and flow are converted to their corresponding gas phase values. The final units of the measurements were $[\mathrm{Mm}^3\mathrm{d}^{-1}]$. No geo-coordinates are given for LNG terminals within the GIE data set. This information has been retrieved from the INET data set by a comparison of the name and the country code of the facility.

Storages

A meta-data set for the storages is available as Excel book and can be downloaded from the following URL: https://www.gie.eu/maps_data/downloads/2018/Storage_DB_Dec2018.xlsx.

In this Excel book, the sheet "Storage DB" contains the following columns:

- Country: string indicating the country of the storage
- Concatenate: –missing description–
- Country Code: two letter acronym for country code
- Company code: number of company
- Facility code: code of the facility
- Operator: name of operator
- Facility/Location: name of facility location
- Status: status of storage unit (operational/under construction/planned)
- Investment: string indicating the investment (existing/expansion/new facility)
- Start-up year: year when started operation
- Type: storage type, e.g. depleted field, salt cavern,. . .
- Notes:
- onshore/offshore: either onshore of offshore location of the gas storage
- Working gas (technical) TWh: maximum working gas volume in units of [TWh]
- Working gas TPA TWh: maximum working gas volume under TPA in units of [TWh]
- Working gas no TPA TWh: maximum working gas volume not under TPA in units of [TWh]
- Withdrawal technical GWh/day: maximum withdrawal rate of gas in units of [GWh/d]
- Withdrawal TPA GWh/day: maximum withdrawal rate of gas under TPA in units of [GWh/d]
- Withdrawal no TPA GWh/day: maximum withdrawal rate of gas not under TPA in units of [GWh/d]
- Injection technical GWh/day: maximum injection rate of gas in units of [GWh/d]
- Injection TPA GWh/day: maximum injection rate of gas under TPA in units of [GWh/d]
- Injection no TPA GWh/day: maximum injection rate of gas not under TPA in units of [GWh/d]
- Access regime: access regime with two options "nTPA", "rTPA", and "No TPA"
- in EU28 number: string ("n" or "y") if part of the 28 EU members
- in EU28 SUM: string ("n" or "y") if part of the 28 EU members
- EU 28 filter: string ("NO" or "YES") if part of the 28 EU members.

A subset of the above data needs to be saved as column data into a CSV file, containing only the following parameters with their data:

- Country
- Type
- EIC Code
- Short Name

- Name
- nameShort

This file needs to be name "GIE_Storages.csv" and needs to be stored in the folder "/SciGRID_gas/Eingabe/GIE/".

These is subsequently used to get access to the time series of the storage data set, by using the facility code, the country and the EIC-code.

All time series consist of the daily "working gas volume", the "daily injection capacity" and the "daily withdraw capacity". Maximum values for each of those parameters are extracted from those time series.

However, as was carried out for the LNG data set, the same testing of the goodness of the data was carried out.

In addition, gas flow values were converted from [GWh/d] to [Mm^3/d].

3.3.3 GIE data density

All GIE components (**Storages** and **LNGs**) have the following mandatory attributes:

- *id*: unique identifier
- *name*: name of the pipe-segment
- *source_id*: a source id
- *node_id*: the id of the start and the end node of the pipe-segment
- *lat*: a list of latitude values
- *longitude*: a list of longitude values
- *country_code*: a string pair indicating the country code of the start and the end point
- *comment*: a user comment.

LNGs

Overall, there are 21 LNG terminals in the GIE data set. In addition to the default attributes, the following non-standard attributes (see Table 3.10) are supplied. The number of attribute values supplied for each attribute is given by the parameter 'data density' (see Chapter 8.1):

Table 3.10: GIE *LNGs* data density

Attribute name	Description	Units	Data density [%]
eic_code	EIC code of LNG terminal		100
facility_code	unique facility code		100
max_cap_store2pipe_M_m3_per_d	maximum gas flow from storage to pipeline	Mm^3/d	100
max_workingGas_M_m3	maximum stored gas in LNG terminals	Mm^3	100
median_cap_store2pipe_M_m3_per_d	medium gas flow from storage to pipeline	Mm^3/d	100
name_short	short name of the facility		100

Storages

Overall, there are 109 storage facilities in the GIE data set. In addition to the default attributes, the following non-standard attributes (see Table 3.11) are supplied and partially populated with data:

Table 3.11: GIE *Storages* data density

Attribute name	Description	Units	Data density [%]
eic_code	EIC code of storage facility		100
facility_code	unique facility code		100
max_cap_pipe2store_M_m3_per_d	maximum gas flow from pipeline to storage	$\mathrm{Mm^3 d^{-1}}$	100
max_cap_store2pipe_M_m3_per_d	maximum gas flow from storage to pipeline	$\mathrm{Mm^3 d^{-1}}$	100
max_workingGas_M_m3	maximum working gas in storage	$\mathrm{Mm^3}$	100
name_short	short name of the facility		100

Nodes

Overall, there are 115 node points in the GIE data set. In addition to the default attributes, the following non-standard attributes (see Table 3.12) are supplied and partially populated with data:

Table 3.12: GIE *Nodes* data density

Attribute name	Description	Units	Data density [%]
exact	boolean indicating that storage is planed		100
eic_code	EIC code of storage facility		100
facility_code	unique facility code		100
name_short	short name of the facility		100
elevation_m	short name of the facility		100

Data availability and data usage

The API of the GIE (Gas Infrastructure Europe (ASBL)) web portal allows for the user to download time series on the daily gas amount (stored or available) for gas storages and LNG terminals. Here, we do not pass on the downloaded time series information, but only other retrieved constant metadata, such as maximum storage capacity or maximum re-gasification from LNG into the gases state, were derived using the time series data.

3.3.4 Copyright

The generally valid copyright regulations for databases apply.

Data disclaimer

In addition the data disclaimer is given as under: https://agsi.gie.eu/#/disclaimer:

> "All data is provided by the contributors on a voluntary basis and free of charge. The data provided by AGSI is for information purpose only. GSE is using reasonable efforts to invest in ensuring the correctness, completeness, and timeliness of the information provided herein. Data have been carefully checked, are updated at regular intervals and may be subject to changes, removal, or amendments without prior notice. GSE neither assumes any warranty or liability for the correctness and completeness of information/services and entries nor for the mode of presentation."

Acknowledgement

Here we would like to acknowledge GIE (Gas Infrastructure Europe with registered office at Avenue de Cortenbergh, 100 - B-1000 Brussels, Belgium).

3.3.5 Summary GIE data

The GIE data set supplies information on gas infrastructure facilities all over Europe, such as gas storages and gas LNG terminals. Data for those facilities are accessible by the SciGRID software through special CSV data files that are downloaded from the GIE web page. The information in those facilities are automatically filtered and reshaped to the data structure of SciGRID_gas. Units are partially converted to align with the other project data. The facilities are further geo-reference by the SciGRID_gas software with the help of the INET data set.

Below a table summarises the number of elements for each component found:

Table 3.13: GIE component summary

Component Name	Count
BorderPionts	0
Compressors	0
ConnectionPoints	0
Consumers	0
EntryPoints	0
InterConnectionPoints	0
LNGs	21
Nodes	115
PipeSegments	0
Production	0
Storages	109

In addition, the map in Figure 3.3 visualizes the data for Germany.

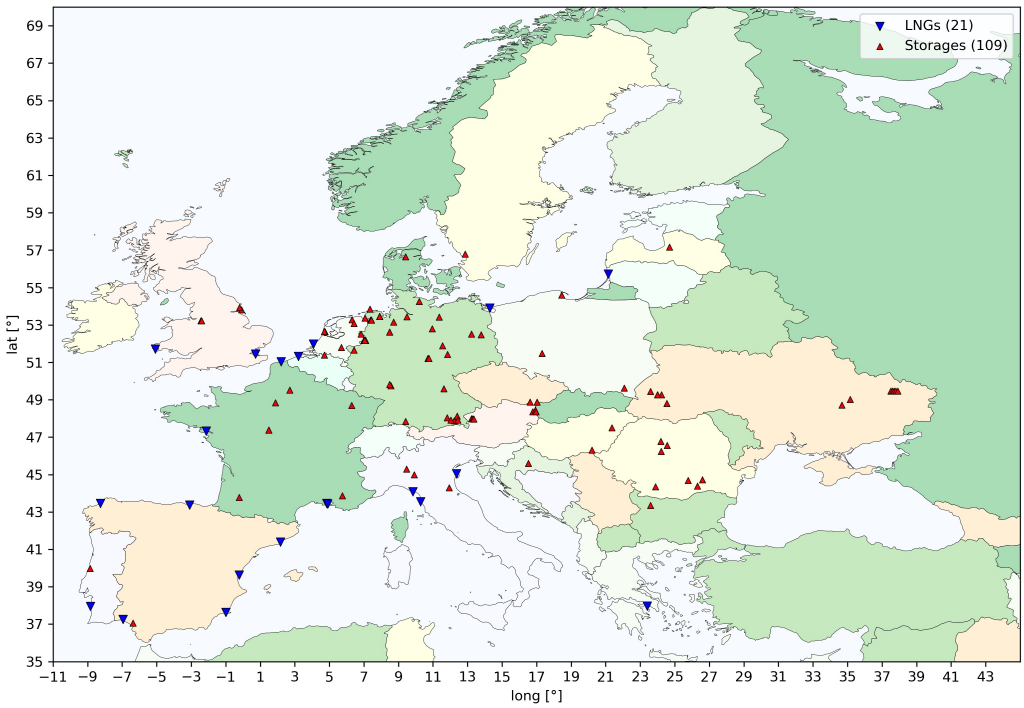


Figure 3.3: Overview map of the GIE data set for Europe.

3.4 The Gas Storage Europe (GSE) data set

This is the data set that was partially explained in the GIE section. However, the **Gas Storage Europe** (**GSE**) data set only contains information for the gas storage units, and contains slightly different information to the GIE data set. The GSE data set will be explained in this section here.

All together there were 254 storage facilities listed in the Excel book. This included planed and operational storage units, and storage units inside and outside of the 28 member EU. For the SciGRID_gas project only those facilities were selected, that fall within the EU.

The Excel book can be downloaded from the following link:

https://www.gie.eu/maps_data/downloads/2018/Storage_DB_Dec2018.xlsx

which can be found on the following URL page:

https://www.gie.eu/index.php/gie-publications/databases/storage-database

3.4.1 Data processing of the GSE data set

Gas infrastructure providers are requested to publish certain gas flow information. This data is accessible through the GSE URLs, and contains a vast amount of meta-data for gas storages throughout Europe. However, whenever the data is downloaded from the GSE web page, the data needs modification, so that it conforms to the SciGRID_gas data model. Tools have been written to achieve this. The GSE specific tools are being described here below.

Overall, there is only one storage specific Excel book that could be downloaded. The Table 3.14 had the following columns:

Table 3.14: Overview of GSE CSV data source

Field identifier	Description	Units	Used within SciGRID_gas
Country	string indicating the country of the storage		
Country Code	two letter acronym for country code		Y
Company code	number of company		
Facility code	code of the facility		
Operator	name of operator		Y
Facility/Location	name of facility location		Y
Status	status of storage unit (operational/under construction/planned)		Y
Investment	string indicating the investment (existing/expansion/new facility)		
Start-up year	year when started operation	yyyy	Y
Type	storage type, e.g. depleted field, salt cavern,...		
Notes			
onshore/offshore	either onshore of offshore location of the gas storage		
Working gas (technical)	maximum working gas volume in	TWh	
Working gas TPA TWh	maximum working gas volume under TPA	TWh	Y
Working gas no TPA TWh	maximum working gas volume not under TPA	TWh	
Withdrawal technical GWh/day	maximum withdrawal rate of gas	GWhd^{-1}	Y
Withdrawal TPA GWh/day	maximum withdrawal rate of gas under TPA	GWhd^{-1}	
Withdrawal no TPA GWh/day	maximum withdrawal rate of gas not under TPA	GWhd^{-1}	
Injection technical GWh/day	maximum injection rate of gas	GWhd^{-1}	
Injection TPA GWh/day	maximum injection rate of gas under TPA	GWhd^{-1}	Y
Injection no TPA GWh/day	maximum injection rate of gas not under TPA	GWhd^{-1}	
Access regime	access regime with two options nTPA, rTPA		
in EU28 number	char (n or y) if part of the 28 EU members		Y
in EU28 SUM	char (n or y) if part of the 28 EU members		
EU 28 filter	string (NO or YES) if part of the 28 EU members		
EU 28 filter	string (NO or YES) if part of the 28 EU members		

As was mentioned for the GIE data, no real lat/long values were given for the storage locations. Hence, the name matching with the Internet data set (including the country code matching) was carried out. To achieve a better match, some of the names needed modification, such as substituting "HGas" and "H-Gas" with "H". In addition, parts of the location names were omitted, such as "SERENE Nord: ", "VGS SEDIANE B: ", "SERENE SUD" "SEDIANE LITTORAL:",.....

Further the gas flow and storage values supplied through the Excel book were of the "wrong" type, and the following gas properties were unit converted:

- 'max_cap_pipe2store_GWh_per_d' to 'max_cap_pipe2store_M_m3_per_d'
- 'max_cap_store2pipe_GWh_per_d' to 'max_cap_store2pipe_M_m3_per_d'
- 'max_workingGas_TWh' to 'max_workingGas_M_m3'.

3.4.2 GSE data density

The data of the GSE data set contains the following components:

- Storages.

The storage component will be described below.

As all components have the following attributes, they are presented here ones:

- *id*: unique identifier
- *name*: name of the pipe-segment
- *source_id*: a source id
- *node_id*: the id of the start and the end node of the pipe-segment
- *lat*: a list of latitude values
- *longitude*: a list of longitude values
- *country_code*: a string pair indicating the country code of the start and the end point
- *comment*: a user comment.

Storages

Overall there are 210 storage facilities in the GSE data set. In addition to the default attributes, the following non-standard attributes (see Table 3.15) are supplied and partially populated with data:

Table 3.15: GSE *Storages* data summary

Attribute name	Description	Units	Data density [%]
max_cap_pipe2store_M_m3_per_d	maximum gas flow from pipeline to storage	$\mathrm{Mm^3 d^{-1}}$	67
max_cap_store2pipe_M_m3_per_d	maximum gas flow from storage to pipeline	$\mathrm{Mm^3 d^{-1}}$	74
max_workingGas_M_m3	maximum working gas in storage	$\mathrm{Mm^3}$	78
name_short	short name of the facility		100
operator_name	name of the operator		100
start_year	year when the storage operation started		87
status	indicating of storage is in operation, planed, or under construction		100

Nodes

Overall there are 160 node points in the GSE data set. In addition to the default attributes, the following non-standard attributes (see Table 3.16) are supplied and partially populated with data:

Table 3.16: GSE *Nodes* data summary

Attribute name	Description	Units	Data density [%]
exact	accuracy of node location		100
elevation_m	elevation of node		100

3.4.3 Copyright and data disclaimer for the GSE data set

Data availability and data usage

The Excel book is available through the internet. However, no copyright has been attached to the data set. Hence, normal copyright applies. Hence, we are not able to pass on this raw information that was derived for the SciGRID_gas network data model to others.

3.4.4 Copyright

The copyright regulations of this data can be found under (https://agsi.gie.eu/#/privacy-policy) .

Data disclaimer

In addition the data disclaimer is given as under (https://agsi.gie.eu/#/disclaimer):

> "All data is provided by the contributors on a voluntary basis and free of charge. The Data provided by AGSI is for information only. GSE is using reasonable efforts to invest in ensuring the correctness, completeness, and timeliness of the information provided herein. Data have been carefully checked, are updated at regular intervals and may be subject to changes, removal, or amendments without prior notice. GSE neither assumes any warranty or liability for the correctness and completeness of information/services and entries nor for the mode of presentation."

3.4.5 Summary GSE data

The GSE data set summarizes information on gas storage facilities throughout Europe. Data for those facilities were accessible through an Excel book that was downloaded from the GIE web page. This data set applies to all of Europe, and special tools had to be written, to align their spatial data points to geo-reference location of the SciGRID_gas data set. Tools have been designed to convert the information from those CSV files and subsequently make them accessible throughout the SciGRID_gas project.

Table 3.17 summarises the number of elements for each component found:

Table 3.17: GSE component summary

Component Name	Count
BorderPoints	0
Compressors	0
ConnectionPoints	0
Consumers	0
EntryPoints	0
InterConnectionPoints	0
LNGs	0
Nodes	160
PipeSegments	0
Production	0
Storages	210

In addition, the map in Figure 3.4 visualizes the data for Europe.

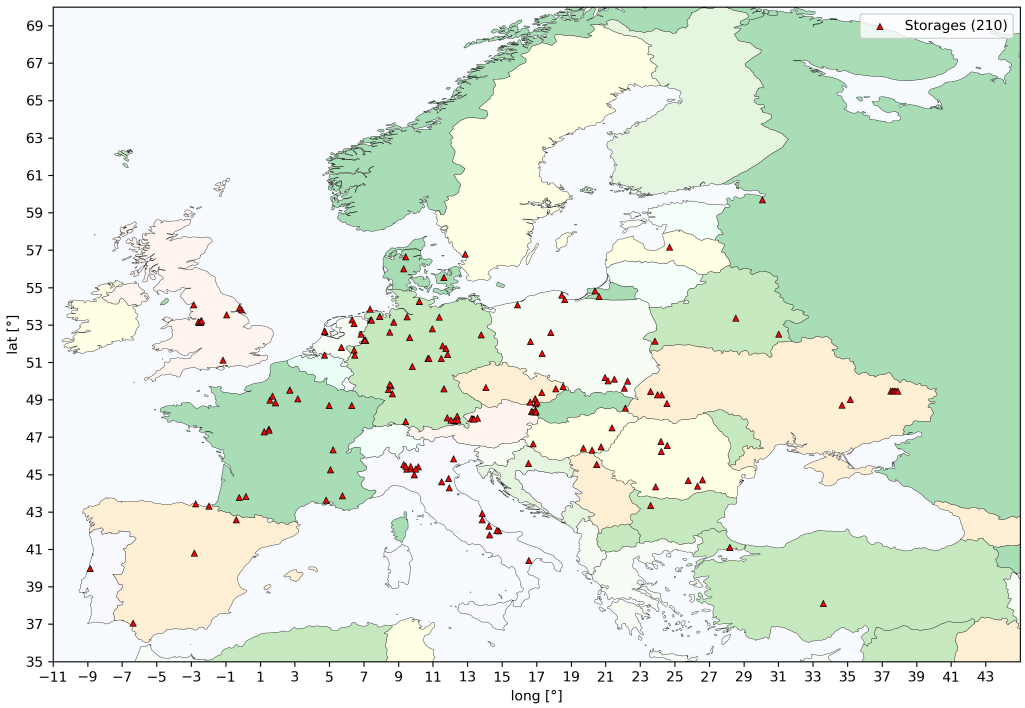


Figure 3.4: Overview map of the GSE data set for Europe.

3.5 Data summary

SciGRID_gas is based on open source data. To generate a gas pipeline network data set, one needs to access different data sets that were found throughout the project and presented here. Emphasis was given to depict the number of elements per component and the data density for each data set.

3.6 Summary

Gas component data sets come in different forms, licenses, formats and detail. The SciGRID_gas project can process such data and combine them to a consistent and reliable network data set.

The underlying gas component data sets were categorized into two different groups:

- OSM data: This is data originating from the OSM data base, containing well geo-referenced locations of gas facilities, such as pipe locations or gas storage facilities. However, it comes with very few meta information.
- Non-OSM data: These are all other data sources, which can "supply" detailed information on some of the gas facilities attributes. However, this information is sparse, as published only for a few facilities. Here, the INET data set was introduced as an example of the non-OSM data set, and the pathway of converting the raw data from the www into SciGRID_gas project component structure.

Here detailed information on one or several data sources have been given, and should be used as a reference for later data processes.

CHAPTER

FOUR

MERGING DATA SOURCES

Several gas facility data sources have been described in Chapter 3, and part of the SciGRID_gas project is to joined (merged) those sets. However, some facilities might be present in more than one data source containing same but also different attributes. Hence, this chapter here will describe the current implemented methods to merge data sources.

4.1 Merging single node elements

So far, only individual data sources have been read in and converted to SciGRID_gas data sets. However, some elements might be described in more than one data set. In addition, they might be populated with different attributes and attribute values. Hence, those elements need to be merged, in such a way, that the topology stays correct and that the attributes are merged correctly, while maintaining maximum information. The tools developed here have been designed for the non-OSM data sets. However, they should be applicable to any gas component data set. In addition, the concept and tools presented here applies to single node elements only. With this it is meant that elements of type *PipeLines* and *PipeSegments* will not be covered in this subsection, as they are elements containing more than one node. Merging tools for *PipeLines* and *PipeSegments* will be presented in subsection `SecMergingPipes`

In this section, the problem of duplicate elements from different data sets is being described with the help of some mock data set. This is used to describe the methods that have been implemented. This will result in a single data set, not containing any duplicate elements.

4.1.1 Problem description

In the Figure 4.1 the problem is depicted. There are elements from different data sets (different colour) with different attributes. For this example (summaries in Table 4.1) three different data sets are depicted for three different *Storages* elements: blue, red, and yellow. In addition, the spatial separation has been supplied in km.

Table 4.1: Summary of data of the three sample *Storages* elements.

Attribute name	Blue data set	Red data set	Yellow data set
name	Atwick	Aldbrough1	Aldbrough
max_cap_pipe2store_M_m3_per_d	1.9	1.0	1.1
max_cap_store2pipe_M_m3_per_d	2.3	1.3	
max_workingGas_M_m3		1800	
store_type	Depleted Field		Salt cavern

As can be seen, some elements have attribute values for the same attribute, and others do not, and the main question is: **Which elements should be merged, and which ones should not be merged?** Should all three be merged, because they are so close to each other, or none, as they all have different names, or just the red and the yellow one?

Here approaches of name similarity, topological distance and country location have been developed so that an automated process can merge those elements that should be merged, and will be described next.

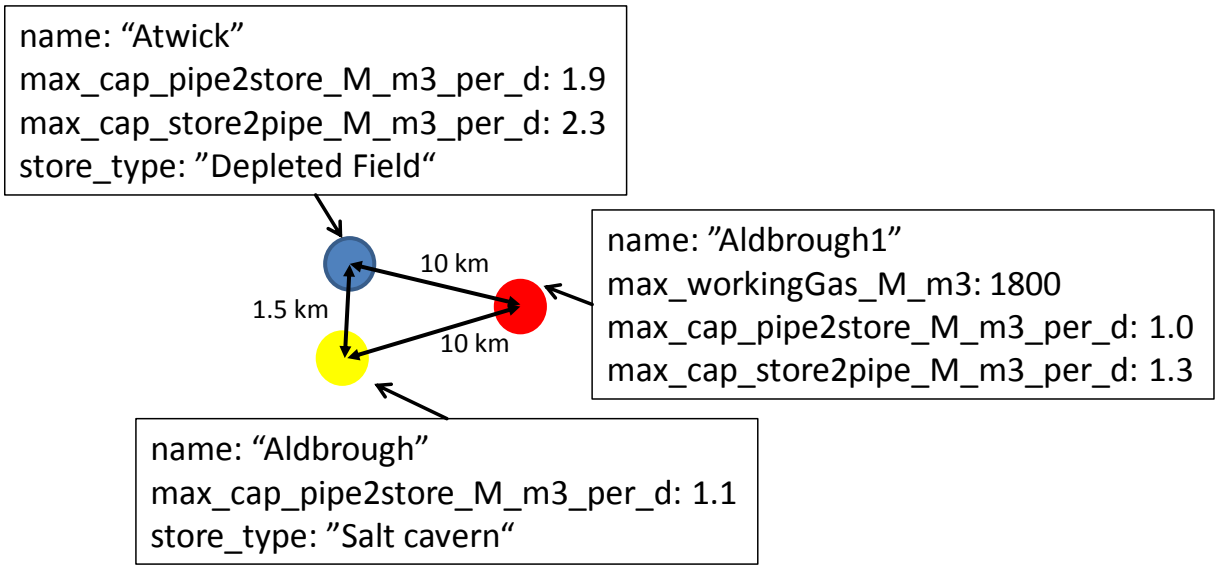


Figure 4.1: Example data sets blue, red and yellow, all depicting a storage element with different attributes and attribute values. The figure also includes the spatial separation between the elements.

4.1.2 Methods of determining if elements are identical

Below different methods are introduced briefly to determine, if facilities from different data sets should be merged or not. The functions introduced are applicable to all components except *PipeLines* and *PipeSegments*. Different functions look at different attribute values, such as *names*, *LatLong* or *country code*. Each function returns a score between 0 and 100, with 0 indicating that there was no match between the attribute values supplied, whereas a score of 100 refers to a perfect match between the attribute values. In a second step, the user can set thresholds, so that a function returning a score larger than the set threshold is assumed to be describing the same facility. However, as single attribute comparison might be misleading (e.g. very similar place name in two different countries), Hence, multiple attribute comparisons methods have also been introduced.

Spatial distance

This method determines if two elements can be classed as the same by their geo-reference location, by calculating the distance between the two locations. If the distance between two elements is 500 km, then it would be highly unlikely that the elements are of the same facility. However, if the distance between the locations is 10 km or less, then in the scheme of Europe they might be describing the same facility. The distance can be weighted in different ways, such as just the inverse distance, the inverse power distance or the inverse log distance. Different methods work best for different components. Here again, if the lat/long of two elements is equal, then this function would return a score of 100, whereas if the distance between two elements is several 100 or even 1000 km, then this function would return a very small score, such as 10 or 5, depending on the method selected.

Name comparison

This method helps to determine if two elements describe the same facility by comparing their location *names*. For the method return score of 100, the location names are identical, whereas for a method return score of 0 there is no similarity between the names at all. The names of "UGS Stollen" and "Stollen" would return a score of about 70, as the word "Stollen" is partially in the name "UGS Stollen". The method implemented here contains an external Python module, called: "FussyWuzzy".

An additional aspect was added to this method. If one entire name is part of the other name (name-in-name), then the user can specify that the return score should be increased by a user specified value. For the case where the names are "Aldbrough" and "Aldbrough1", and the name-in-name score be 100, then the final score would be 195. However, if the name-in-name score was not implemented, then the overall output score for the location name pair of "UGS Stollen" and "UGS" would be 43 only. In case that the user had specified a threshold score of 60, the storages with names "UGS Stollen" and "UGS" would not be merged, if the additional name-in-name would not have been implemented. Better results were achieved with the additional name-in-name method.

Country code comparison

Another key factor in determining if two elements should be merged is their corresponding country-code. In case that the country-codes of the elements are known, one can determine the equality of the country-code.

This method only returns two values:

- "0": the country code entries of the two elements are different.
- "100": the country code entries of the two elements are the same.

However, it was experienced, that individual single method selections did not result in the expected element selection. From the above example, if one had selected the spatial distance method, then "Atwick" might be merged with "Aldbrough", as they are closer than "Aldbrough" and "Aldbrough1".

Hence, combinations of the above methods were developed. This is achieved by executing the methods subsequently to each other, resulting in a combined method return score. Two elements were deemed to be the same, if the final score was larger than a user specified score.

Example results

Above an example was given in Figure 4.1. "Atwick" and "Aldbrough" are only 2 km apart, whereas "Aldbrough1" is separated by 10 km to any of the other two elements.

First of all the method return score was determined for the spatial separation of the elements. The "Atwick"-"Aldbrough" spatial separation lead to a method return score of 50, whereas the same value for the "Aldbrough" and "Aldbrough1" pair is 10 only. In a second step the names were compared, resulting in method return scores of 0 and 195 respectively. Hence, for a user specified threshold score of 60, only the elements "Aldbrough" and "Aldbrough1" would be merged. As can be seen in Table 4.1, the elements "Aldbrough" and "Aldbrough1" have same and complementing attributes. The attributes that the resulting merged element will have will be described in the subsection below.

Attributes of resulting element

As can be seen in Table 4.1, "Aldbrough" and "Aldbrough1" have a mix of different and same attributes, with partially different values for the same attribute. Here the following attribute merge path is being implemented:

- Assume that "Aldbrough1" will be merged into "Aldbrough".
- The resulting element will have all those values from element "Aldbrough"
- Any element that was not given for "Aldbrough", and is present in "Aldbrough1" will be copied to "Aldbrough"

Hence, the resulting "Aldbrough" element would have the following attributes with the following values:

- name: "Aldbrough"
- max_cap_pipe2store_M_m3_per_d: 1.1
- store_type: "Salt cavern"
- max_workingGas_M_m3: 1800
- max_cap_store2pipe_M_m3_per_d: 1.3.

Summary

The above text examples were used trying to explain the merge process of single node elements, such as *LNGs*, *Storages* and *Productions*. This section will be followed by explaining a method that can be used for trying to merge pipes, which are elements connecting more than one node.

4.2 Application to the INET, GIE and GSE data set

For the data sets of INET, GIE and GSE, elements from the following two components needed to be merged:

- Storages
- LNGs

Only the INET data set contained other components than the ones listed above, such as *PipeSegments*. However, those did not need to be merged.

4.2.1 Merging *Storages*

For the identification of the correct elements from the different data sets, a combination of "name" and "spatial distance" was implemented. An overall threshold score of 60 was set for the data sets. Hence, in a first step the distance was investigated. Here the inverse method was selected. For this method the spatial distance between two elements is being determined and returned as distance in units of km. Then the following equation was carried out: $score = min(100/distance\_km, 100)$.

In a second step the method return score for the name is being determined. Values can range between 0 and 200, as the name-in-name method was also included.

In the final step both method return scores were added. And element pairs with a value of 60 or larger were deemed to be the same and were merged.

The `TabMergeINETGIEGSE_Storages` shows the number of *Storages* of the individual data set prior to the merge process, and the resulting number of elements after the merge process. As can be see, by combining the GIE and the GSE data sets to the INET data set, only 25 additional elements were added to the INET data set. However,

part of the merge process was also the migration of the attributes and attribute values, which will be discussed in more detail in Chapter 6.

Table 4.2: Number of *Storages* elements per input data set and merged data set.

Data set	Number of *Storages* elements
INET	199
GIE	109
GSE	210
Merged data set	254

4.2.2 Merging *LNGs*

Merging LNG terminals follows the same path as described for merging *Storages* elements. Here only the INET and the GIE data sets contained any information on the component *LNGs*. It was determined, that the user specified threshold value of 60 works best for LNG elements as well.

The number of elements per data set are listed in `TabMergeINETGIEGSE_LNGs`. The table also indicates that the merged data set has the same number of elements as the INET input data set. This indicates that the GIE data set did not contain any new facilities that were not present in the INET data set. However, different attributes and attribute values were supplied through the GIE data set, resulting in "better" data of the merged data set.

Table 4.3: Number of *LNGs* elements per input data set and merged data set.

Data set	Number of *LNGs* elements
INET	32
GIE	21
Merged data set	32

4.2.3 Summary

In Chapter 4 different merge selection methods were introduced. These were applied to the INET, GIE, and the GSE data sets for the components *Storages* and *LNGs*. Merging the data sets for the component *Storages* resulted in additional elements, when compared with the INET data set. Merging the data set for the component *LNGs* did not result in additional elements, when compared with the INET data set. However, in both cases the resulting elements would have more numbers of attribute values, as will be demonstrated in Chapter 6.

4.3 Summary

When several data sets are combined, the situation can occur, that the same facility is presented by two or more data sets. Instead of this facility being present several times in the final merged data set, methods were presented, that would determine the likelihood that elements from different data sources are describing the same facility. Those element pairs were detected through a comparison of names, location and country-code values. Elements that were deemed to be the same were merged accordingly, so that individual facilities were only present ones in the final data set.

CHAPTER

FIVE

HEURISTIC ATTRIBUTE VALUE GENERATION

Gas facility data sources have been described in Chapter 3. However, those data sources might not contain values for all attributes, and hence, those values need to be generated. This chapter here will describe the current implemented heuristic methods that can be used to estimate any missing attribute value.

5.1 Attribute value generation

The SciGRID_gas project has been set up to deliver a data set of the European gas transmission network. Despite merging several data sources of gas facilities, the resulting gas component data set will contain a large number of missing values. This section here describes how missing attribute values can be generated through different heuristic methods.

In this section, the problem of missing data is described with the help of some synthetic data set. This is followed by the description of the heuristic methods that have been implemented, and the general pathway that the user needs to undertake to eliminate missing values.

Problem description

In Figure 5.1 the data sets contain different elements of different components, where many attributes values could not be found. The example given in the following sections shall depict the gas pipelines, where the attributes in question are *diameter*, *capacity* and *pressure*. The data is summarized in Table 5.1.

Table 5.1: Summary of data of the nine sample pipelines from Figure 5.1.

Pipeline name	*capacity* [M m ^{3} d $^{-1}$]	*pressure* [bar]	*diameter* [mm]
Jagal	76	80	1200
RHG		84	800
Midal 1	40		900
Midal 2	50		1000
Midal 3	35		800
Midal 4	34		800
Stegal_1			800
Stegal_2			900
Wedal	27		

As can be seen, all but one *PipeSegments* contain an attribute value for the attribute *diameter*. For the attribute *capacity* three values are missing, and of all nine *PipeSegments*, only two have a value for the attribute *pressure*. The corresponding data densities for the attributes *capacity*, *pressure* and *diameter* are 67 %, 22 % and 89 % respectively. The overall goal will be to achieve a data density of 100 % for all attributes.

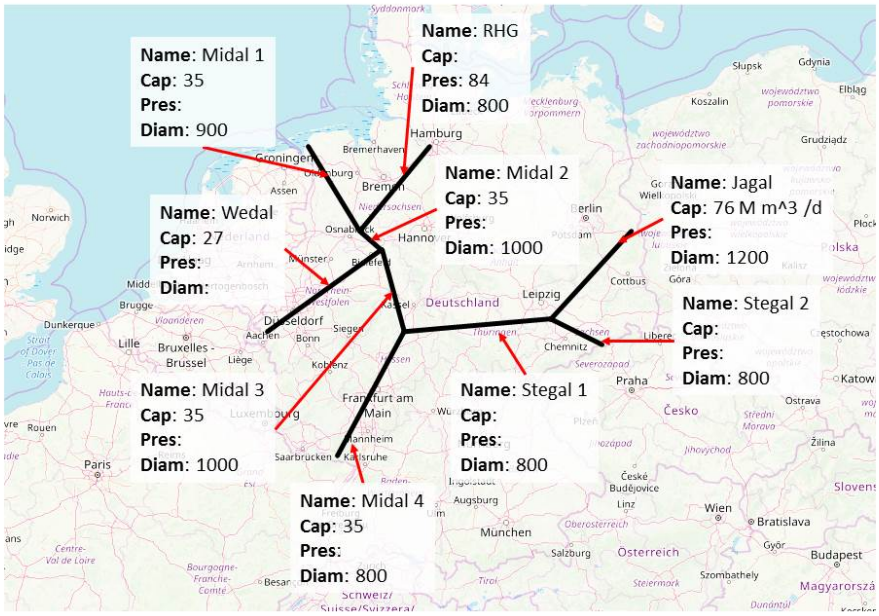


Figure 5.1: Map of some of the larger pipelines in Germany, with corresponding attributes *capacity* (cap), *pressure* (pres), and *diameter* (diam).

5.1.1 Fill value methods

As one can see, the *capacity* attribute value is given for six of the nine facilities. Several options exist in determining the missing values. A simple solution would be to use the average or median of the input values as a method of estimating any missing value. Here the **mean** and **median** value are $41\,\mathrm{Mm^3 d^{-1}}$ and $35\,\mathrm{Mm^3 d^{-1}}$, respectively. However, selecting the best approach can be difficult, and needs to be transparent. Hence, an "estimation uncertainty" term could be used as decision criteria to determine the best method.

Conventionally, in the worlds of data engineers and big data, one splits the data into a training data set and a test data set. Normally a 70/30 rule is applied, where 70 % of the data ends up in the training data set, and 30 % in the test data set. In the first step a method (e.g. **median**) is applied to the training data set. In the second step, the fitted method results are used to predict the values of the test data set. In the third step one calculates the absolute error between the method results and the test data set. The smaller the absolute error, the better the method. This error value could be used as the "estimation uncertainty" and could be used to choose the method that would estimate any missing values with the smallest error values.

However, the SciGRID_gas project only contains relatively small data sets. Any splitting of the input data set into training and test data sets would create a data set too small for training and testing purposes. As an example, there are roughly 35 *LNGs* terminals in Europe, and splitting such data set would result in roughly 10 values for testing purposes only. Hence, throughout the SciGRID_gas project the "Leave-one-out" method will be used (see Chapter 8.7), and the error is calculated using the "mean absolute error" (*MAE*), where the absolute error is the absolute difference between a single raw input data value and the model estimation of that value instance. This means, instead of having a 70/30 percent split, one uses all but one data value for training the model and then uses the trained model to estimate the one data value that was not part of the training process. This is being repeated for all data values.

The *MAE* for the **mean** and the **median** method is $25\,\mathrm{Mm^3 d^{-1}}$ and $16\,\mathrm{Mm^3 d^{-1}}$, respectively. Hence, based on the *MAE*, it would be best to use the **median** method approach, and one could fill all missing values with the value of $35\,\mathrm{Mm^3 d^{-1}}$, with an *MAE* of $16\,\mathrm{Mm^3 d^{-1}}$. The **median** method is normally selected for data sets, which have outliers or the data is not normal distributed. However, the sample size is small, and one could argue, to select the method with

the smallest *MAE*. However, overall, the *MAE* is very large in respect of the actual *capacity* value. Therefore other method approaches also need to be investigated.

An attribute could have a linear correlation with one or several other attributes. Here, one could use a linear regression. However, linear regressions tend to weight the independent feature data equally, if more than one is given. Other methods, such as the Lasso-linear regression, tend to weight the independent variables unequally and can even indicate that it would be better to remove some independent variables [Wik20d]. Therefore, if not stated otherwise, the Lasso-linear regression will be used here, instead of a simple linear regression.

Here, the Lasso-linear regression is applied to the *capacity* variable (also referred to as the "predictor" or "regression input"), and the variable *diameter* is the independent variable (also referred to as the "feature" variable). For the pipe RHG, where the *capacity* value is missing and a *diameter* value of 800 mm is given, the Lasso-linear regression estimated the following *capacity* value: $33.9\,\mathrm{Mm^3 d^{-1}}$ with a *MAE* of $2.4\,\mathrm{Mm^3 d^{-1}}$. As one can see, the *MAE* of the Lasso method is significantly smaller when compared with the *MAE* of the **mean** and the **median** methods. However, this example should not lead to the assumption, that a Lasso-linear regression is always better than a simple estimation using a **mean** or a **median** value. For example, an attribute data set could be unrelated to any other attribute; hence using a Lass method would be wrong. In addition, for some attribute values the methods of **mean** or **median** might have to be used, due to lack of feature data.

The processes described above have been applied to the example data presented in Table 5.1, Table 5.2 and Table 5.3 summarize the input values, estimation attribute values, estimation method, and the corresponding *MEA* based on the "Leave-one-out" approach, for the attribute *capacity* and *diameter* respectively. As the attribute *pressure* only contained two input values, no values could be estimated with the above process, as the system has been set up that it needs at least four values. For the other two attributes, the input and estimated values are being presented, and the difference between estimated and input value is close to the given uncertainty. As one can see, the estimated values agree better with the input data for the method of "Lasso", when compared with the method of "mean". However, not all values could be estimated using the Lasso method, due to missing values (e.g. *diameter* for pipeline Stegal_2).

Table 5.2: Input and estimated *capacity* data of the example, including the method of estimation and the corresponding estimated error. Values given in units of [M m ^{3} d $^{-1}$].

Pipeline name	Input *capacity*	Estimated *capacity*	Method	Uncertainty
Jagal	76	69.7	Lasso	2.4
RHG		33.9	Lasso	2.4
Midal 1	40	42	Lasso	2.4
Midal 2	50	51.8	Lasso	2.4
Midal 3	35	33.9	Lasso	2.4
Midal 4	34	33.9	Lasso	2.4
Stegal_1		33.9	Lasso	2.4
Stegal_2		42.8	Lasso	2.4
Wedal	27	43.7	Mean	12.9

Table 5.3: Input and estimated *diameter* data of the example, including the method of estimation and the corresponding estimated error. Values are given in units of [mm].

Pipeline name	Input *diameter*	Estimated *Diameter*	Method	Uncertainty
Jagal	1200	1233	Lasso	23
RHG	800	900	Mean	100
Midal 1	900	875	Lasso	23
Midal 2	1000	975	Lasso	23
Midal 3	800	826	Lasso	23
Midal 4	800	816	Lasso	23
Stegal_1	800	900	Mean	100
Stegal_2	900	900	Mean	100
Wedal		746	Lasso	23

Hopefully the above example and description can be used as a blueprint of the problem that the SciGRID_gas project is facing, and how the missing value generation can be approached. The following section will describe the implemented method pathway within the SciGRID_gas project code.

5.1.2 Attribute value generation pathway

This section describes how the generation of the missing attribute values has been implemented. Overall, there are six steps that need to be carried out in order. They are described in more detail in the following sub-sections:

1) Loading network data
2) Configuration of the setup files
3) Generation of plots for data QA
4) Parameters generation for the heuristic methods
5) Selecting individual estimation methods for each attribute
6) Simulation of missing attribute values

1) Loading network data

As the first step, the data needs to be loaded into memory. Functions have been designed as part of the SciGRID_gas project, and will be introduced in an upcoming documentation.

2) Configuration of the setup files

In the next step the user needs to set up the two required setup files. In the first one ("StatsMethodsSettings.csv") meta information for each method (e.g. **mean**, **median**) is being supplied in addition to other settings. The second setup file ("StatsAttribSettings.csv") contains a list of attributes, including attribute specific metadata. Both setup files are described in more detail below.

StatsMethodsSettings.csv

In this file the user selects which methods (e.g. "Lasso") shall be used for testing the data and their relationships. A sample method setup file is given in Figure 5.2.

	A	B	C
1	MethodNam	Param	ToBeApplied
2	Lasso		1
3	LogisticReg	{'solver':'lbfgs'}	1
4	Mean		1
5	Median		1
6	Min		1
7	Max		1

Figure 5.2: Sample file of the file "StatsMethodsSettings.csv"

Column "A", which has the label "MethodName", contains the heuristic method names that have been implemented into the SciGRID_gas project code. Currently the following methods have been implemented:

- **Lasso**: A type of linear regression that uses shrinkages. It has been described as [sl19]: "The Lasso is a linear model that estimates sparse coefficients. It is useful in some contexts due to its tendency to prefer solutions with fewer non-zero coefficients, effectively reducing the number of features upon which the given solution is dependent. For this reason Lasso and its variants are fundamental to the field of compressed sensing. Under certain conditions, it can recover the exact set of non-zero coefficients."
- **LogisticReg**: Here the attributes to be predicted are of binary type or are multiple discrete values. The Logistic-regression is described by the scikit-learn.org web portal as [sl19]: "Logistic regression, despite its name, is a linear model for classification rather than regression. In this model, the probabilities describing the possible outcomes of a single trial are modelled using a logistic function.".
- **Mean**: Calculation of the **mean** attribute value of the predictor attribute values.
- **Median**: Calculation of the **median** value of the predictor attribute values.
- **Min**: Calculation of the **min** value of the predictor attribute values.
- **Max**: Calculation of the **max** value of the predictor attribute values.

The second column with the label "Param" contains possible parameters that are applied to the method within the SciGRID_gas Python code. Here for the **LogisticReg** a solver needed to be specified. As can be seen, the following entry was supplied:"{'solver':'lbfgs'}" (See [Wik20e] for an explanation of the 'lbfgs' solver). All other methods currently do not need additional parameter settings.

The column "ToBeApplied" describes if the method should be a part of the test suit (1) or not(0).

StatsAttribSettings.csv

In this CSV file (**StatsAttribSettings.csv**), additional information in respect of the attributes is being supplied. Here, the user selects the attributes (e.g. *max_cap_M_m3_per_d*), which shall be used during the heuristic testing suit. A sample of such file is presented in Figure 5.3.

The file consists of seven columns and they are described as follow:

- **CompName**: This column contains the component name. Options are all component names as introduced in Chapter 2.

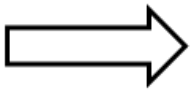
	A	B	C	D	E	F
1	CompName	AttribName	Features	Predictors	Convert2Float	RegressionType
2	Compressors	max_cap_M_m3_per_d	1	1	0	lin
3	Compressors	is_H_gas	1	1	0	log
4	Compressors	max_power_MW	1	1	0	lin
5	Compressors	max_pressure_bar	1	1	0	lin
6	Compressors	num_turb	1	1	0	lin
7	Compressors	turbine_fuel_isGas_1	1	1	0	log
8	Compressors	turbine_fuel_isGas_2	1	1	0	log
9	Compressors	turbine_fuel_isGas_3	1	1	0	log

Figure 5.3: Sample file of the file "StatsAttribSettings.csv"

- **AttribName**: This column contains the attribute names of the component given under "CompName", that can be part of the heuristic testing process.
- **Features**: This indicates that the attribute values shall be a feature variable ("1") or not ("0").
- **Predictor**: This indicates if this variable shall be tested ("1") or not ("0"). Attributes with value settings of "1" will be loaded, independent of the settings under "Feature".
- **Convert2DiscreteValue**: This indicates, if the loaded data is to be converted from string variables to numbers. Below in Figure 5.4 an example is given of a column of "gender" entries and "age" values, where the attribute *gender* is being converted.

Gender	Age
Male	25
Male	31
Female	30
Male	45

Convert2DiscreteValue



Gender_Male	Gender_Female	Age
1	0	25
1	0	31
0	1	30
1	0	45

Figure 5.4: Example of converting strings attributes to number attributes.

RegressionType This is a string, indicating the regression method to be applied to the data. The following two options are currently implemented:

- "lin": This stands for "linear regression", and includes the Lasso linear regression, median, min and max sample values.
- "log": This stands for "logistic regression", and refers to a logistic regression.

Hence, with the above settings, the user can supply all information required for the testing phase, and the user has the option of modifying the testing runs by excluding certain variables. The following section will describe further required steps the user will need to undertake as part of the attribute value generation.

3) Generation of plots for data QA

Having a good understanding of the quality and quantity of the data is very important, before one can apply any heuristic methods for generating missing attribute values. Hence, **THE USER NEEDS TO (VISUELLY) INSPECT THE DATA THAT CAN BE USED AS INPUT FOR THE HEURISTIC PROCESSES!**

This is carried out with the function **M_Stats.gen_DataHists(** *Netz, CompNames, AttribNames, StatsInputDirName, DataStatsOutput*). It requires the following inputs:

- *Netz*: A copy of the network.
- *CompNames*: A list of components to be visualized.
- *AttribNames*: A list of attribute names to be visualized.
- *StatsInputDirName*: A relative path to the above setup file "StatsAttribsSettings.csv".
- *DataStatsOutput*: A relative path to the main folder, where the plots will be stored to. After the plot generation, this folder will contain the following:
  - **HistPlots**: This is a subfolder containing further subfolders, one for each component, and each subfolder will contain the corresponding plots. Each plot consists of a scatter-plot of the data, and a histogram, see Figure 5.5 as an example. In addition, the title contains the name of the attribute next to information in respect of the attribute data density.
  - **Overview.png**: This is a file with the name "Overview.png" and contains pair-plots of attributes. (See Figure 5.6 as an example). Here each attribute of a component is plotted against all other attributes of the same component. This can be used to investigate if there are correlations between individual attributes already.

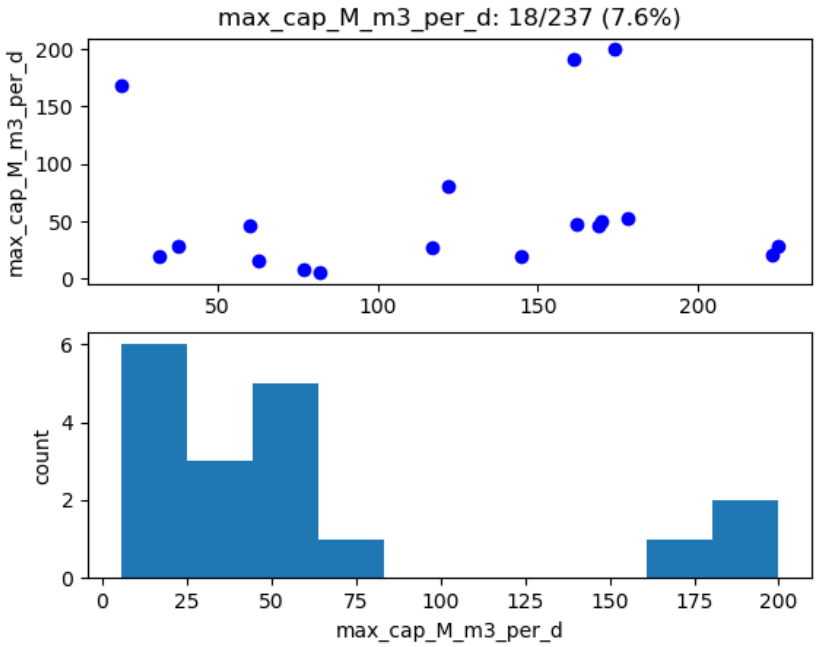


Figure 5.5: Example histogram plot of the *Compressors* attribute *max_cap_M_m3_per_d*.

With the help of the plots and data density values, the user can embark on the following steps:

- Correct any wrong data.

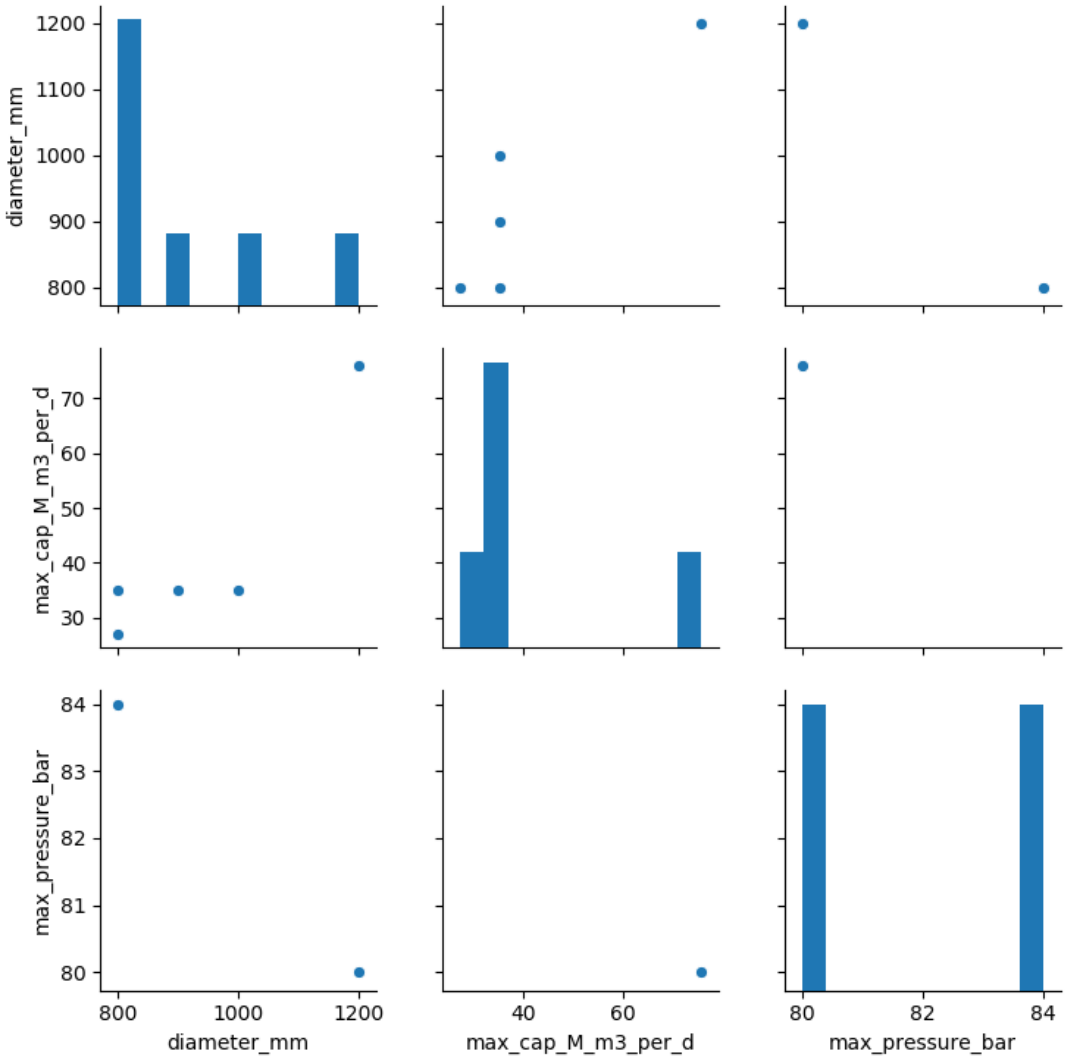


Figure 5.6: Overview of the mutual attribute relations for the component *Compressors*.

- Adding more data where data density is low, if possible.
- Select and unselect attributes from the subsequent steps due to data distribution and data density issues, resulting in changes in the setup files.

4) Parameters generation for the heuristic methods

After the data has been loaded into the Python memory and the setup files have been adjusted, the methods in conjunction with the feature attributes will be used to test to generate missing values (predictors). For this the function **M_Stats.gen_StatsParam(** *Netz, CompNames, StatsInputDirName, DataStatsOutput, MaxCombDepth* **)** has been generated. It needs the following inputs:

- *Netz*: A copy of the gas component data set.
- *CompNames*: A list of component names for which this process needs to be carried out.
- *AttribNames*: A list of attribute names for which this process needs to be carried out.
- *StatsInputDirName*: A relative path, where both input setup files can be found.
- *DataStatsOutput*: A relative path, where output information will be written to.
- *MaxCombDepth*: This gives the number of independent attributes, which can be used by each estimation method. The larger this value, the more combinations exists for a given list of independent attributes. However, more significant is that larger "MaxCombDepth" can lead to over-fitting. The number of resulting combinations of attributes can be estimated using $n!/(r!(n-r)!)$, where n the number of attribute variables to choose from, and r of them are chosen, where repetition is not allowed and order does not matter.

The output of the function **M_Stats.gen_StatsParam()** will be twofold: additional plots and measures of fit values.

A sample of such a plot is given in Figure 5.7. Each predictor (here *max_cap_M_m3_per_d*) is plotted against the selected features that were used to determine the predictor attribute (here *max_power_MW*). Here the predictor is plotted on the y-axis, whereas the feature is plotted on the x-axis. The solid line is the estimation of the method used. The title contains information on the method selected, and an R-square value of the fit that was determined using the method.

In addition to the graphical output, additional simulation information is stored in individual CSV files for each component. These files are described in more detail below.

An example output file is given in Figure 5.8 and Figure 5.9 for the component *LNGs*.

These files are written to the folder "/Ausgabe/Sample/StatsData/". All generated files start with the name "RetSummary" and are followed by the name of the component, separated by an underscore. Therefore, the CSV file name is "RetSummary_LNGs.csv" for the component *LNGs*.

The files contain information on attributes, methods, errors and parameter settings, where each line is a single run/test result. The columns are as follow:

- *CompName*: Name of the component.
- *AttribName*: Name of the predictor attribute.
- *NumElements*: Number of elements of this component.
- *MethodName*: Name of the method used that was selected through the setup file "StatsMethodsSettings.csv".
- *NumFeatures*: Number of features used to estimate the predictor.
- *FeatureNames*: List of feature attribute names that were used to estimate the predictor.
- *Plots*: A link to the individual plots of the features and attribute relationship, where the hyperlink currently works under Excel on Windows only.

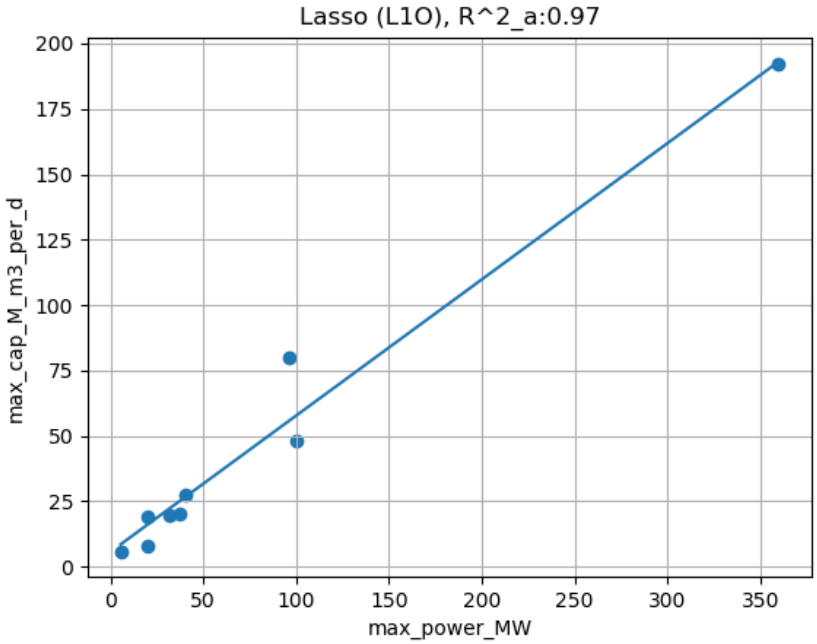


Figure 5.7: Example of attribute *max_power_MW* versus *max_cap_M_m3_per_d* from the component *Compressors*. The solid line represents the fit of the Lasso method to the data.

	A	B	C	D	E	F
1	CompName	AttribName	NumElements	ModelName	NumFeatures	FeatureNames
2	LNGs	max_cap_store2pipe_M_m3_per_d	32	Lasso	1	["Pipe_max_cap_M_m3_per_d"]
3	LNGs	max_cap_store2pipe_M_m3_per_d	32	Lasso	1	["median_cap_store2pipe_M_m3_per_d"]
4	LNGs	max_cap_store2pipe_M_m3_per_d	32	Lasso	1	["max_workingGas_M_m3"]
5	LNGs	max_cap_store2pipe_M_m3_per_d	32	Mean	1	["max_cap_store2pipe_M_m3_per_d"]
6	LNGs	max_cap_store2pipe_M_m3_per_d	32	Median	1	["max_cap_store2pipe_M_m3_per_d"]
7	LNGs	max_workingGas_M_m3	32	Lasso	1	["median_cap_store2pipe_M_m3_per_d"]
8	LNGs	max_workingGas_M_m3	32	Lasso	1	["max_cap_store2pipe_M_m3_per_d"]
9	LNGs	max_workingGas_M_m3	32	Mean	1	["max_workingGas_M_m3"]
10	LNGs	max_workingGas_M_m3	32	Median	1	["max_workingGas_M_m3"]

Figure 5.8: Example CSV output of heuristic model results for the component *LNGs*, depicting columns A - F.

G	H	I	J	K	L	M	N	O
Plots	NumSamples	NumFill	BIC	MeanAbsError	R_2	R_2_adj	ReplaceType	ModelParam
../StatsDa	4	0	14.3057177	4.845552454	0.72296201	0.584443015		{"SC_Mean": [34.5343801375], "SC_Scale": [28
../StatsDa	21	0	85.2509268	4.756034276	0.822467826	0.813124027		{"SC_Mean": [29.326994301428574], "SC_Scale
../StatsDa	28	4	109.381584	5.140814158	0.846444198	0.840538205		{"SC_Mean": [256364758.0], "SC_Scale": [1687
../StatsDa	29	3	166.939796	12.85032496	0	-0.037037037		{"SC_Mean": [0], "SC_Scale": [0], "Intercept":
../StatsDa	29	3	168.158632	12.42324043	-0.04292456	-0.081551394		{"SC_Mean": [0], "SC_Scale": [0], "Intercept":
../StatsDa	21	0	764.014679	69016010.55	0.786511086	0.775274828		{"SC_Mean": [29.326994301428574], "SC_Scale
../StatsDa	28	2	1011.07223	56118773.21	0.849922646	0.84415044		{"SC_Mean": [24.677103718199607], "SC_Scale
../StatsDa	31	1	1180.27533	149945270.6	0	-0.034482759		{"SC_Mean": [0], "SC_Scale": [0], "Intercept":
../StatsDa	31	1	1181.666	147160879	-0.04588166	-0.081946546		{"SC_Mean": [0], "SC_Scale": [0], "Intercept":

Figure 5.9: Example CSV output of heuristic model results for the component *LNGs*, depicting columns G - O.

- *NumSamples*: Number of samples of the feature data, which were used as part of this method evaluation (this number can never be larger than the value in column *NumElements*).
- *NumFill*: Number of elements for which the predictor attribute can be simulated with the method, where the attribute had missing values. (This value also includes the value given under *NumSamples*.)
- *BIC*: Indicator for the goodness of fit of the model using the BIC (Bayesian information criterion) value. The lower the BIC value the better the method fit.
- *MeanAbsError*: Measure of goodness of fit of the model using the mean absolute error (MAE).
- *R_2*: R-square model value.
- *R_2_adj*: Adjusted R-square value.
- *ReplaceType*: An empty column that will be used at a later stage.
- *ModelParam**: An entry containing all the fitting parameters used by the methods and attributes, the scaling values of the features attributes ("SC_Mean", and "SC_Scale"), and the method parameters ("Intercept", "Coef").

With the above information, visual and values, the user can make an informed decision in respect of which method could be used with which attribute to fill missing values.

5) Selecting individual estimation methods for each attribute

As described in the above processes, the function **M_Stats.gen_StatsParam()** generates plots and CSV files containing information on the goodness of the methods for each attribute. With this information the user can decide which method in combination with feature attribute values can be used to generate the missing attribute values.

Hence, in the next step the user needs to create a setup file, which contains the settings for methods and attributes that will be used for the generation of those missing attribute values. For this the user can use the output files from the previous step, by carrying out the following actions:

- Copy the above output CSV files to a new location.
- Open one of those files after the other, and carry out the next steps for each file:
  - With the information of the graphs and the indicator of goodness of fit values (e.g. MAE), remove all those method attribute combinations that shall not be used for any heuristic processes.
  - Place one of the following keywords into the column *ReplaceType*:
    - "replace": All values will be replace with the simulated value. Even the original input data will be replaced by the newly simulated values.
    - "fill": Here only the missing attribute values will be determined, therefore, the original input data will not be overwritten, in contrast to option "replace".
    - "fill_ARR": Here missing attribute values are being filled, and values that stem from copyright protected sources are also being overwritten.

However, independent on the replace type setting, some attribute values might not be estimated with a single method and single feature attribute set. This can be due on missing feature attribute values required during the estimation process. Hence, the user will need to select several different methods for the generation of all missing attribute values, by retaining several different method lines for a single attribute in the CSV file. This can be seen in Figure 5.8 in the depicted rows two to four. The attribute to be estimated and the model method are the same. However, the feature input variables differ for each line. With this approach one should be able to estimate all missing values. To retain the highest confidence in the estimated values, the user will need to select only those methods and feature attribute value combinations, that results in smallest errors.

Here, it is important to notice, that the attribute values are generated in the order as they appear in the CSV input file. Hence, the user should order the methods in such a way, that the method with the "best" predictions are being carried

out first. This could be followed by methods that generate attribute values with larger errors. To assure that there are no further missing values one could retain the **mean** or **median** method as the last method, filling any values that were left unfilled by any previous estimation.

6) Simulation of missing attribute values

The actual simulation and filling of the attributes is carried out with the function **M_Stats.pop_Attribs(** *Netz, CompNames, StatsInputDirName* **)** and is the last step in getting attribute values filled in a gas component data set. This function requires the following input:

- *Netz*: A copy of the component data set.
- *CompNames*: A list of components for which the element's attributes shall be generated and filled.
- *StatsInputDirName*: A relative path name of the location of the above modified setup files.

The return of this function is a component data set, where all missing attribute values have been generated.

5.2 Example value estimation

As an example, a result for the attributes *max_cap_pipe2store_M_m3_per_d* and *max_cap_store2pipe_M_m3_per_d* of the component *Storages* will be presented for the combined IGG data set. The table contains three columns with numbers, with the following definition:

- "N": This is the number of raw input values; hence this number is equal or smaller than the number of all facilities of this component.
- "A": This is the overall average value after all missing values have been estimated, using input and estimated values.
- "M": This is the mean absolute error, of those elements, of which the attribute value had to be determined.

Overall, there are 216 *Storages* elements in the data set. 48 values were missing for both attributes. After the attribute value estimation, the overall mean () of the attributes *max_cap_pipe2store_M_m3_per_d* and *max_cap_store2pipe_M_m3_per_d* were 13.9 and 14.6 respectively. The mean absolute error (M) calculated to be 10.9 and 11.2 for the attributes *max_cap_pipe2store_M_m3_per_d* and *max_cap_store2pipe_M_m3_per_d*. This seems large in comparison with the overall average value A. However, the individual values range from 0 to more than 100 for both attributes.

Table 5.4: List of attributes of the *Storages* component for the IGG data sets, with some statistical properties.

Attribute name	N	A	M
max_cap_pipe2store_M_m3_per_d	168	13.9	10.9
max_cap_store2pipe_M_m3_per_d	168	14.6	11.2

A histograms of the raw and the estimated values, depicted in Figure 5.10, gives the distribution for both attributes.

The estimated values are roughly distributed the same way that the raw values are distributed. The exceptions are the larger counts of the bin containing the median value of the raw data set. Here the median value is the values used, if there was no other means of determining a missing value. As can be seen, the median value was used substantially for several elements.

Here a quick statistical Z-score was carried out [UoO14], giving Z-score values of around -1.45 for both attributes. This indicates that the raw and the estimated distributions are the same, as their absolute values are smaller than two.

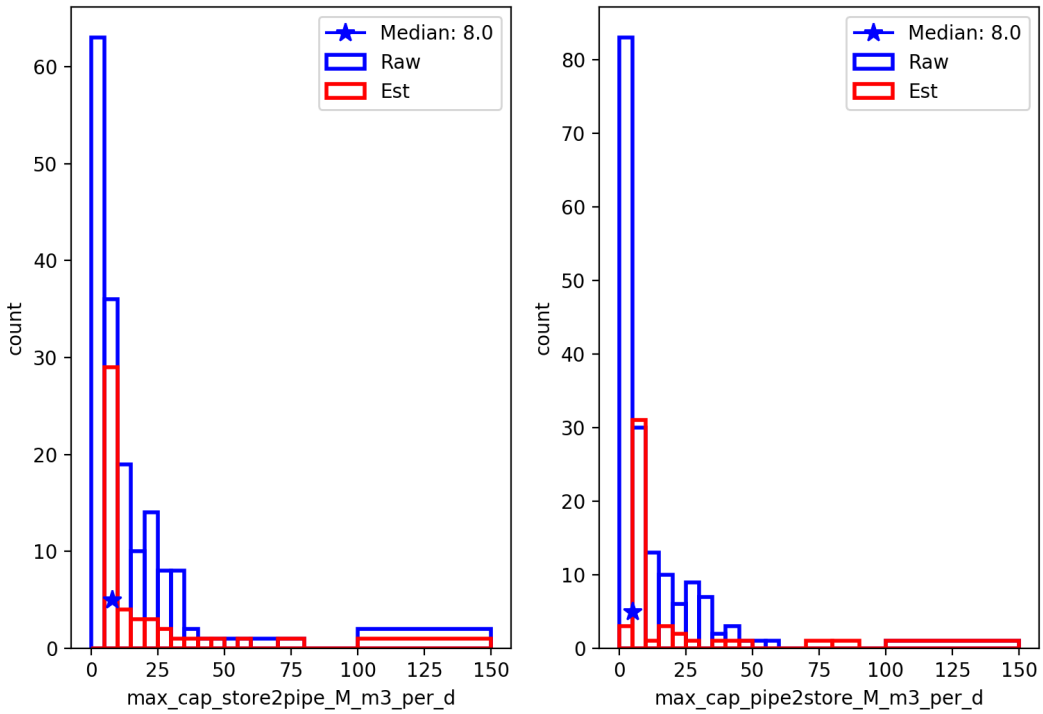


Figure 5.10: Histogram of raw (blue) and estimated (red) values for *max_cap_store2pipe_M_m3_per_d* (left) and *max_cap_pipe2store_M_m3_per_d* (right) of the *Storages* component. Both subplots also indicate the location of the median value for the raw data (star).

5.3 Automated attribute value generation

In addition to the manual process described in Chapter 5.1, an automated process has also been developed and will be briefly explained below. The automated process has been implemented for users with little statistical background, and to get first results fast.

However, the user should be aware, that by applying the automated process, some methods might be selected, that lead to incorrect results (e.g. negative *Storages* capacity for increasing max pipeline pressure of connected pipes). Hence, the user should carry out the manual process, instead of relying on the automated process results, where those bad relations could be eliminated.

The difference to the manual process described in Chapter 5.1 is that the selection of the attribute generation methods, as described in Chapter 5.1.2, has been automated. As was described in Chapter 5.1.2, one is supposed to select those methods with the best goodness of fit, e.g. BIC or MAE. Here for the automated process, the MAE value is the value that has been selected to determine which attribute generation method is to be used. The automated process selects the methods with increasing MAE value. Up to four different methods are automatically selected. In addition, if the median method is not part of the selected methods, then this method will be added to the list of methods to be executed, and will be executed last.

All other processes are as described in Chapter 5.1.

Values supplied with this data set here have been generated using the automated attribute value generation process.

5.4 Single network generation

So far raw data has been loaded, and converted into SciGRID_gas data sets. Any missing attribute values have been generated with the help of implemented regression methods. The last step is to assure, that all elements of all components are connected with each other into one large network. Here a method has been created that looks for facilities, such as *Storages* elements, that are not connected to a pipeline. Then the closest pipeline is determined, and checked, if the pipeline is closer than a user specified distance. In case that the facility is closer than this distance, the facility is moved to the pipeline. This is carried out with the function **M_Shape.moveComp2Pipe(** *Netz, CompName, PipeName, maxDistance_km* **)**. The inputs are as follow:

- *Netz*: A copy of the gas component data set.
- *CompName*: A name of the component for which this process needs to be carried out.
- *PipeName*: A name of the type of pipeline that are used in the network. Options are "PipeSegments" and "PipeLines".
- *maxDistance_km*: The maximum distance by which the facility will be moved in units of [km].

The table below (Table 5.5) shows the number of elements prior and after this process, whereas the number of segments and length of overall network did not change in this process. Here the value for *maxDistance_km* was set to 100 km.

Table 5.5: IGG number of elements prior and post connection with pipelines.

Component name	# of elements prior to process	# of elements post process
Compressors	249	230
Storages	254	216
InterConnectionPoints	118	117
EntryPoints	37	37
BorderPoints	119	118
LNGs	32	29

As can be seen, this resulted in discarding several elements, as their distance to the nearest pipeline was larger than the set 100 km. However, this assures now, that the entire data set is a gas network data set, where all elements are connected with each other and all attribute values have been estimated.

5.5 Summary

Here a method pathway has been described to fill missing attribute values. This is a complex process, where the Python code generates plots and model output values, which need to be considered by the user. With the information on hand, the user can decide if certain missing attribute values should be estimated using implemented regression methods. In addition, an automated process has been described, that can be used to generate all missing values without any additional user tasks, however the user has been made aware, that this can lead selecting incorrect attribute relationships, leading to incorrect values, as expert input is missing.

In addition, a process to generate a single network was briefly introduced, so that all elements, such as LNG terminals, are connected with pipelines with each other. Such generated data set is ready to be used by modellers.

CHAPTER

SIX

FINAL DATA SET

The SciGRID_gas project has the goal of generating a transmission gas network data set for all of Europe. Several individual data sources have been found as part of the project. However, they cannot be used individually, as individual data sets do not contain all the information that is needed for a complete gas transmission network data set. Therefore, several data sets have been combined into a single data set with methods described in previous chapters. After such a processes, significant number of attribute values were still missing in the resulting data set. Chapter 5 described a pathway of how to generate missing attribute values. This resulted in a final gas transmission network data set.

Here the final data set will be described, and differences to a previously published SciGRID_gas data set will be presented as well.

6.1 Combined IGG data set

This chapter here will describe the resulting gas transmission network data set, which was constructed by combining the INET, GIE and the GSE data sets, resulting in the so called IGG data set (also known as the INET-GIE-GSE data set). Each component will be described briefly, mainly focusing on the number of raw versus estimated values. In addition, the IGG data set will be compared with the previously published INET data set [DPM20a], emphasising on the increase of elements, increase of attributes, and the increase of raw input values.

6.1.1 Storages

Overall there are 205 *Storages* elements in the final data set, whereas in the previous INET data set, there were only 187 *Storages* elements. The Table 6.1 depicts the most important attributes that are part of the *Storages* elements. The table column headings are described below, and will be applicable to all other tables in this chapter here as well:

- "Attribute name": This is the attribute name.
- "N(INET)": This is the number of elements of the INET data set, that contained raw data of this attribute.
- "N(IGG)": This is the number of elements of the IGG data set, that contained raw data of this attribute.
- "A(INET)": This is the overall average value of the attribute from the INET data set.
- "A(IGG)": This is the overall average value of the attribute from the IGG data set.
- "M(INET)": This is the mean uncertainty of the attribute from the INET data set, for which only the non-raw data values were selected.
- "M(IGG)": This is the mean uncertainty of the attribute from the IGG data set, for which only the non-raw data values were selected.

Table 6.1: List of attributes of *Storages* elements for the INET and IGG data sets, with additional statistical properties for each attribute.

Attribute name	N(INET)	N(IGG)	A(INET)	A(IGG)	M(INET)	M(IGG)
max_cap_store2pipe_M_m3_per_d	143	175	11.0	15.2	8.98	12.3
is_H_gas	33	33	0.97	0.98	0.5	0.5
max_cap_pipe2store_M_m3_per_d	143	173	7.01	12.0	6.03	10.1
start_year	182	194	2080	1998	20	20
end_year	5	5	2049	2049	20	20
max_workingGas_M_m3	150	175	605	663	420	509

For the attributes of *start_year* and *end_year*, no heuristic process exists to relate the missing values with other attributes or to determine the missing values heuristically. Hence any missing values for those two attributes were given a constant value of "1983" and "2050", respectively. While setting this missing value for those elements, an uncertainty was also given to those attributes for those elements. Here an uncertainty value of "20" years was selected. This approach has been carried out for all components.

Further the attribute *is_H_gas* is a further attribute, for which no relation to any other attribute could be determined. Hence, a constant value of "1" was used to fill all missing attribute values *is_H_gas*, where an uncertainty of "0.5" was also written into the data set. Again, this approach has been applied to all missing attribute values for all components.

For the other three attributes *max_workingGas_M_m3*, *max_cap_pipe2store_M_m3_per_d* and *max_cap_store2pipe_M_m3_per_d*, one can see that due to incorporating the GIE and the GSE data set to the INET data set, the number of raw values increased. The estimated mean absolute error M increased for all three attributes.

For the attribute *max_workingGas_M_m3*, the number of raw attribute values increased from 150 to 175, and in similar way for the other two attributes as well. The next two columns give the average value for each of those attributes. For the attribute *max_workingGas_M_m3*, the average values (A) changed from 605 to 663. In addition, the overall mean absolute error (M) increased from 420 to 509. This value is large with 509, especially when compared with the average value A(IGG) of 663. This indicates that there was large uncertainty in the estimation of the missing values. However, raw input data ranged from single digits to more than 6000.

6.1.2 LNGs

Overall there are 29 *LNGs* elements in the final data set. The Table 6.2 depicts all important attributes of the *LNGs* component. In addition, the table also presents information for the INET data set, as was given in :TabFinalDataSet_INETGIEGSE_Storages:``.

Table 6.2: List of attributes of *LNGs* elements for the INET and IGG data sets, with additional statistical properties for each attribute.

Attribute name	N(INET)	N(IGG)	A(INET)	A(IGG)	M(INET)	M(IGG)
max_workingGas_M_m3	28	28	251	204	56.2	63.7
max_cap_store2pipe_M_m3_per_d	27	27	24.5	24.5	5.14	6.55
median_cap_store2pipe_M_m3_per	0	21	N/A	25.3	N/A	2.48

For the attributes of *end_year* and *is_H_gas* no raw input values were given in any of the data sets. However, for the attribute "start_year" the combined IGG data set contained 28 raw values, whereas the INET data set contained none. As can be seen, the data sets IGG and INET contained the same original information for the attribute *max_cap_store2pipe_M_m3_per_d*. The number of raw data supplied is high, and the estimation uncertainty is low, when compared with the average attribute value.

For the attribute *max_workingGas_M_m3* the IGG data set contained slightly different input values, leading to a different average values. From the M(IGG) value, one can see that the one value that needed determining, the uncertainty

is of the order of 63.7, large when compared with the average value. However, raw input values are in access of 6000 M m^3.

For the attribute *median_cap_store2pipe_M_m3_per*, the INET data did not contain any raw values, whereas the new IGG supplied 21 raw input values. Here one can see that the estimated mean absolute error (M(IGG)) is small when compared with the actual values of A(IGG).

After the original heuristic generation of the attributes *median_cap_store2pipe_M_m3_per* and *max_cap_store2pipe_M_m3_per_d*, it was found that the average value and the P(10) value of the attribute *median_cap_store2pipe_M_m3_per_d* were larger than the corresponding values of the attribute *max_cap_store2pipe_M_m3_per_d*. So why is the median value of the maximum flow from the storage into the pipe larger than the maximum values??? The answer is that those two attributes originate from different data sources. The attribute *max_cap_store2pipe_M_m3_per_d* originated from the INET and the GSE data set, whereas the attribute *median_cap_store2pipe_M_m3_per_d* originated from the GIE data set. As the median value was derived from daily GIE time series data, the SciGRID_gas project puts more trust on the time series, than a maximum value derived by the GSE or from the INET data set. Hence, only when there were no attribute values from the GIE data set, then they were supplemented with data from other sources.

For the subsequent components, there are no differences between the IGG and the INET data set. Hence only the information for the IGG data set needs presenting.

6.1.3 BorderPoints

Overall there are 118 *BorderPoints* elements in the final data set. The overall attribute density for elements of type *BorderPoints* is low. There are only three attributes: *start_year*, *end_year* and *pipe_name*. There were no raw input values for the attributes *start_year* and *end_year*. Hence all of those attributes were determined as described above. For the attribute *pipe_name*, 17 elements contained a value. However, currently there is no method of generating any additional pipe-line names.

6.1.4 Compressors

Overall there are 230 *Compressors* elements in the final data set. The `TabFinalDataSet_INETGIEGSE_Compressors` depicts the most important attributes that are part of the *Compressors* component.

Table 6.3: List of attributes of *Compressors* elements for the INET and IGG data sets, with additional statistical properties for each attribute.

Attribute name	N(IGG)	A(IGG)	M(IGG)
end_year	0	2050	20
is_H_gas	228	0.98	0.5
max_power_MW	37	51.9	7.29
max_pressure_bar	17	95.6	5.46
num_turb	37	2.99	0.70
turbine_fuel_isGas_1	36	0.97	0.5
turbine_fuel_isGas_2	35	0.97	0.5
turbine_fuel_isGas_3	23	0.99	0.50
turbine_fuel_isGas_4	8	1	0.50
turbine_fuel_isGas_5	3	1	0.5
turbine_fuel_isGas_6	0	1	0.5
start_year	27	1984	20
max_cap_M_m3_per_d	18	36.6	13.7
turbine_power_1_MW	19	15.8	2.97
turbine_power_2_MW	18	16.0	3.02
turbine_power_3_MW	13	15.5	2.83
turbine_power_4_MW	3	13.2	5.02
turbine_power_5_MW	2	15.5	6.53
turbine_power_6_MW	0	N/A	N/A

As can be seen, for most attributes, the data density is sparse. Only the attribute *is_H_gas* contained raw data for all but 2 elements. For all other attributes, the density is 16 % or smaller.

When comparing the average attribute value (A(IGG)) with the mean absolute error U, then one can see that for some attributes, the mean absolute error is small when compared with the mean attribute value, e.g. see *max_power_MW*, or *max_pressure_bar*. However for other attributes, such as *turbine_power_3_MW* and *turbine_power_4_MW*, the estimation of the missing values increases significantly the overall mean absolute error in the data set. Here it is important, that the user is aware of the larger uncertainty of the heuristic data generation process for some attributes.

6.1.5 EntryPoints

Overall there are 37 *EntryPoints* elements in the final data set. There are only two attributes: *start_year* and *end_year*. There were no raw input values for the attributes *start_year* and *end_year*. All attribute values were derived as has been described for the component *Storages*.

6.1.6 InterConnectionPoints

Overall there are 117 *InterConnectionPoints* elements in the final data set. There are only three attributes: *start_year*, *end_year* and *pipe_name*. There were no raw input values for the attributes *start_year* and *end_year*. All attribute values were derived as has been described for the component *Storages*. For the attribute *pipe_name*, 17 contained a value. However, currently there is no method of generating any additional pipe-line names.

6.1.7 Nodes

Overall there are 668 *Nodes* elements in the final data set. The IGG data set contains additional attributes, when compared with the INET data set. The IGG data set contained additional 62 raw entries for the attributes *ei_code* ("energy identification code" generated through EntsoG, who are the acting "Central Issuing Office"). However, there are no heuristic methods that could be used to generate those values for all other sites.

6.1.8 PipeSegments

Overall there are 920 *PipeSegments* elements in the final data set. The `TabFinalDataSet_INETGIEGSE_PipeSegments` depicts the most important attributes that are part of the *PipeSegments* elements. The table also presents the number of raw original data, and the number of values that were generated heuristically, including some uncertainty values.

Table 6.4: List of attributes of *PipeSegments* elements and their ratio of raw versus heuristically generated attribute values.

Attribute name	N(IGG)	A(IGG)	M(IGG)
is_H_gas	867	0.99	0.5
max_pressure_bar	281	77.2	10.9
is_bothDirection	88	0.05	0.5
max_cap_M_m3_per_d	145	49.0	27.7
diameter_mm	399	968	132

As can be seen, the attribute *is_bothDirection* contained the least number of raw input values with 87 only. This relates to a data density of less than 10 %. As no method has been developed so far to estimate this attribute, all missing values were filled with a constant value of "0", indicating, that the pipeline is uni-directional.

On the other hand, the attribute *is_H_gas* has a data density of 94 %, and a high average value (A(IGG)) of 0.99, indicating, that most pipelines in this data set are transporting high calorific gas.

The data density for the attribute *max_cap_M_m3_per_d* is only 16 %. Here the mean absolute error M has a value of 27.7, whereas the mean value is 49, meaning there is a large uncertainty in respect of the attribute values. However, the range of raw input data ranged from a value of 5 to a value of 200.

The attribute *max_pressure_bar* has a mean value of 77.2, whereas the uncertainty M is 10.9 only, indicating that the heuristic processes worked fairly well.

Overall, by adding the GIE and the GSE data set to the INET data set, and forming the IGG data set, for some components the number of facilities could be increased. In addition, additional attributes were added to some components.

6.1.9 Resulting map of data set

Below a spatial presentation of the final IGG data set is given in the map given in Figure 6.1. In addition, the number of elements for each component is listed in Table 6.5.

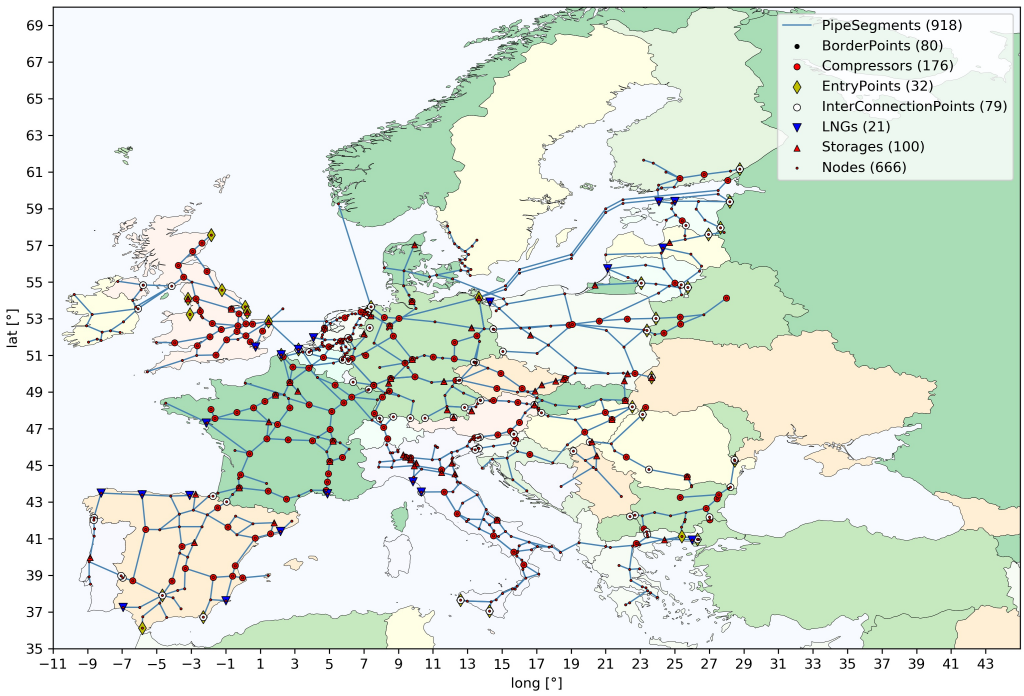


Figure 6.1: Map of the final IGG data set.

Table 6.5: List of components with number of elements of the final merged and filled IGG network data set.

Component name	Number of elements
BorderPoints	118
Compressors	230
EntryPoints	37
InterConnectionPoints	117
LNGs	29
Nodes	668
PipeSegments	920
Storages	205

CHAPTER

SEVEN

CONCLUSION

This document here is the documentation of the combined INET, GIE and GSE data sets, which are part of the SciGRID_gas project. This document here started off with the introduction of the SciGRID_gas project, such as funding, duration and goals. In a subsequent chapter the data structure within the SciGRID_gas project was described, such as components, elements, attributes and attribute values, and how a transmission network data set could be an input to certain gas flow model. The third chapter introduced the individual raw data set: INET, GIE, and GSE. In a subsequent chapter, it was explained, how the data sets were joined, forming the IGG data set. The next chapter described how missing attribute values could be generated heuristically. This chapter also included a description of the process of moving some unconnected facilities to pipeline start or end points. The last chapter gave a more detailed account of the resulting IGG gas transmission network data set, including a comparison with the previously published INET data set.

CHAPTER

EIGHT

APPENDIX

8.1 Glossary

Dataset abbreviations can be found in Table 8.1.

Table 8.1: Dataset abbreviations

Name	Abbreviation	Description
Raw InternetDaten data set	INET	Label/name for the raw InternetDaten data set
Raw Gas Infrastructure Europe data set	GIE	Label/name for the raw Gas Infrastructure Europe data set
Raw Gas Storage Europe data set	GSE	Label/name of the raw Gas Storage Europe data set
Raw Norwegian data set	NO	Label/name for the raw Norwegian data set
Raw Long-term planning and short-term optimization data set	LKD	Label/name for the raw Long-term planning and short-term optimization data set
Raw International Gas Union data set	IGU	Label/name for the raw International Gas Union data set
Raw EntsoG-Map data set	EMAP	Label/name for the raw EntsoG-Map data set
Merged and filled IGG data set	IGG	Filled data sets, for which the **I**NET, **G**IE and **G**SE data sets were merged
Merged and filled IGGI data set	IGGI	Filled data sets, for which the **I**NET, **G**IE, **G**SE and **I**GU data sets were merged
Merged and filled IGGIG data set	IGGIG	Filled data sets, for which the **I**NET, **G**IE, **G**SE, **I**GU and the **G**B data sets were merged

The glossary terms can be found in Table 8.2.

Table 8.2: Glossary

Name	Abbreviation	Description
component		A gas network consists of different components, such as: pipelines, compressors, LNG terminals, storages, entry points and production sites
element		Elements are instances of component. Hence, "10 compressor elements" refers to a data set that contains information for 10 compressor stations
attribute		Gas facilities, such as pipelines or compressors, can be described with a large set of parameters, such as pipeline diameter, or compressor capacity. Those parameters are referred to as attributes
facility		General term used for a gas appliance, such as a single compressor station, or a single LNG terminal
PipeLine		This is a gas pipeline entity, which has one start and one end point, however can run via many nodes
PipeSegment		This is a gas pipeline, that has only one start and one end point, but no nodes in-between
LNG	LNG	Liquefied natural gas
CNG	CNG	Compressed natural gas
flow duration curve	FDC	It is the cumulative frequency curve that shows the percent of time specified flow were equal or exceeded during a given period. The temporal information, when certain events occur, is lost
Energiewende		German term for the change in using primary energies, the move away from coal to renewable energies, such as wind or solar
gas component data set		Raw input data, associated with components of the gas transmission grid
gas network data set		Output data, a coherent network of gas transmission components
OSM	OSM	Data that is available from the openstreetmap.org
non-OSM	Non-OSM	Data that is not part of the OSM data set
gas type		There are two types of gas High (H) and Low (L) calorific gas
mean absolute error	MAE	mean difference between input values and estimated values
data density		This is the ratio of the number of usable (not missing) attribute values over number elements of the component, in units of [%]
Transmission System Operators	TSO	This is an entity entrusted with the transportation of natural gas/electricity, as defined by the European Union
gas transmission network		This describes the physical gas transmission grid, however it excludes any facilities/components that would be part of a distribution network and their facilities
gas component data set		The term "gas component data set" is used for raw data sets of gas network facilities. However, not all elements (e.g. compressors) need to be connected to pipelines, where the emphasis is on the term **component**
gas network data set		A "gas component data set" can be converted into a "gas network data set", by connecting all non-pipeline elements to nodes and all nodes are connected to pipelines. Hence, the emphasis here is on the term **network**

8.2 Unit conversions

Table 8.3: Unit conversions

From Unit	To Unit	MultiVal
LNG Mt	LNG Mm^3	2.47
gas tm^3/h	gas Mm^3/d	24/1000
LNG Mm^3	gas Mm^3	584
LNG t	gas Mm^3	1442.48

8.3 References for INET data set

Below a list of those sources used to generate the INET data set.

- http://belarus-tr.gazprom.ru/
- http://corporate.vattenfall.com/about-vattenfall/operations/market-transparency/gas-storage/
- http://en.gaz-system.pl//
- http://gaslager.energinet.dk/EN/Pages/default.aspx
- http://interfaxenergy.com/article/19138/lng-better-than-norway-pipeline-ex-polish-pm
- http://ir.gasplus.it/home/show.php?menu=00002
- http://italgasstorage.it/eng/progetto.html
- http://media.edfenergy.com/Misc/AboutUs.aspx
- http://mmbf.hu/en/company/gas_storage
- http://mndgsgermany.com/
- http://mysolar.cat.com/cda/files/870985/7/Solar_Turbines_5000_Gas_Compressor_News_Rel_Sent.pdf
- http://sse.com/whatwedo/ourprojectsandassets/thermal/Aldbrough/
- http://sse.com/whatwedo/wholesale/gasstorage/
- http://www.bayernugs.de/4-1-Home.html
- http://www.bendisenergy.com.tr/tr/Projelerimiz/24-toren-dogalgaz-depolama-ve-madencilik-as
- http://www.berliner-erdgasspeicher.de/en/Pages/default.aspx
- http://www.botas.gov.tr/
- http://www.bulgartransgaz.bg/en/pages/transstorge-110.html
- http://www.caythorpegasstorage.com/caythorpe/
- http://www.centrica-sl.co.uk/
- http://www.ceskaplynarenska.cz/en/ultimate-speed-underground-gas-storage
- http://www.dea-speicher.de/en
- http://www.depomures.ro/
- http://www.edisonstoccaggio.it/en
- http://www.ekb-storage.de/de/home/

- http://www.emplpipeline.com/en/the-gas-pipeline/
- http://www.emplpipeline.com/en/the-gas-pipeline/,Extra
- http://www.enagas.es/enagas/en/Transporte_de_gas/Almacenamientos_Subterraneos
- http://www.energystock.com/
- http://www.ewe-gasspeicher.de/english/index.php
- http://www.fluxys.com/belgium/en/Services/Storage/Storage
- http://www.gasnaturalfenosa.com/en/activities/lines+of+business/1285338591925/supply+and+transportation+of+gas.html
- http://www.gasspeicher-hannover.de/startseite.html
- http://www.gasstorage.cz/en/operation-information/available-firm-capacity/
- http://www.gasstoragebergermeer.com/gas-storage-bergermeer-2/
- http://www.gastrade.gr/en/the-company/the-project.aspx
- http://www.gas-union-storage.de/
- http://www.gatewaystorage.co.uk/
- http://www.gazprom.com/about/production/underground-storage/
- http://www.geogastock.it/ITA/Home.asp
- http://www.grtgaz.com/en/major-projects/beynes-compressor-station/presentation/news/compressor-station-at-the-beynes-site.html
- http://www.grtgaz.com/fileadmin/plaquettes/en/2017/Essentiel-plaquette-institutionnelle-EN-2017.pdf
- http://www.gsa-services.ru/
- http://www.halite-energy.co.uk/our-project/project-overview/
- http://www.hradf.com/en/portfolio/south-kavala-natural-gas-storage
- http://www.humblyenergy.co.uk/about-us#useful-information
- http://www.islandmageestorage.com/
- http://www.kge-gasspeichergesellschaft.de/
- http://www.kgsp.co.uk/
- http://www.kingstreetenergy.com/
- http://www.kinsaleenergy.ie/gas-storage.html
- http://www.le.lt/index.php/projects-in-progress/syderiai-underground-gas-storage/535
- http://www.lg.lv/index.php?id=3376&lang=eng
- http://www.magyarfoldgaztarolo.hu/en/Lapok/default.aspx
- http://www.mnd.eu/en/2014-11-26-12-13-02/mnd-group-companies
- http://www.nafta.sk/en/about-gas-storage
- http://www.nam.nl/en/about-nam/facts-and-figures.html
- http://www.omv.com/portal/01/com/gas/storage
- http://www.petroceltic.com/operations/bulgaria.aspx
- http://www.pgnig.pl/reports/annualreport2012/en/ar-obrot-magazynowanie-2.html

- http://www.pozagas.sk/en/?PHPSESSID=8d83cc7890abb7980f6793cf56633a72
- http://www.psp.hr/home
- http://www.rag-energy-storage.at/en.html
- http://www.romgaz.ro/en/content/ugs-n-366-new-gas-storage-facility-romania
- http://www.romgaz.ro/en/content/ugs-n-371-sarmasel-storage-facility-upgrading
- http://www.romgaz.ro/en/inmagazinare
- http://www.rwe.com/web/cms/de/37110/rwe/presse-news/pressemitteilungen/?pmid=4005467,http://digitalnewsservice.net/clients/net4gas-nimmt-neue-hochdruck-gas-pipeline-gazelle-in-betrieb/
- http://www.rwe.com/web/cms/en/531750/rwe-gasspeicher/
- http://www.scottishpower.com/pages/hatfield_moor_gas_storage_facility.asp
- http://www.snam.it/en/transportation/Thermal_Year_Archive/Thermal_Year_2013_2014/Info-to-users/index.html
- http://www.sppstorage.cz/#
- http://www.srbijagas.com/naslovna.1.html
- http://www.stogit.it/en/index.html
- http://www.storengy.com/countries/deutschland/en/products-services.html
- http://www.storengy.com/countries/france/en/
- http://www.storengy.com/countries/unitedkingdom/en/oursites.html
- http://www.taqaglobal.com/our-regions/netherlands/gas-storage/peak-gas-installation/overview?sc_lang=en
- http://www.terranets-bw.de/en/gas-transmission/we-transport-your-natural-gas/
- http://www.thueringerenergie.de/Unternehmen/Ueber_uns/Geschaeftsfelder/Speicher.aspx
- http://www.tigf.fr/en/what-we-can-offer/storage.html
- http://www.tpao.gov.tr/eng/?tp=m&id=31
- http://www.tpao.gov.tr/eng/?tp=m&id=84
- http://www.trianel-gasspeicher.com/
- http://www.ugs-katharina.de/en/unternehmen.html
- http://www.vng-gasspeicher.de/content/en/Speicher/index.html
- https://de.wikipedia.org/wiki/Baumgarten_an_der_March
- https://de.wikipedia.org/wiki/Erdgasleitung_Jamal%E2%80%93Europa,https://en.wikipedia.org/wiki/Yamal%E2%80%93Europe_pipeline
- https://de.wikipedia.org/wiki/Hungaria-Austria-Gasleitung
- https://de.wikipedia.org/wiki/MIDAL,https://www.gascade.de/netzinformationen/unser-leitungsnetz/midal/
- https://de.wikipedia.org/wiki/Mittel-Europ%C3%A4ische_Gasleitung,https://en.wikipedia.org/wiki/MEGAL_pipeline
- https://de.wikipedia.org/wiki/NEL_(Pipeline),https://en.wikipedia.org/wiki/NEL_pipeline,https://www.fluxys.com/nel/en/NELSystemInfo/AboutNEL
- https://de.wikipedia.org/wiki/Norddeutsche_Erdgas-Transversale,https://en.wikipedia.org/wiki/Netra

- https://de.wikipedia.org/wiki/OPAL_(Pipeline),https://en.wikipedia.org/wiki/OPAL_pipeline,https://www.opal-gastransport.de/netzinformationen/ostsee-pipeline-anbindungsleitung/
- https://de.wikipedia.org/wiki/Penta-West
- https://de.wikipedia.org/wiki/Rehden-Hamburg-Gasleitung,https://en.wikipedia.org/wiki/Rehden%E2%80%93Hamburg_gas_pipeline
- https://de.wikipedia.org/wiki/Trans_Austria_Gasleitung,https://en.wikipedia.org/wiki/Trans_Austria_Gas_Pipeline
- https://de.wikipedia.org/wiki/Trans-Adria-Pipeline,https://en.wikipedia.org/wiki/Trans_Adriatic_Pipeline
- https://de.wikipedia.org/wiki/Trans-Europa-Naturgas-Pipeline
- https://de.wikipedia.org/wiki/Transgas-Pipeline,Extra
- https://de.wikipedia.org/wiki/WEDAL,https://www.gascade.de/netzinformationen/unser-leitungsnetz/wedal/
- https://de.wikipedia.org/wiki/West-Austria-Gasleitung
- https://en.wikipedia.org/wiki/Arad%E2%80%93Szeged_pipeline
- https://en.wikipedia.org/wiki/BBL_Pipeline
- https://en.wikipedia.org/wiki/BRUA_Pipeline
- https://en.wikipedia.org/wiki/Europipe_II
- https://en.wikipedia.org/wiki/Giurgiu%E2%80%93Ruse_pipeline
- https://en.wikipedia.org/wiki/MEGAL_pipeline,https://de.wikipedia.org/wiki/Mittel-Europ%C3%A4ische_Gasleitung
- https://en.wikipedia.org/wiki/National_Transmission_System
- https://en.wikipedia.org/wiki/Scotland-Northern_Ireland_pipeline,E127
- https://en.wikipedia.org/wiki/South_Wales_Gas_Pipeline
- https://en.wikipedia.org/wiki/Transitgas_Pipeline,https://web.archive.org/web/20070808033932/http://www.swissgas.ch/en/3_2.php
- https://en.wikipedia.org/wiki/Transitgas_Pipeline,transitgassystem_en.gif,https://web.archive.org/web/20070808033932/http://www.swissgas.ch/en/3_2.php
- https://en.wikipedia.org/wiki/V%C3%A1rosf%C3%B6ld%E2%80%93Slobodnica_pipeline
- https://www.fnb-gas.de/media/FNB_GAS_Projekte_2014_02_17_anlage_6_nep-gas-2014_projekt-steckbriefe.pdf
- https://globallnghub.com/wp-content/uploads/2018/09/King.pdf
- https://globallnghub.com/wp-content/uploads/2018/09/King.pdf
- https://news.err.ee/610905/vopak-to-build-initially-4-000-cubic-meter-lng-terminal-at-muuga
- https://globallnghub.com/wp-content/uploads/2018/09/King.pdf
- https://www.lngworldnews.com/tallinna-sadam-alexela-to-work-on-paldiski-lng-terminal/
- https://globallnghub.com/wp-content/uploads/2018/09/King.pdf
- https://www.sourcewatch.org/index.php/Delimara_Malta_LNG_Terminal
- https://theodora.com/pipelines/france_and_belgium_pipelines.html
- https://theodora.com/pipelines/france_and_belgium_pipelines.html, E21

- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E10
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E106
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E11
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E112
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E113
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E13
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E14
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E16_1
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E16_2
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E17_Skikda
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E22_Arzew_1
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E22_Arzew_2
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E48
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E64
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E65
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E78
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E80_1
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E80_2
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E81
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E85
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E86
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E87
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E88
- https://theodora.com/pipelines/france_and_belgium_pipelines.html,E91
- https://transparency.entsog.eu/
- https://www.astora.de/storage-locations/haidach-storage-facility.html?L=1
- https://www.astora.de/storage-locations/jemgum-storage-facility.html?L=1
- https://www.astora.de/storage-locations/jemgum-storage-facility.html?L=2
- https://www.astora.de/storage-locations/rehden-storage-facility.html?L=1
- https://www.baltic-pipe.eu/de/das-projekt/
- https://www.enagas.es/stfls/ENAGAS/Transporte%20de%20Gas/Documentos/CAT_English.pdf
- https://www.enbw.com/unternehmen/konzern/geschaeftsfelder/speicher/gasspeicher/zahlen-daten-fakten.html
- https://www.eneco.nl/over-ons/projecten/gasspeicher/voorraadniveau
- https://www.energiefachmagazin.de/Branchen-News/VNG-Gasspeicher-GmbH-legt-Erdgasspeicher-Buchholz-still
- https://www.enovos.de/industrie/ueber-uns/erdgasspeicher

- https://www.eugal.de/eugal-pipeline/,https://www.mdr.de/nachrichten/politik/regional/baubeginn-erdgastrasse-eugal-umstritten-100.html
- https://www.europipe.com/de/referenzen/referenzprojekte/
- https://www.eustream.sk/en_transmission-system/en_transmission-system
- https://www.fluxys.com/belgium/en/about%20fluxys/infrastructure/network/network
- https://www.gascade.de/en/our-network/compressor-stations/radeland/
- https://www.gascade.de/en/our-network/our-pipelines/jagal/
- https://www.gascade.de/netzinformationen/unser-leitungsnetz/stegal/
- https://www.gascade.de/netzinformationen/unser-leitungsnetz/stegal/,https://en.wikipedia.org/wiki/STEGAL, https://de.wikipedia.org/wiki/STEGAL
- https://www.gascade.de/presse/presseinformationen/pressemitt,http://www.friedrich-vorwerk.de/de/aktuell/projekte/neubau-nowal-dn-1000.htmleilung/news/bau-der-nord-west-anbindungsleitung-nowal-startet-anfang-maerz/
- https://www.gasinfocus.com/en/indicator/existing-and-planned-lng-terminals/
- https://nauticor.de/lng-terminal-nynaeshamn
- https://www.gazprom.com/f/posts/86/569604/portovaya_eng.pdf
- https://www.habau.at/de/projekte/erdgasleitung-wag-expansion-3
- https://www.habau.at/de/projekte/erdgasleitung-wag-plus-600-phase-1
- https://www.hydrocarbons-technology.com/projects/swedegas-lng-facility-port-gothenburg/
- https://www.ign.ren.pt/en/armazenamento-subterraneo3
- https://www.ign.ren.pt/en/armazenamento-subterraneo4
- https://www.innogy-gasstorage.cz/en/index/
- https://www.innogy-gasstorage.cz/en/stramberk/
- https://www.n-ergie.de/geschaeftskunden/produkte/erdgas/erdgasspeicher.html
- https://www.ontras.com/fileadmin/user_upload/Dokumente_Download/Publikationen/ONTRAS_Netzpufferanlage_Burggraf_Bernsdorf.pdf
- https://www.osm.pgnig.pl/en
- https://www.rnf.de/hintergrund-die-erm-gasleitung-von-ludwigshafen-nach-karlsruhe-58182/
- https://www.shz.de/lokales/landeszeitung/wissenschaftler-unter-zeitdruck-id5845016.html
- https://www.sourcewatch.org/index.php/Lithuania-Latvia_Interconnection_Gas_Pipeline
- https://www.storengy.com/countries/france/en/nos-sites/beynes.html
- https://www.storengy.com/countries/france/en/nos-sites/cere-la-ronde.html
- https://www.storengy.com/countries/france/en/nos-sites/manosque.html
- https://www.storengy.com/countries/france/en/our-sites/saint-clair-sur-epte.html
- https://www.swedegas.com/Our_services/services/Storage
- https://www.uniper-energy-storage.com/cps/rde/xchg/ust/hs.xsl/3252.htm?rdeLocaleAttr=en
- https://www.uniper-energy-storage.com/cps/rde/xchg/ust/hs.xsl/3437.htm?rdeLocaleAttr=en
- https://www.vng-gasspeicher.de/storage_locations

- https://www.wesernetz.de/netznutzung/bremen/gasnetz-speicheranlagen.php
- https://www.wingas.com/storage-uk-ltd/home.html
- https://www.PLE
- https://www.www.gascade.de/Verdichterstation_Bunde_2016.pdf
- https://www.www.gascade.de/Compressor_station_Eischleben_2016.pdf
- https://www.www.gascade.de/Verdichterstation_Lippe_72dpi060614.pdf
- https://www.www.gascade.de/Anlandestation_Greifswald_Lubmin_2016.pdf
- https://www.www.gascade.de/Verdichterstation_Mallnow_2016.pdf
- https://www.www.gascade.de/Compressor_station_Olbernhau_2016.pdf
- https://www.www.gascade.de/Verdichterstation_Reckrod_2016.pdf
- https://www.www.gascade.de/Verdichterstation_Rehden_2016.pdf
- https://www.www.gascade.de/Compressor_station_Rueckersdorf_2016.pdf
- https://www.www.gascade.de/Verdichterstation_Weisweiler_201609.pdf
- https://www.opal-gastransport.de/Compressor_Station_Radeland_72dpi.pdf
- https://www.opal-gastransport.de/Verdichterstation_Radeland_2016.pdf
- https://www.pipelinesystems.com/: "NETRA compressor station Wardenburg"
- https://www.grtgaz.com: Plan_decennal_2017-2026.pdf
- https://www.streicher.de
- https://www.open-grid-europe.com
- https://www.open-grid-europe.com
- https://www.open-grid-europe.com, Pressinformation, May 2017, "Herbstein compressor station new build project"
- https://www.fluxys.com/tenp/de
- Presseinfo Bayernets, WinGas, 19-Sep-2008
- NWZonline.de, 22-04-2010: "ExxonMobil gibt kräftig Gas" by Tanja Mikulski
- Porzerleben.de: 6-sep-2011, "Open Grid Europe investiert in europäischen Netzverbund"
- Christoph Edler, Bachelorarbeit PR 370005, Technische Universität Wien, "Das österreichische Gasnetz", Juli 2013.

8.4 Location name alterations

Location names should be changed into the 26 letters used in the English language.

For names from the individual countries please follow the suggested approach:

- Germany/Austria: *Umlaute* to be replaced with the letter followed by an 'e', e.g.: ü = ue.
- France/Belgium: Omit accent de gues and accent de graphs, e.g.: ó = o.
- Sweden: Please change the last three letters of the Swedish alphabet and replace e.g.: ä = a.

- Poland: Please change any letter, that cannot be found in the English alphabet, knowing that for some letters, that one can only use a single letter instead of the three different letters used in the Polish alphabet, e.g.: z = z.
- Spain/Portugal: Please change any letter, that cannot be found in the English alphabet, e.g.: ñ = n.
- Greece: Please do not use Greek letters. Please try to write the Greek words with Latin letters.
- Denmark: Please change any letter that contains non-English letters, e.g.: "å" with "aa".
- Slovakia, Czech Republic, Hungary, Rumania, Latvia, Lithuania, Estonia, Bulgaria, Slovenia, Croatia: PLEASE use your common sense, based on the examples from the other countries above.

8.5 Changes to previous releases

Below a list of changes are being summarized in reverse order. Main information will be the new document and Zenodo version number, the date if problem solution, and a brief description of the changes implemented.

8.5.1 Version 1.1

Date: 10-09-2020

Description: Bug found where not all *node_id* from components (e.g. *Compressors*) were in list of *node_id* of component *Nodes*.

8.5.2 Version 1.2

Date: 15-09-2020

Description: As there were large start_year values for the component *Storages*, which originated from the INET data set, an assumption has been implemented, that for all storage facilities, that are in planing/constructoin site, a start_year value of 2050 is assumed, replacing the previous start year value of 2999.

Date: 15-09-2020

Description: Merging elements of type *Storages*, multiple selection of sites from the INET data set were not allowed. However several *storages* facilities from the GIE, GSE,... and other data sets are located at the same node,... hence it is now allowed, that several storage facilites, with differnt attribute values, are sharing the same node, with identical node_id.

8.6 Country name abbreviations

For convenience we provide a short list of names and two-digit codes (see Table 8.4) for the probably most important countries associated with the European Transmission Grid.

Table 8.4: Country codes

Country name	Country code	Country name	Country code
Albania	AL	Kosovo	XK
Armenia	AM	Latvia	LV
Austria	AT	Liechtenstein	LI
Azerbaijan	AZ	Lithuania	LT
Belarus	BY	Luxembourg	LU
Belgium	BE	Malta	MT
Bosnia and Herzegovina	BA	Moldova	MD
Bulgaria	BG	Montenegro	ME
Croatia	HR	Netherlands	NL
Cyprus	CY	Norway	NO
Czech	CZ	Poland	PL
Denmark	DK	Portugal	PT
Estonia	EE	Romania	RO
Finland	FI	Serbia	RS
France	FR	Slovakia	SK
Georgia	GE	Slovenia	SI
Germany	DE	Spain	ES
Greece	GR	Sweden	SE
Hungary	HU	Switzerland	CH
Iceland	IS	Turkey	TR
Ireland and Northern Ireland	IE	Belarus	UA
Italy	IT	Great Britain	GB
Russia Federation	RU	Europe	EU

8.7 Statistical background

Here some of the statistical methods mentioned in the document are described briefly. This is so that actions described in this document can be understood better by the user, and is not thought of giving a full explanation. Most descriptions have been copied from the Wikipedia pages, or other internet pages, and will be referenced accordingly.

8.7.1 Out-of-bag

This is a method of measuring the prediction error of random forests, boosted decision trees, and other machine learning models utilizing bootstrap aggregating (bagging) to sub-sample data samples used for training. [Wik20f]

8.7.2 Leave p-out cross-validation

The following has been copied from [Wik20b]:

"Leave-p-out cross-validation (LpO CV) involves using p observations as the validation set and the remaining observations as the training set. This is repeated on all ways to cut the original sample on a validation set of p observations and a training set.

LpO cross-validation requires training and validating the model C_p^n times, where *n* is the number of observations in the original sample, and where C_p^n is the binomial coefficient. For *p > 1* and for even moderately large *n*, LpO CV can become computationally infeasible. For example, with *n = 100* and *p = 30 %* of *100*, $C_{30}^{100} \approx 3 \times 10^{25}$."

8.7.3 Leave one-out cross-validation

The following has been copied from [Wik20b]:

"Leave-one-out cross-validation (LOOCV) is a particular case of leave-p-out cross-validation with *p = 1*.

The process looks similar to jackknife; however, with cross-validation one computes a statistic on the left-out sample(*s*), while with jackknifing one computes a statistic from the kept samples only.

LOO cross-validation requires less computation time than LpO cross-validation because there are only $\mathrm{C}_1^n = \mathrm{n}$ passes rather than C_k^n. However, *n* passes may still require quite a large computation time, in which case other approaches such as k-fold cross validation may be more appropriate."

8.7.4 Jackknifing

The following text has been copied from [Wik20c]:

"In statistics, the jackknife is a resampling technique especially useful for variance and bias estimation. The jackknife pre-dates other common resampling methods such as the bootstrap. The jackknife estimator of a parameter is found by systematically leaving out each observation from a data set and calculating the estimate and then finding the average of these calculations. Given a sample of size *n* , the jackknife estimate is found by aggregating the estimates of each

The jackknife technique was developed by Maurice Quenouille (1924-1973) from 1949, and refined in 1956. John Tukey expanded on the technique in 1958 and proposed the name "jackknife" since, like a physical jack-knife (a compact folding knife), it is a rough-and-ready tool that can improvise a solution for a variety of problems even though specific problems may be more efficiently solved with a purpose-designed tool.

The jackknife is a linear approximation of the bootstrap."

8.7.5 Bootstrap

The following has been copied from [Wik20a]:

"Bootstrapping is any test or metric that uses random sampling with replacement, and falls under the broader class of resampling methods. Bootstrapping assigns measures of accuracy (bias, variance, confidence intervals, prediction error, etc.) to sample estimates. This technique allows estimation of the sampling distribution of almost any statistic using random sampling methods.

Bootstrapping estimates the properties of an estimator (such as its variance) by measuring those properties when sampling from an approximating distribution. One standard choice for an approximating distribution is the empirical distribution function of the observed data. In the case where a set of observations can be assumed to be from an independent and identically distributed population, this can be implemented by constructing a number of resamples with replacement, of the observed data set (and of equal size to the observed data set)."

8.8 Acknowledgement

We acknowledge the contribution of Dr. Ontje Luensdorf from the DLR Institute of Networked Energy System to the SciGRID_gas project.

BIBLIOGRAPHY

[AFW14] M. Ahmed, B.T. Fasy, and C. Wenk. *New Techniques in Road Network Comparison*. Penguin Random House, New York, NY, 2014.

[AG99] H. Alt and L. Guibas. *Discrete geometric shapes: matching, interpolation, and approximation-a survey*. Sack JR, Urrutia J, Handbook of Computational Geometry, Elsevier, New York, NY, 1999.

[DPM20a] J.C. Diettrich, A. Pluta, and W. Medjroub. *SciGRID_gas: The INET gas transmission network data set*. DLR-Institut für Vernetzte Energiesysteme e.V., Oldenburg, Germany, Aug 2020. URL: https://doi.org/10.5281/zenodo.4008975, doi:10.5281/zenodo.4008975.

[DPM20b] J.C. Diettrich, A. Pluta, and W. Medjroub. *SciGRID_gas: The combined IGG gas transmission network data set*. DLR-Institut für Vernetzte Energiesysteme e.V., Oldenburg, Germany, Aug 2020. URL: https://doi.org/10.5281/zenodo.4009129, doi:10.5281/zenodo.4009129.

[DPM20c] J.C. Diettrich, A. Pluta, and W. Medjroub. *SciGRID_gas: The combined IGGI gas transmission network data set*. DLR-Institut für Vernetzte Energiesysteme e.V., Oldenburg, Germany, Aug 2020.

[DPM20d] J.C. Diettrich, A. Pluta, and W. Medjroub. *SciGRID_gas: The raw INET data set*. DLR-Institut für Vernetzte Energiesysteme e.V., Oldenburg, Germany, Aug 2020. URL: https://doi.org/10.5281/zenodo.3985249, doi:10.5281/zenodo.3985249.

[FMWP+17] Kunz F., Kendziorski M., Schill W.-P., Weibezahn J., Zepter J., von Hirschhausen C., and Hauser P. *Electricity, Heat, and Gas Sector Data for Modeling the German System*. Deutsches Institut für Wirtschaftsforschung, Daten Documentation 92, Berlin, 2017.

[GH85] R.L. Graham and P. Hell. On the history of the minimum spanning tree problem. *Annauls of the History of Computer*, 7(1):43–57, 1985. doi:{10.1145/2729977}.

[Hel18] D. Helle. OpenStreetMap - Deutschland. https://www.openstreetmap.de/, 2018. Accessed: 2019-12-12.

[Kha13] Y. Khalid. What is Pickle in python? https://pythontips.com/2013/08/02/what-is-pickle-in-python/, 2013. Accessed: 2019-10-10.

[LSS+19] P. Lustenberger, F. Schumacher, M. Spada, P. Burgherr, and B. Stojadinovic. Assessing the performance of the european natural gas network for selected supply disruption scenarios using open-source information. *Energies*, 12(4685):1–28, 2019. doi:{10.3390/en12244685}.

[MMK16] C. Matke, W. Medjroubi, and D. Kleinhans. SciGRID - An Open Source Reference Model for the European Transmission Network (v0.2). https://power.scigrid.de, 2016. Accessed: 2019-09-09.

[San19] B. Sandvik. World Borders. http://thematicmapping.org/downloads/world_borders.php, 2019. Accessed: 2019-07-07.

[SAB+17] M. Schmidt, D. Aßmann, R. Burlacu, J. Humpola, I. Joormann, N. Kanelakis, T. Koch, D. Oucherif, M.E. Pfetsch, L. Schewe, R. Schwarz, and M. Sirvent. *GasLib—A Library of Gas Network Instances*. 2017. doi:{10.3390/data2040040}.

[sl19] scikit-learn. 1.1. Linear Models (scikit learn). https://scikit-learn.org/stable/modules/linear_model.html, 2019. Accessed: 2019-08-08.

[UoO14] USA University of Oregon. Comparing distributions: Z Test. http://homework.uoregon.edu/pub/class/es202/ztest.html, 2014. Accessed: 2020-07-07.

[Wik20a] Wikipedia. Bootstrapping (statistics). https://en.wikipedia.org/wiki/Bootstrapping_(statistics), 2020. Accessed: 2019-06-06.

[Wik20b] Wikipedia. Cross-validation (statistics). https://en.wikipedia.org/wiki/Cross-validation_(statistics)#Exhaustive_cross-validation, 2020. Accessed: 2019-07-07.

[Wik20c] Wikipedia. Jackknife resampling. https://en.wikipedia.org/wiki/Jackknife_resampling, 2020. Accessed: 2019-08-08.

[Wik20d] Wikipedia. Lasso (statistics). https://en.wikipedia.org/wiki/Lasso_(statistics), 2020. Accessed: 2020-04-04.

[Wik20e] Wikipedia. Limited-memory BFGS. https://en.wikipedia.org/wiki/Limited-memory_BFGS, 2020. Accessed: 2020-06-06.

[Wik20f] Wikipedia. Out-of-bag error. https://en.wikipedia.org/wiki/Out-of-bag_error, 2020. Accessed: 2019-07-07.

[Wik20g] Wikipedia. Transmission system operator. https://en.wikipedia.org/wiki/Transmission_system_operator/, 2020. Accessed: 2019-09-09.

[Wik20h] Wikipedia. JAGAL. https://en.wikipedia.org/wiki/JAGAL, 2020. Accessed: 2020-01-01.

[YEZ20] I. Yueksel-Erguen and J. Zittel. Approach of converting a PDF map into shape file. priv. comms, 2020.

[BMWi11] BMWi. Forschung für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/6-energieforschungsprogramm-der-bundesregierung.pdf?__blob=publicationFile&v=12, 2011. Accessed: 2019-02-02.

[BMWi20] BMWi. Home page of BMWi. https://www.bmwi.de/Navigation/DE/Home/home.html, 2020. Accessed: 2020-03-03.

[BundesregierungDeutschland20] Bundesregierung Deutschland. Home page of Bundesregierung Deutschland. https://www.bundesregierung.de/Webs/Breg/DE/Themen/Energiewende/_node.html, 2020. Accessed: 2020-01-01.

[GasIEurop20] Gas Infrastructure Europ. Home page of Gas Infrastructure Europ. https://agsi.gie.eu, 2020. Accessed: 2020-01-01.

[GasSEurop20] Gas Storages Europ. Home page of Gas Storages Europ. https://www.gie.eu/index.php/transparency/gse-transparency-template, 2020. Accessed: 2020-01-01.

[Gassco20a] Gassco. Data page of facilities from Gassco. https://www.npd.no/en/about-us/information-services/available-data/map-services/, 2020. Accessed: 2020-01-01.

[Gassco20b] Gassco. Home page of Gassco Norway. https://www.gassco.no/en/, 2020. Accessed: 2020-01-01.

[IGU20] IGU. Home page of International Gas Union. https://www.igu.org/, 2020. Accessed: 2018-10-01.

[nationalGrid20] nationalGrid. Home page of National Grid UK. https://www.nationalgrid.com/uk/, 2020. Accessed: 2018-10-01.