Unit Investment Cost Indicators - Project Support to ACER

Final report

14 June 2023

Final version

pwc

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1. Executive summary

This document presents the findings of the *Unit Investment Cost (UIC) Indicators – project support to ACER,* which involved collecting data on energy infrastructure projects. It also includes desk research on new technologies and their associated costs, taking into account limitations in cost data to provide a comprehensive overview of the calculated UIC figures.

The project successfully developed robust indicators for mature infrastructure, such as overhead lines and underground cables. However, for other asset categories where data was collected, the indicators were less reliable due to limitations in the size or nature of the collected data. Data sets for individual asset categories suffered from the various flaws or a combination thereof, which affected the quality of the results:

- Small sample sizes for certain asset categories or subcategories
- Wide variation in the main cost-driver parameter
- Data originating from a single country or significant regional differences in costs

The results are presented in the form of mean, median and quartiles serving as reference values for the cost indicators. To ensure reliability and observe trends, a comparison was made with the results from 2015 UIC Report, assuming that the data sets from the exercises conducted in 2015 and 2023 were both reliable and comparable. It was found that costs for the majority of infrastructure types had increased, likely due to factors such as inflation, among others

2. Introduction

2.1. Purpose of the document

This document summarizes the data collection, data processing, research and presentation of the results of the *Unit Investment Cost (UIC) Indicators Project Support to ACER*, and the related services based on the contract between the European Union Agency for the Cooperation of Energy Regulators and PricewaterhouseCoopers (PwC). The document presents the UIC results for individual assets, for which data is collected via a data collection questionnaire, and the production of the results. It also reflects cost data limitations to create a comprehensive picture regarding the calculated UIC figures.

The data in the project was collected for the purpose of UIC indicator and corresponding reference values calculation. Information was also collected by desk research for new infrastructure categories, for which data was not available from the data collection (such as electrolysers and hydrogen network assets). The final deliverable - 2023 Unit Investment Cost Report ("UIC Report") is intended to assist the European Network of Transmission System Operators (ENTSO) in carrying out a cost-benefit analysis for the Ten-Year Network Development Plan (TYNDP). It will also support project promoters in assessing investment requests and support the national regulatory authorities (NRAs) in making informed Cross-border Cost Allocation (CBCA) decisions and raise transparency regarding the levels of energy infrastructure in the EU, and energy infrastructure cost structure or factors affecting the costs.

The document follows the structure of its previous version - the 2015 UIC Report – while updating the data based on more recent information and revising collected data with regards to Regulation (EU) No. 2022/869 repealing Regulation (EU) No. 347/2013 that sets out the obligation to prepare the UIC Report. The main changes to data collection includes the addition of new types of energy infrastructure equipment and the exclusion of traditional gas infrastructure assets. Following discussion with ACER, further simplifications in some areas that were unavailable in the 2015 UIC collection were introduced. The main changes to the content of data collection are described in Section 3.2. Legal basis of this document.

ACER will continue collecting data. Additional assets or information about existing assets would greatly enhance the quality of the calculated results. ACER will continue to press project promoters to produce robust UIC indicators.

Clear communication regarding the infrastructure blending gas, biomethane and hydrogen would produce a more robust database supporting indicator calculation. The category blending gas/biomethane/hydrogen was included following the suggestion of stakeholders in the preliminary phase of this project.

2.2. Project timeframe

First draft of the final project result - 2023 UIC Report - was submitted for review by ACER and the NRAs on 27 March 2023 for return with comments by the 14 April 2023. A consultation was held providing a project overview and the most tangible or the most counterintuitive results to the NRAs. As was the case for interim reports 1, 2 and 3, NRAs were required to provide their feedback as comments and tracked changes to the submitted draft report. Comments regarding interim reports were implemented and interim reports were incorporated into the draft report.

All project deliverables were reviewed. Inputs have been considered and changes made where relevant. The deliverables were submitted on time for review to ACER. ACER commented on all draft reports: interim report No. 1, interim report No. 2, draft report (interim report No. 3) and the final report (interim report No. 4).

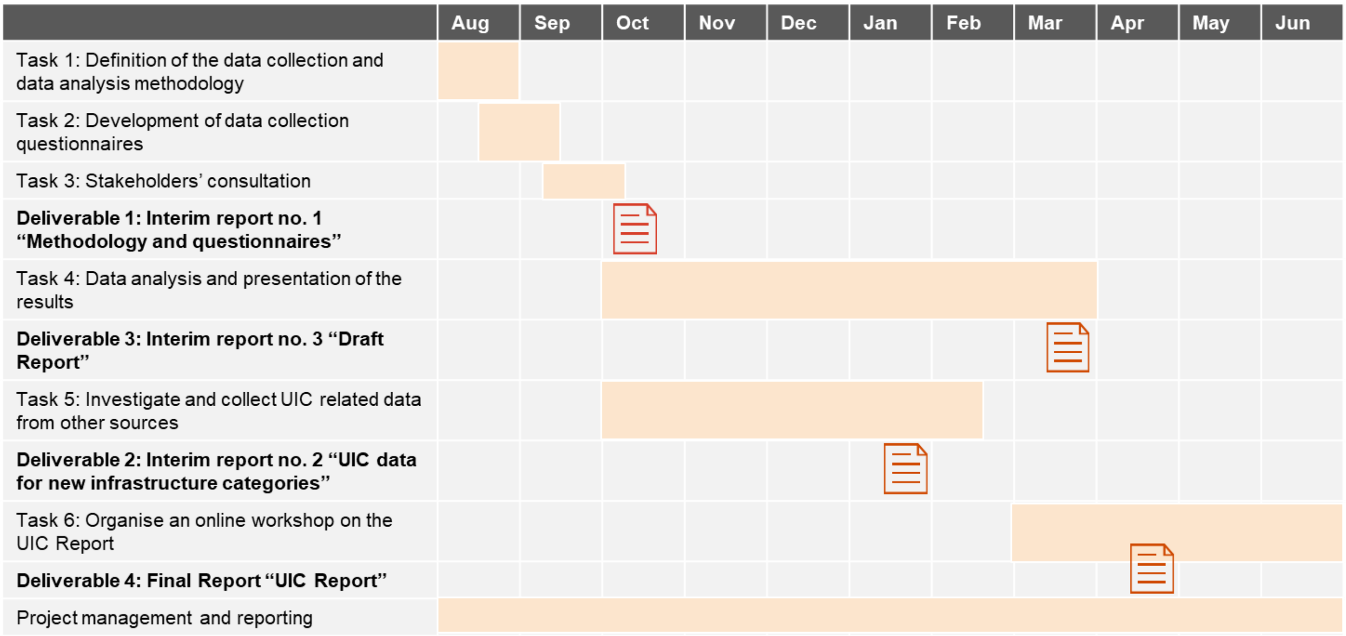
Interim report No. 1 was submitted on 2 September 2022, followed by the data questionnaires submitted by 27 September 2022. The NRA of Austria and ACER commented on interim report No. 1. The NRAs of Austria and Germany commented on the proposals regarding data questionnaires.

Data collection was launched on 17 November 2022 and planned for completion by 11 January 2023. Following several requests for an extension of the collection period, it was extended until 31 January 2023.

Interim report No. 2 was submitted on 13 January 2023. The NRAs of Spain and Austria have commented on interim report No. 2. Interim report No. 3 was submitted on 17 February 2023, and has been reviewed internally by ACER.

The final report was submitted on 27 March 2023. The NRAs of Belgium, Cyprus, Sweden, Austria and Germany commented on the final report. Prior to the deadline for providing feedback, a consultation with the NRAs was held by ACER and the contractor. During the consultation, major irregularities were presented and discussed. Most of the questions posed by participants were addressed during the consultation.

The project timeframe was as follows:



	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Task 1: Definition of the data collection and data analysis methodology	▨										
Task 2: Development of data collection questionnaires	▨	▨									
Task 3: Stakeholders' consultation		▨	▨								
Deliverable 1: Interim report no. 1 "Methodology and questionnaires"			📄								
Task 4: Data analysis and presentation of the results			▨	▨	▨	▨	▨	▨			
Deliverable 3: Interim report no. 3 "Draft Report"								📄			
Task 5: Investigate and collect UIC related data from other sources			▨	▨	▨	▨	▨				
Deliverable 2: Interim report no. 2 "UIC data for new infrastructure categories"						📄					
Task 6: Organise an online workshop on the UIC Report								▨	▨	▨	▨
Deliverable 4: Final Report "UIC Report"									📄		
Project management and reporting	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

📄 Deliverable completion ▨ Task completion

2.3. Abbreviations

Abbreviation	Description
AC	Alternating current
ACER	European Union Agency for the Cooperation of Energy Regulators
ANL	Argonne National Laboratory
CBCA	Cross-border Cost Allocation
CO_2	Carbon dioxide
DC	Direct current
DLR	Dynamic line rating for electric utilities
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EU	European Union
EUR	Euro
EUR/kg	Euro per kilogram
EUR/MW	Euro per megawatt
GHG	Green-house gas
GW	Gigawatt
H_2	Hydrogen
HDSAM	Hydrogen delivery scenario analysis model
HVDC	High-voltage direct current
ICT	Information and Communication Technologies
INES	Initiative Save Energy (Initiative Energien Speichern)
IRENA	International renewable energy agency
km	Kilometer
LC-gas	Low-carbon gas
LNG	Liquefied natural gas
Mm^3	Million cubic meters

Abbreviation	Description
MW	Megawatt
NRA	National Regulatory Authority
OIES	Oxford Institute for Energy Studies
PEM	Polymer electrolyte membrane
PP	Project promoter
PwC	PricewaterhouseCoopers
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
TSO	Transmission system operator
TYNDP	Ten-Year Network Development Plan
UIC	Unit Investment Cost
USA	United States of America
USD	US dollar

2.4. Figures

2.5. Tables

3. Context and legal basis

3.1. Context of the UIC indicators

The first reports on UIC indicators and corresponding reference values for electricity and gas infrastructure were published by ACER in 2015 (Gas Infrastructure UIC Report[1], Electricity Infrastructure UIC Report[2]). They were prepared by NRAs cooperating under the framework of ACER. The next UIC report collating indicators for selected energy infrastructure categories will be produced and published by ACER by 24 April 2023 (for selected indicators).

The structure and content of the 2023 UIC report will be updated in two major aspects compared to the 2015 issue:

- **Categories of energy infrastructure**: the revision of EU targets and of underlying regulation revisions will involve changes to infrastructure categories developed in order to implement the new energy infrastructure priorities. These changes exclude the traditional gas infrastructure, and intend to promote the inclusion of smart gas grid equipment, repurposed or new infrastructure for hydrogen, electrolyser facilities and carbon dioxide infrastructure.
- The **level of costs**: the costs of infrastructure assets changes with time primarily due to inflation and technological innovation. Thus, more recent cost data is necessary for more reliable cost-benefit analyses results related to the infrastructure projects.

The main objectives of the UIC Report are:

1. Development of UIC indicators and corresponding reference values for energy infrastructure types underlined in the recent strategic goals and documents (Green Deal etc.)
2. Provision of benchmarks for the ENTSOs' cost-benefit analyses
3. Provision of guidance to project promoters in assessing investment and performing analyses associated with public financial assistance
4. Support to NRAs in making informed Cross Border Cost Allocation (CBCA) decisions
5. Elevated transparency of the levels of energy infrastructure in the EU, its cost structure and cost drivers

3.2. Legal basis

The development of UIC indicators by ACER is an obligation set out by Article 11(9) of Regulation (EU) No. 2022/869 replacing the requirement set out in Article 11(7) of Regulation (EU) No. 2013/347. The Agency will incorporate the 2015 UIC Report with changes introduced by the revision of the TEN-E Regulation, i.e. the applicable infrastructure categories where the traditional gas infrastructure category has been excluded, while hydrogen-related, carbon dioxide and smart gas grid infrastructure are added as per the detail stipulated by Annex II of the Regulation (EU) No. 2022/869.

The EU launched the Green Deal in its communication from December 2019 with the goal of becoming the world's first climate-neutral bloc by 2050. Following the launch of this initiative, the European Parliament called for a

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[1] :The report is available here https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/UIC%20Report%20-%20Gas%20infrastructure.pdf

[2] The report is available here: https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/UIC%20Report%20%20-%20Electricity%20infrastructure.pdf

revision of the guidelines for trans-European energy infrastructure set out in Regulation (EU) No. 2013/347. The revision considered, in particular, the Union's 2030 targets for energy and climate and its 2050 climate neutrality objectives and the energy efficiency first principle. Despite the objectives of Regulation (EU) No. 2013/347 being recognized as largely valid, a new political context and upgraded targets for 2030 and 2050 required revision. The political context coupled with technical abilities provide the basis for the revision of the selection criteria for projects of common interest as well as the priority corridors and specific areas.

In accordance with the EU Commission's impact assessment accompanying the Commission's communication from September 2020 entitled 'Stepping up Europe's 2030 climate ambition – Investing in a climate-neutral future consumption of natural gas must be reduced, while the consumption of biogas, renewable and low-carbon hydrogen and synthetic gaseous fuels is expected to increase significantly. Therefore, cost indicators associated with the gas infrastructure will shift from traditional gas-related items to those specifically enhancing the integration of low-carbon gas energy carriers and promoting the creation of a smart gas grid.

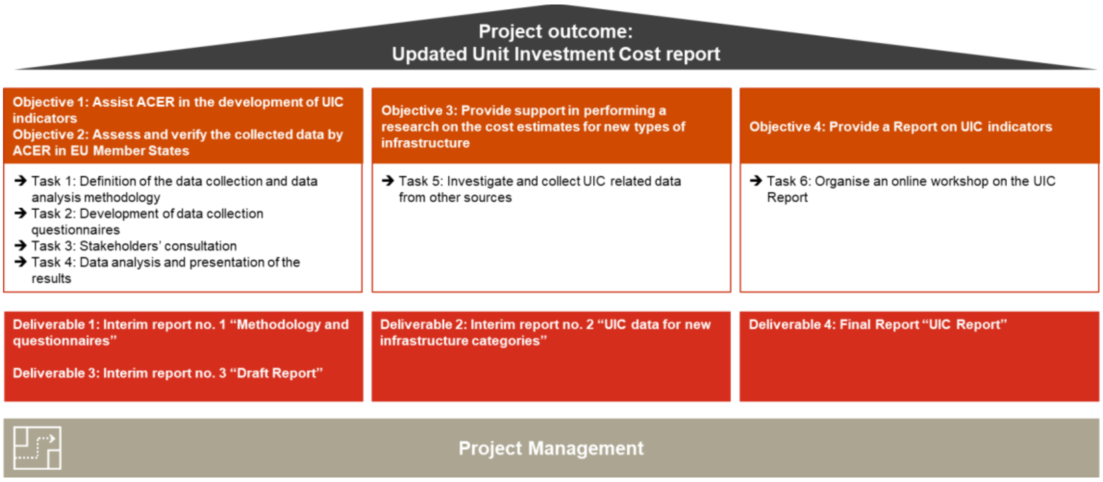
The EU Commission communication 'Powering a climate-neutral economy: An EU Strategy for Energy System Integration' acknowledges that the criteria for the integration of national electricity grids and various sectors into a comprehensive circular energy system needs to be simplified. The criteria need to include technological innovation, digital aspects and items enabling integrated energy infrastructure planning across energy carriers, infrastructures, and consumption sectors.

Renewable and low-carbon hydrogen as an energy carrier replacing hydrocarbons in areas where electrification is not yet a viable option is emphasised in 'A hydrogen strategy for a climate-neutral Europe'. The development of a Union-wide network will be enabled by repurposing or building new hydrogen transmission infrastructure and storage as well as fostering electrolyser facilities. The UIC Report 2023 provides UIC indicators on these assets based on the current availability of underlying data.

Where carbon dioxide emissions cannot be avoided, carbon dioxide should be captured in accordance with Directive 2010/75/EU for carbon dioxide streams originating from installations covered by that Directive, and for geological storage pursuant to Directive 009/31/EC. The UIC Report 2023 provides UIC indicators for these assets based on the current availability of underlying data.

3.3. Scope of the project

The project *Unit Investment Cost Indicators Project Support to ACER* aims to develop and propose UIC indicators requested in TEN-E regulation. The project is structured around four specific objectives, i.e.: (1) Assist ACER in the development of UIC indicators, (2) Assess and verify the collected data by ACER in EU Member States, (3) Provide support for research on the cost estimates for new types of infrastructure, and (4) Create a report on UIC indicators.



4. Methodology for UIC calculation

4.1. Overview of the process

Defining UIC indicators and reference value calculation consisted of the following steps:

- Definition of data to be collected,
- Consultation with stakeholders,
- Data collection,
- Data verification
- Data analysis and presentation of calculated results.

The 2015 UIC Report and the Regulation 2022/869 served as a foundation for the definition of the data to be collected. Infrastructure categories were divided into asset categories and cost breakdowns based on their specific features.

In the next stage, discussions with ACER, the NRAs, ENTSOs and other stakeholders resulted in the addition of suggested asset categories and data types, such as hydrogen blending facilities. Based on this, the definition of asset categories and collected data items were drafted. This was discussed and agreed at a later stage during the stakeholders' presentation, with the relevant stakeholders (TSOs and other project promoters). The final list of defined assets is presented in Section *4.2.1. Selected infrastructure and asset categories*.

Finally, the collected data was sorted into subcategories with regards to the cost-driver of the specific asset. The relations between a specific feature and total cost level of assets in the sample defined the convergence of cost for assets sharing the same technical feature, such as pipeline diameter or voltage level of an electric cable. The subcategories were treated for outliers and analysed to produce more specific UIC indicators. The results were first presented in an interim report and then by a presentation of the final results in the final report.

4.2. Data definitions

The definition of the data to be collected was the starting point of the data collection process. It consisted of defining two main aspects:

- Asset categories, i.e. the types of assets for which the data was be collected (electricity overhead lines, substations, other network assets, energy storage equipment, hydrogen and electrolysers related asset, smart equipment, etc.)
- Types of data to be collected, i.e. types of costs, their breakdown, time periods, asset-specific technical characteristics, etc.

The underlying data collected for the 2023 UIC Report are historic data for projects commissioned from 2014 to 2023 for electricity infrastructure projects and projects for blending renewable gases in natural gas infrastructure. The timeframe for smart gas grid equipment and projects related to hydrogen or carbon dioxide is not limited.

During the data definition consultations with relevant stakeholders were conducted as follows: national regulatory authorities (NRAs), European networks of transmission system operators for electricity (ENTSO-E) and gas (ENTSOG) and other relevant stakeholders (GIE, Hydrogen Europe). The stakeholders were asked to provide their feedback via a consultation on whether the required data and data granularity serves a purpose as regards UIC indicators calculation. Project promoters may encounter difficulties with the initial proposal of the data collection request, as the structure and granularity of the cost reporting may differ from the structure proposed in this exercise. Therefore, an authentication of the asset categories and data types by the relevant stakeholders was crucial for the success of subsequent data collection. The process is described in more detail in Section 2.2 Project timeframe.

4.2.1. Selected infrastructure and asset categories

Selected infrastructure and asset categories for which data was collected are listed in the following table. As technological innovation is developing rapidly, project promoters may invest in equipment assets that contribute to the functioning of a selected infrastructure type but are not strictly defined in the Regulation (EU) No. 2022/869.

Infrastructure category	Infrastructure subcategory	Asset category
Electricity	Transmission lines	• High-voltage (220 kV and more) and extra high-voltage (380 kV and more) overhead lines • Underground transmission lines • Submarine transmission cables • Offshore transmission cables (transmission cables transporting electricity from offshore renewable energy sources) • AC substations • Offshore AC and DC substations • HVDC converters
	Electricity storage facilities	• Electric batteries
	Smart equipment	• SSSC • DLR • STATCOM • Synchronous condensers
Infrastructure for gas / biomethane / hydrogen blending	Transmission network	• Pipelines • Compressor stations • International metering stations
	Storage	• Low-carbon gas storage in depleted fields or geological formations
	LNG projects	• LNG terminals
Smart gas grids	Equipment for the integration of renewable and low-carbon gases	• Renewable gas grids (connections to the grid) • Compression stations • Advanced metering equipment (chromatographs)
Hydrogen	Hydrogen transmission	• High-pressure hydrogen pipelines • Compressor stations
	Hydrogen processing facilities	• Reception facilities • Regasification facilities • Decompression facilities • Liquefaction facilities • Blending facilities • Pumping facilities
	Hydrogen storage	• Storage in depleted fields or other geological formations
	Other equipment	• Operational support equipment
Electrolyser facilities	Electrolysers	• Electrolysers of at least 50 MW capacity, complying to GHG emission savings requirements and with network-related function
	Other	• Operational support equipment
Carbon dioxide	Carbon dioxide pipelines	• Dedicated CO_2 pipelines • Compression stations

Infrastructure category	Infrastructure subcategory	Asset category
	Carbon dioxide facilities	• Liquefaction and buffer storage facilities
	Other	• Operational support equipment

4.2.2. Types of collected data

Collected information about assets can be divided into two major categories:

- **General**: this data is collected for all items
  - Asset/Project category – ascribes the item to broader infrastructure type
  - Investment year – defines a time horizon in which the project/asset was constructed, so the cost information can be adjusted for inflation
- **Specific**: this data is collected for each individual asset category and the level of details is based on technical specificities. Specific data includes categories and subcategories of cost breakdown. In some cases, specific technical features may be included, for example, the exact capacity of assets may offer the opportunity to sort the assets into groups based on collected data. This data category is further divided into:
  - Technical specifications
  - Cost breakdown for project management units (permitting, manufacturing, installation, etc.)
  - Cost breakdown for structural components

Disclaimer: The availability of data for the different types of infrastructure analysed in this report varies. Therefore, external sources (i.e. studies, reports and publicly available information) were reviewed and used to produce UIC indicators for new assets. A different timeframe for targeted projects and different level of granularity compared to the collected data was applied to an additional review of external sources. The table below provides details on the differences in collected information for analysed infrastructure types.

Infrastructure type	Timeframe	Source	TEN-E requirement for the UIC Report 2023
Electricity	2014-2023	Project promoters	✓
Infrastructure for gas / biomethane / hydrogen blending	2014-2023	Project promoters	✓
Smart gas grids	Any	Project promoters	✓
Hydrogen network	Any	Studies + Project promoters	✓
Electrolyser facilities	Any	Studies	X (required after 2025)
Carbon dioxide network	Any	Studies + Project promoters	X (required after 2025)

4.2.3. Specifications of data

Treatment of taxes

Data analysis project promoters were requested to confirm that the provided cost was **net of taxes** (direct or indirect), in order to eliminate the effects of taxation on the reported investment costs.

Treatment of inflation

In order to effectively compare the investment costs from different years, all nominal values of the investments were adjusted for inflation, with 2023 as the base year. PwC proposed a harmonized price index of consumer goods as an inflation factor. The NRAs were requested to confirm or propose their respective inflation rates in specific sectors (i.e. construction sector or manufacturing sector inflation) in the given country for every year between 2013 and 2022.

Since it was difficult to provide sector specific inflation rates and their source, general inflation rates published by Eurostat were proposed and provided for consultation to NRAs. Eurostat was considered the most reliable source for data for EU countries in a unified manner. Three options in the Eurostat database were considered in terms of price inflation: (1) general inflation in the form of HICP[3] (harmonized index of consumer prices), (2) construction producer prices or costs of new residential buildings, and (3) total producer prices in industry.

Several arguments supported using general inflation values. First, the values were the closest to the average of all three for all but two countries. Overall, they were in between the levels of price change in construction and industry.

Second, neither of the two specific price level categories matches the investment scope including purchase of material and asset parts, transportation, installation, and preparatory phases. Specific price developments would be more suitable to apply if information for cost breakdown structure was a mandatory requirement. The specific information was unlikely to be provided by the majority of project promoters. Determining specific inflation indicator for separate cost breakdown categories would require more substantial research. Therefore, the specific inflation rate would not be suitable for the entirety of an energy infrastructure project costs and the general inflation rate avoids a mismatch of applying inappropriate inflation type to a specific type of cost.

Last but not least, infrastructure types and various assets falling under the same category of infrastructure type in this study differ as regards the structure of financing, source of material, labour, etc. As neither of the two specific available inflation categories could be applied without limitations, it has been concluded that general inflation is a more suitable option.

Additionally, a GDP deflator was proposed by some NRAs as a more suitable reflection of inflation for energy infrastructure installation. However, GDP deflator values are not available for years prior to 2019. Thus, it was concluded that HICP will be applied, with the exception of Romania. The figures for specific years were fixed according to the recommendation of the Romanian NRA. A table with the final figures is included in Annex A.1 Appendix – Inflation rates.

Investment year

Project promoters were requested to provide the year of signature of the contract and the year of commissioning of the project for projects that were not implemented within one year, in order to determine the approx. year of the project investment for correct inflation adjustment. The calculation was done as follows: using the average of (1) the year a contract was signed, and (2) the year the project was commissioned (i.e. contract signed in 2015 and commissioning in 2017 will result in the reported investment year 2016). If the year of commissioning is the year following the contract signature year, the earlier year was considered the investment year for the inflation adjustment purposes.

Treatment of exchange rates

Project promoters were requested to submit cost data in millions of EUR. Cost data was submitted in local currency and converted to EUR using an appropriate currency exchange rate:

- Suggested approach: an average currency exchange rate of the local currency to EUR published by ECB as an average for an investment year
- Alternative approach: a specific currency exchange rate that the project promoter used to convert currency for the project[4]

To determine the year for the selection of the correct conversion rate, the project promoter was instructed to use the year in which the asset was commissioned. If the asset was constructed over several years, the year was to be determined as an average between the year of the start of the construction (contract signature) and year of commissioning (completion of the project).

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[3] Inflation figures are available, here: https://ec.europa.eu/eurostat/databrowser/view/prc_hicp_aind/default/table?lang=en

[4] No significant threat to accuracy is expected, as the indicators will be defined as a range, not an exact reference value.

4.3. Data collection process

In order to collect the data for the UIC indicators' calculation, PwC used various resources in cooperation with ACER. Primarily, ACER approached and requested project promoters of relevant infrastructure projects to submit costs and technical data for their commissioned projects. Project promoters were requested to submit the data to ACER's online tool (UNIC). Data collection took place from October until 1 February 2023.

Project promoters were requested to submit data (going back no more than 7 years for traditional gas and electricity assets) belonging to infrastructure types listed in section 4.2.1 Selected infrastructure and asset categories. The timeframe for smart gas grid equipment and projects related to hydrogen or carbon dioxide was not limited, as this is the first time these assets have been included in the UIC Report.

On behalf of consultations with the NRAs, we identified and addressed assets that were most likely to lack available data acquired via data collection. In contrast to the 2015 UIC Report, this report presents information and proposes UIC indicators for new infrastructure categories and assets. The source of this information may lead to a consideration of infrastructure projects implemented outside of the EU, as some of the selected technologies are not yet mature in most EU Member States.

4.4. Data treatment and analysis

This section defines a set of data samples that were analysed in order to produce UIC indicators. The set of assets presented in Section 4.2.1 Selected infrastructure and asset categories consists of two groups:

- Assets that are numerous and contribute to existing infrastructure networks
- Assets that belong to new infrastructure categories

This subchapter pertains to the first group where data is available, not to the new assets (hydrogen network assets, electrolysers, CO_2 network).

Thresholds

Project promoters were asked to submit data for relevant infrastructure assets commissioned in the period 2014-2023 for electricity infrastructure projects and projects for blending renewable gases in natural gas infrastructure. The timeframe for smart gas grid equipment and projects related to hydrogen or carbon dioxide was not limited. During the data treatment, the data that did not fit within the thresholds of the minimum size as defined below, were removed from the samples. This is to ensure the samples are representative of the infrastructure specified in the Regulation and small-scale projects do not distort the calculation. The minimum thresholds were applied as follows:

- Transportation pipelines / transmission lines: length of more than 5 km
- Associated equipment (protection, monitoring, and control systems, integrating ICT components, etc.): historic costs of more than EUR 20 thousand

The projects included in the sample were to be restricted to those already constructed and commissioned. Collected information about planned or infrastructure currently being implemented was analysed in the chapter on new infrastructure categories.

Treatment of outliers

Outliers were removed from the dataset before the calculation of the UIC indicators if they were above the upper or under the lower quartile values by a factor of 1.5 of the interquartile range, in line with the Tukey-Boxplot method. This step is particularly important for smaller data sets, where one or a couple of outliers can significantly distort the average UIC indicator for an asset.

Minimum number of data points

The minimum number of data points in a data sample after removal of thresholds and outliers is important to ensure the confidentiality of the data when calculating the UIC indicators. Therefore, at least **three** valid and complete data points (data entries) were collected and formed a group without outliers in order to calculate a UIC indicator for a specific asset (i.e. if less than the 3 data entries were collected for a certain category, the UIC indicator was not calculated or presented for that asset category).

Information collected included data for project identification, i.e. project name, code in various plans and lists of projects, the name of the project promoter, the year the project was put into operation, etc. The data provided by the promoters was anonymized using the ACER's UNIC tool (the names of the promoter, project name, code and other identifiers were removed) before the transfer of the data to PwC data analysis expert team. The UIC indicator for the infrastructure assets with the number of collected data points lower than 3 was not published on confidentiality grounds.

If the data sample was relatively small, only the statistics (median, average, standard deviation, etc.) which could be meaningfully derived were published.

Data verification

When reviewing the collected information, deficient data (e.g. investments for which the basic technical data - such as length, compressor power, etc. needed for the calculation of the indicators, and the reference values are not provided) were identified. To ensure the consistency of the information, additional clarifications were requested from 4 project promoters. As a result, the investment assets considered for the UIC indicators are less numerous than the collected raw data samples.

4.5. Calculation of UIC indicators

Following the initial analysis of the collected data distribution into technical subcategories (i.e. voltage level of electricity cables), subcategories were formed for the assets where data was abundant, and a distribution based upon a single parameter was possible. Once a data sample adhering to one subcategory was treated, cost data for assets falling in the same technical subcategory were used to calculate average mean, median values and quartiles defining scale in addition to the specific average value. Results were calculated based on the principles agreed with ACER, primarily considering the methodology for calculation in the 2015 UIC Reports.

A defining indicator unit has been proposed for each asset. In some cases, the specific unit or indicated range of a unit depends on the nature of the collected data, for example, line voltages in electricity assets or storage size for hydrogen and electricity.

No assets were submitted for the categories coloured grey in the following table.

Asset category	UIC indicator	Potential subcategories variable(s)	Infrastructure category
Overhead lines	EUR / km	Voltage level, Number of circuits	Electricity
Underground lines	EUR / km	Voltage level, Number of circuits	Electricity
Submarine cables	EUR / km		Electricity
Offshore transmission	EUR / km		Electricity
Onshore AC substation	EUR / asset	Number of bays, type, project status (new, upgrade, refurbishing)	Electricity
Offshore AC substation	EUR / asset		Electricity
Offshore DC substation	EUR / asset		Electricity

Asset category	UIC indicator	Potential subcategories variable(s)	Infrastructure category
HVDC converter	EUR / kV		Electricity
Electricity storage	EUR / h		Electricity
Smart grid equipment	EUR / asset		Electricity
Pipelines	EUR / km	Diameter	Infrastructure for gas / biomethane / hydrogen blending
Compression station	EUR / MW	Installed power	Infrastructure for gas / biomethane / hydrogen blending
International stations	EUR / asset		Infrastructure for gas / biomethane / hydrogen blending
Storage	EUR / Mm³		Infrastructure for gas / biomethane / hydrogen blending
LNG	EUR / Mm³		Infrastructure for gas / biomethane / hydrogen blending
Pipelines	EUR / km		Smart gas equipment
Compression station	EUR / MW		Smart gas grid equipment
Processing plant	EUR / asset		Smart gas grid equipment
Advanced equipment	EUR / asset		Smart gas grid equipment
Pipelines	EUR / km	Diameter	Hydrogen
Compression station	EUR / MW		Hydrogen
Storage	EUR / ton		Hydrogen
Processing facilities	EUR / asset		Hydrogen
Other equipment	EUR / asset		Hydrogen
Electrolyser facility	EUR / MW		Electrolyser facility
Other equipment	EUR / asset		Electrolyser facility
Pipelines	EUR / km		Carbon dioxide infrastructure
Processing facilities	EUR / asset		Carbon dioxide infrastructure

5. Data questionnaires

5.1. General structure and granularity of data questionnaire

The data questionnaire file contains a separate sheet for each infrastructure type. In the Excel sheet, each type is further divided into infrastructure and asset categories. In this chapter, the document provides a list of requested information for each asset category. Collected information about items is divided into two major categories:

- **General**: this data is collected for all items
    - Asset category – ascribes the item to a broader infrastructure category
    - Investment year – defines the time horizon in which the asset was constructed or when it was put into operation, so that the cost information can be correctly adjusted for inflation
- **Specific**: this data is dependent on and specific for each asset category and the level of detail for which information is accessible. This category of data is further divided into:
    - Technical specifications
    - Cost breakdown for project management units
    - Cost breakdown for structural technical components

The differences in the features of the collected datasets are outlined in the following table:

Infrastructure type	Year of commissioning
Electricity	2014 and later
Infrastructure for gas / biomethane / hydrogen blending	2014 and later
Smart gas grids	Any
Hydrogen network	Any
Electrolyser facilities	Any
Carbon dioxide network	Any

5.2. Electricity infrastructure

The network for transmission and distribution of electricity is being radically changed by the integration of renewable energy generation sources. Regulation 2022/869 specifies the types of equipment that upgrade the transmission system and facilitate integration of renewable energy generation sources into the grid. Building up a comprehensive network necessitates collecting information about the following equipment:

> *(a) high and extra-high voltage overhead transmission lines, crossing a border or within a Member State territory including the exclusive economic zone if they have been designed for a voltage of 220 kV or more, and underground and submarine transmission cables if they have been designed for a voltage of 150 kV or more. For Member States and small isolated systems with a lower voltage overall transmission system, these voltage thresholds are equal to the highest voltage level in their respective electricity systems;*
>
> *(b) any equipment or installation in the energy infrastructure category referred to in point (a) enabling transmission of offshore renewable electricity from offshore generation sites (energy infrastructure for offshore renewable electricity);*
>
> *(c) energy storage facilities, in individual or aggregated form, used for storing energy on a permanent or temporary basis in above-ground or underground infrastructure or geological sites if they are directly connected to high-voltage transmission lines and distribution lines designed for a voltage of 110 kV or more. For Member*

> *States and small isolated systems with a lower voltage overall transmission system, these voltage thresholds are equal to the highest voltage level in their respective electricity systems;*
>
> *(d) any equipment or installation essential for the systems referred to in points (a), (b) and (c) to operate safely, securely and efficiently, including protection, monitoring and control systems at all voltage levels and substations;*
>
> *(e) smart electricity grids: any equipment or installation, digital systems and components integrating information and communication technologies (ICT), via operational digital platforms, control systems and sensor technologies at transmission and medium and high voltage distribution level, aiming to ensure a more efficient and intelligent electricity transmission and distribution network, increased capacity to integrate new forms of generation, energy storage and consumption and facilitating new business models and market structures, including investments in islands and island systems to decrease energy isolation, to support innovative and other solutions involving at least two Member States with a significant positive impact on the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective, and to contribute significantly to the sustainability of the island energy system and that of the Union;*
>
> *(f) any equipment or installation in the energy infrastructure category referred to in point (a) having dual functionality: interconnection and offshore grid connection system from the offshore renewable generation sites to two or more Member States and third countries participating in projects on the Union list, including the onshore prolongation of this equipment up to the first substation in an onshore transmission system, and any offshore adjacent equipment or installation essential to operate safely, securely and efficiently, including protection, monitoring and control systems, and substations if they also ensure technology interoperability, inter alia, interface compatibility between various technologies (offshore grids for renewable energy);*

The data questionnaire on the electricity infrastructure is divided into two subcategories in line with Annex II of the Regulation – high-voltage and extra high-voltage transmission lines, and electricity storage. The granularity of the requested data in questionnaires regarding the transmission lines follows the manner used in the 2015 UIC report to the extent possible. The data granularity of the requested for the storage facilities is defined in a similar manner adjusted for the technical peculiarities of the asset category.

5.2.1. High-voltage and extra high-voltage transmission lines

The questionnaire on the high-voltage and extra high-voltage transmission lines is built on the asset sub-categories as defined in Annex II of the Regulation and the 2015 UIC Report questionnaire. The infrastructure subtypes include transmission lines (overhead, underground, submarine, transmission cables transporting electricity from offshore renewable energy sources), substations (AC, offshore AC, offshore DC), and HVDC converters.

5.2.2. Electricity storage facilities

Electricity storage facilities ensure sufficient flexibility of the energy system to stabilize fluctuations in demand and supply functions. Energy storage will play a key role in the transition to a carbon-neutral economy. The questionnaire on electricity storage facilities was not part of the 2015 UIC report.

The data request follows the manner and granularity of the questionnaire on the electricity transmission line.

5.3. Smart gas grids infrastructure

A "smart gas grid" is a gas transmission network that is flexible enough to integrate decentralized production and blending of low-carbon gases into natural gas network. EU Regulation 2022/869 seeks to facilitate integration of equipment that upgrades the gas transmission system to a smart gas grid by collecting information about the following equipment to support its integration:

> *"equipment or installation enabling and facilitating the integration of a plurality of low-carbon and particularly renewable gases, including* ***biomethane or hydrogen****, into the gas network:* ***digital systems and components integrating ICT*** *[Information and Communication Technologies],* ***control systems*** *and* ***sensor technologies*** *to enable the interactive and intelligent monitoring, metering, quality control and management of gas production, transmission, distribution, storage and consumption within a gas network. Such projects may also include* ***equipment to enable reverse flows*** *from the distribution to the transmission level, including*

> *the related **physical upgrades** if indispensable to the functioning of the equipment and installations **for integration of low-carbon and particularly renewable gases**"*

5.3.1. Infrastructure for gas / biomethane / hydrogen blending

The same infrastructure assets used for natural gas can be utilised for hydrogen and low-carbon gasses. Therefore, cost indicators for these assets are calculated to complement scarce data on existing hydrogen assets. The practical implementation document for developing the 10-year network development plan (TYNDP) 2022 defines the assets as follows:

- "A gas transmission pipeline, technically suited to transport safely, securely and efficiently increasing percentages of H2 (up to 100%)"
- "A new gas storage facility or an upgrade of an existing gas storage used for storing gas in underground reservoirs (depleted gas fields, salt caverns or aquifer) under pressure, technically suited to store safely, securely and efficiently increasing percentages of H2 (up to 100%)"
- "A new LNG/CNG terminal/facility or an upgrade of an existing terminal technically suited to transport safely, securely and efficiently increasing pre-defined percentages of liquefied H2 (up to 100%)"

5.4. Hydrogen infrastructure

As the ambitious goals of European transition initiatives envision the creation of a holistic functioning hydrogen transmission network, possibly replacing gas as regards some types of flexible infrastructure, the following assets are considered in the UIC analysis:

> - *"**pipelines** for the transport, primarily at high pressure, of hydrogen, including repurposed natural gas infrastructure, giving access to multiple network users on a transparent and non-discriminatory basis"*
> - *"**storage facilities** connected to high-pressure hydrogen pipelines"*
> - *"**reception, storage** and **regasification or decompression facilities** for **liquefied hydrogen** or hydrogen embedded in other chemical substances with the objective of injecting the hydrogen, where applicable, into the grid"*
> - *"any **equipment or installation** essential for the **hydrogen system to operate safely**, securely and efficiently or to **enable bidirectional capacity**, including compressor stations"*
> - *"any equipment or installation allowing for hydrogen or hydrogen-derived fuels use in the transport sector within the TEN-T core network identified in accordance with Chapter III of Regulation (EU) No 1315/2013 of the European Parliament and of the Council (1)"*

The assets listed may be newly constructed or **repurposed from natural gas to hydrogen**, or a combination of the two.

Hydrogen carriers were suggested by ENTSOs as assets that can be considered as "equipment or installation allowing for hydrogen […] fuels in the transport sector […]".

5.5. Electrolyser facilities infrastructure

An electrolyser facility is an indispensable part of every green hydrogen production site. Therefore, the technology is essential for the creation of a holistic hydrogen network in Europe. Electrolysers meeting the following criteria are to be considered, when collecting price information about existing facilities:

> - *"have at least 50 MW capacity, provided by a single electrolyser or by a set of electrolysers that form a single, coordinated project"*

- *“the production complies with the life cycle greenhouse gas emissions savings requirement of 70% relative to a fossil fuel comparator of 94 g CO_2eq/MJ as set out in Article 25(2) and Annex V to Directive (EU) 2018/2001*[5]*”*
- *“have a network-related function, particularly with a view to overall system flexibility and overall system efficiency of electricity and hydrogen networks”*

5.6. Carbon dioxide infrastructure

Captured carbon dioxide storage is an interim option to full transition from carbon-free technologies. Storage facilities are primarily in rock formations below the ground or reservoirs. The facilities generating carbon dioxide as a by-product are dispersed across the countries. A carbon dioxide network must be developed to connect facilities for capturing the carbon dioxide with storage. Therefore, the following categories of assets are considered in the analysis:

- *Dedicated pipelines, other than upstream pipeline network, used to transport carbon dioxide from more than one source, for permanent geological storage of carbon dioxide under Directive 2009/31/EC*
- *Fixed facilities for liquefaction, buffer storage and converters of carbon dioxide to facilitate transportation through pipelines and in dedicated modes of transport such as ship, barge, truck, and train*
- *Without prejudice to any prohibition of geological storage of carbon dioxide in a Member State, surface and injection facilities associated with infrastructure within a geological formation that is used, under Directive 2009/31/EC, for the permanent geological storage of carbon dioxide, where they do not involve the use of carbon dioxide for the enhanced recovery of hydrocarbons and are necessary to allow the cross-border transport and storage of carbon dioxide*
- *Any equipment or installation essential for the system in question to operate properly, securely, and efficiently, including protection, monitoring and control systems*

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[5] Life cycle greenhouse gas emissions savings are calculated using the methodology referred to in Article 28(5) of Directive (EU) 2018/2001 or using ISO 14067 or ISO 14064-1. Life cycle greenhouse gas emissions must include indirect emissions. Quantified life cycle greenhouse gas emission savings are verified in line with Article 30 of Directive (EU) 2018/2001 where applicable, or by an independent third party.

6. Data analysis

This chapter provides a summary of the data collected as part of the data collection process organised by ACER in the period from October 2022 to February 2023. It provides high-level statistics for the collected data and a closer look at the implementation of methodological steps, i.e. details of how the data was adjusted, screened, sorted, and analysed.

6.1. Summary of the data collection outcomes

6.1.1. Sample size by types of infrastructure and asset category

The data collected in the data collection process included historic data on completed assets, as provided by project promoters from Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Latvia, Lithuania, the Netherlands, Poland, Portugal, Slovakia, Slovenia and Spain.

Table 1. Number of collected electricity assets per Member State

	BE	BG	CZ	DK	DE	EE	GR	ES	FR	IT	LV	LT	NL	AT	PL	PT	SI	SK	FI
Overhead lines	0	5	1	2	5	2	2	60	16	6	3	6	3	4	4	12	1	4	9
Underground cables	1	0	0	26	1	0	1	26	14	6	0	2	3	0	0	1	0	0	0
Submarine cables	1	0	0	7	0	0	1	0	0	5	0	1	1	0	0	0	0	0	0
Offshore transmission cables	0	0	0	1	3	0	0	0	0	0	0	0	2	0	0	1	0	0	0
AC substations	0	0	1	16	6	5	1	76	22	15	1	4	3	4	3	9	1	6	9
Transformers	0	0	0	6	3	0	0	13	6	0	1	4	0	6	1	5	0	5	7
Offshore AC substations	1	0	0	1	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0
HVDC converters	1	0	0	2	3	0	0	0	0	2	0	2	1	0	0	0	0	0	0
SSSC	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synchronous condenser	0	0	0	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Electric batteries	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0

Table 2. Number of collected assets contributing to low-carbon gases infrastructure per member state

	DK	DE	EE	GR	FR	HU
Transmission pipelines	0	15	2	2	0	0
Compression stations	4	0	2	2	3	0
Advanced metering equipment	0	0	0	0	0	3

327 projects were submitted in total containing 510 assets. The sample sizes (number of submitted assets) vary across infrastructure categories and assets. The raw data sample describes the number of submitted assets before treatment, and analysed investment items are the final data sets considered for the calculation of UIC indicators (i.e. excluding outliers and assets below threshold defined in Section 4.4).

No indicator was produced for the categories coloured grey in the following table.

Asset category	Raw data sample	Investment assets (analysed)	Investment years period
Overhead lines	145	99	2012 - 2022
Underground lines	81	42	2012 - 2021
Submarine cables	16	15	2012 - 2020
Offshore transmission cables	7	7	2015 - 2020
Onshore AC substation	182	162	2012 - 2022
Transformers	57	37	2014 - 2021
Offshore AC substation	6	6	2016 - 2020
HVDC converter	11	7	2012 - 2020
Electricity storage	4	4	2026 - 2028*
Pipelines for LC gas blending	19	5	2016 - 2022
Compression stations for LC gas blending	4	4	2020 - 2021
Smart equipment - SSSC	15	15	2016 - 2020
Smart equipment – Synchronous condenser	5	5	2020 - 2021
Smart equipment - compression station	7	6	2011 - 2021
Metering stations	4	4	2020
Advanced metering equipment	3	3	2022 - 2023
Hydrogen pipeline	1	1	2017 - 2022

*Exception to the collection of historic data: estimates for future costs were provided by project promoters.

6.1.2. Validation and cleaning of data

Data cleaning was executed following the steps proposed in the methodology as described in Section 4.4 Data treatment and analysis. UIC indicators for asset categories which did not amount to a statistically sufficient number of submitted assets, were not calculated. The submitted cost data was adjusted for inflation to better reflect cost in 2023 and was then plotted into graphs showing the general UIC distribution with relation to various technical parameters of the asset. Based on the UIC distribution, potential outliers and assets groups of similar cost level and technical features were identified.

The thresholds (minimum length and commissioning period) were applied to an extent that did not reduce the quality of indicators by shrinking the data sets to small samples. The assets were then distributed into potential groups based on the dominant technical feature influencing the cost (a cost driver) based on the available technical asset characteristic. Whole data sets for an asset and all data groups were examined for outliers.

The number of potentially excluded data for proposed subcategories was compared with the number of excluded assets if outliers were identified before grouping into subcategories. It was concluded that outliers are to be identified and excluded within the respective groups instead of removing outliers at the level of the full data set. 9 assets were withheld and formed a group instead of being removed as outliers.

Finally, groups or asset data sets that did not consist of at least 3 assets were either merged into another group or not presented due to their incompatibility with other assets and low abundance of data. The possibility of a merger into another group was assessed based on the affinity of technical features between the two groups.

6.1.3. Identified data issues and deficiencies

If data sets did not create a meaningful indicator of cost, i.e. individual cost items varied widely, project promoters were requested to verify the submitted information.

For unclear or missing information on significant technical parameters, project promoters were requested to provide additional information. If the information on a substantial technical parameter was not provided, the asset was excluded from the analysis. One asset was excluded on such a basis.

6.2. Final data sets used for UIC calculation

Final data sets used for UIC indicators calculation are costs of individual assets placed in a subcategory based on technical requirements and which did not exceed the cost limit identified in the outlier treatment as defined Section 4.4 Data treatment and analysis. Final data sets are outlined in the second column of the table in Section 6.1.1 Sample size by types of infrastructure and asset category.

Data sets for subcategories of the second degree placed in the main subcategories of an asset were selected based on an additional common technical feature of group assets, such as the number of circuits installed in the scope of the project for electricity transmission lines or type of AC substations. They were also treated for outliers and formed final data sets for a subgroup.

6.3. UIC calculation process

UIC indicators were calculated as the average, median and first and third quartiles of submitted unit investment costs for individual projects included in the final data samples. The following formulas were applied for the calculation:

Formula for the calculation of mean UIC indicator:

$$\boldsymbol{Mean\ UIC\ indicator\ (EUR/MW) = \bar{x}(UIC\ of\ individual\ assets)}$$

Formula for the calculation of median UIC indicator:

$$\boldsymbol{Median\ UIC\ indicator\ Q2\ (million\ EUR) = {}^{1}/_{2}(n+1)th\ UIC}$$

- Where n is the number of the UIC in a sequence.

Formula for the calculation of the third quartile UIC indicator:

$$\boldsymbol{Quartile\ UIC\ indicator\ Q1\ (million\ EUR) = \frac{1}{4}(n+1)th\,UIC}$$

- Where n is the number of UIC in a sequence.

Formula for calculation of the third quartile UIC indicator:

$$\boldsymbol{Quartile\ UIC\ indicator\ Q3\ (million\ EUR) = \frac{3}{4}(n+1)th\,UIC}$$

- Where n is the number of UIC in a sequence.

7. UIC indicators calculation and results by category

The data collection process accumulated data sets that allowed for calculation of UIC indicators summarised in the following sections. The chapter is **divided into three main sections,** one for each of the energy infrastructure category, and within each of these sections, there are **subsections for individual assets / sub-categories**.

Each subsection for individual assets / sub-categories is further **divided into the following parts**:

1) **Definition of the asset** – briefly summarising the basis on which the asset / sub-category which was the subject of research was defined.
2) **Definition of the UIC indicator for the asset** – defining the formula and unit of the UIC indicator for the given asset / sub-category, e.g. asset cost per km of length of electricity cable.
3) **Data collection sample** – briefly summarising the outcomes of the data collection for the asset and presenting steps taken to adjust the data set where needed.
4) **Reservations** – summarising the identified limitations of the approach or deficiencies regarding the collected dataset.
5) **Results and conclusion** – summarising the result of the calculation and providing the indicative UIC indicator for the asset/sub-category.

The UIC indicators are the results of an analysis based on database collected by ACER. The database collected information about individual assets in various granularities. Asset subcategories consist of different samples as regards their numerosity. The origin of the project may strongly affect its cost.

7.1. Electricity infrastructure category

The electric infrastructure category was the most extensive in terms of submitted data inputs. The assets collected in this category were the following:

- Transmission lines: overhead, underground, submarine and offshore transmission lines
- AC substations: onshore and offshore
- DC substations
- HVDC converters
- SSSC – smart electricity grid equipment
- Synchronous condenser - smart electricity grid equipment

7.1.1. Overhead lines

7.1.1.1. Definition of the asset

The primary goal of the UIC indicator report was to collect data and produce an indicator for **high and extra-high voltage overhead transmission lines designed for a voltage of 220 kV or more**. The collected data was distributed into 6 subcategories. They are as follows: 110-150 kV (2 circuits), 220-225 kV (1 circuit), 220-225 kV (2 circuits), 330 kV (2 circuits), 380-400 kV (1 circuit) and 380-400 kV (2 circuits).

7.1.1.2. Definition of the UIC for the asset

The UIC indicator was calculated as total cost per kilometre of line from the analysed data sample. The analysed data sample is an outcome of the data treatment, where the collected data was adjusted for inflation and outliers were excluded. The data inputs that did not meet the threshold defined in Section 4.4 (minimum 5 km in length) were not taken into calculation. The remaining assets were distributed into subcategories and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.1.3. Data collection sample

Information was collected for 145 assets. 33 assets did not meet the technical threshold of overall length. Following the initial treatment, the sample was divided into subcategories based on the distribution of UICs with regards to respective voltage levels and number of circuits in individual assets. Each subcategory was then treated for statistical outliers, which were removed before the UIC indicator was calculated.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Overhead lines	145	112	110-150 kV (2): 4 → 3 220-225 kV (1): 7 → 7 220-225 kV (2): 23 → 21 330 kV (2): 6 → 5 380-400 kV (1): 18 → 18 380-400 kV (2): 48 → 45	99

Certain technical specifications were submitted for all assets, such as route length, voltage levels and conductor rating and conductor cross section, while the submission rate of other technical information was not sufficient to calculate a UIC for a more specific subcategory of assets.

7.1.1.4. Reservations

All outliers in the 400 kV 2 circuits subcategory were traced back to the same member state – the Netherlands.

The sample serving as a basis for the calculation of the 380-400 kV overhead line UIC indicator contains assets from different countries. The cost level in different countries varies widely, therefore, the general indicator must be approached with caution.

7.1.1.5. Results and conclusion

The collected data indicates the major impact of the voltage level on investment cost of the transmission line project.

Table 3. UIC indicators for overhead lines of various voltage levels; EUR/km

Asset subcategory (voltage level)	Mean	Interquartile range	Median	Number of assets	Period
110 - 150 kV 2 circuits	324 992	224 370 – 392 977	259 718	3	2014 - 2021
220 - 225 kV 1 circuit	411 887	303 301 - 542 906	362 180	7	2015-2021
220 - 225 kV 2 circuits	530 500	441 693 - 673 142	502 843	21	2014-2021
330 kV 2 circuits	573 600	521 860 - 572 702	530 413	5	2018-2021
380 - 400 kV 1 circuit	465 287	297 744 – 605 806	396 856	18	2012-2021
380 - 400 kV 2 circuits	1 260 970	533 200 – 1 634 892	1 050 044	45	2012-2022

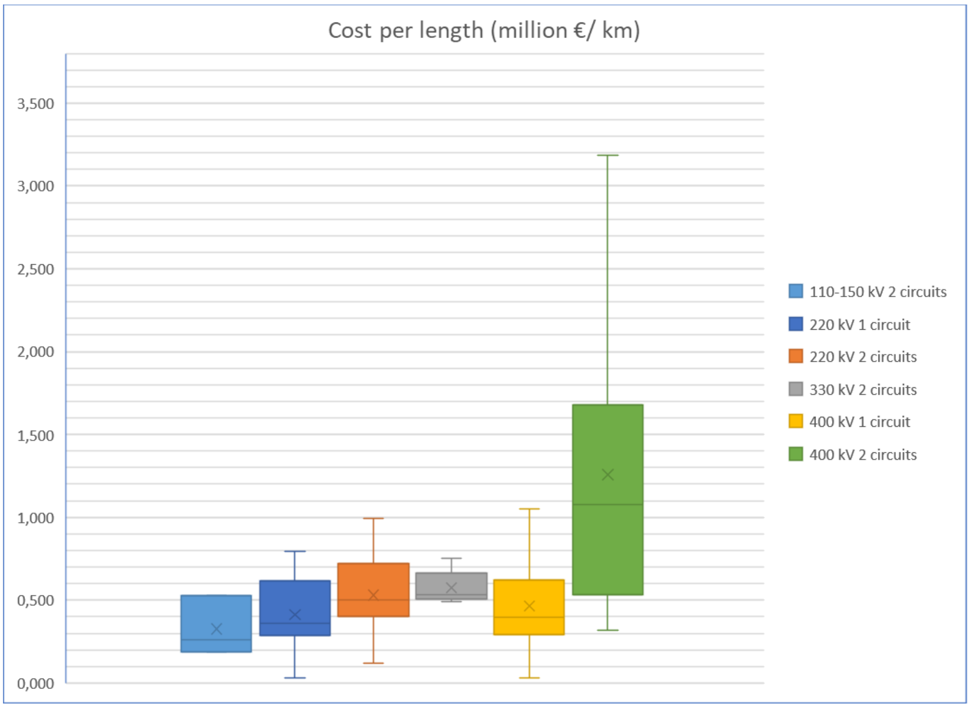

Figure 1. UIC indicators for overhead lines of various voltage levels; million EUR/km

Another significant cost driver is the number of installed circuits. For high-voltage 400kV cables, installing two circuits instead of one doubles the average cost.

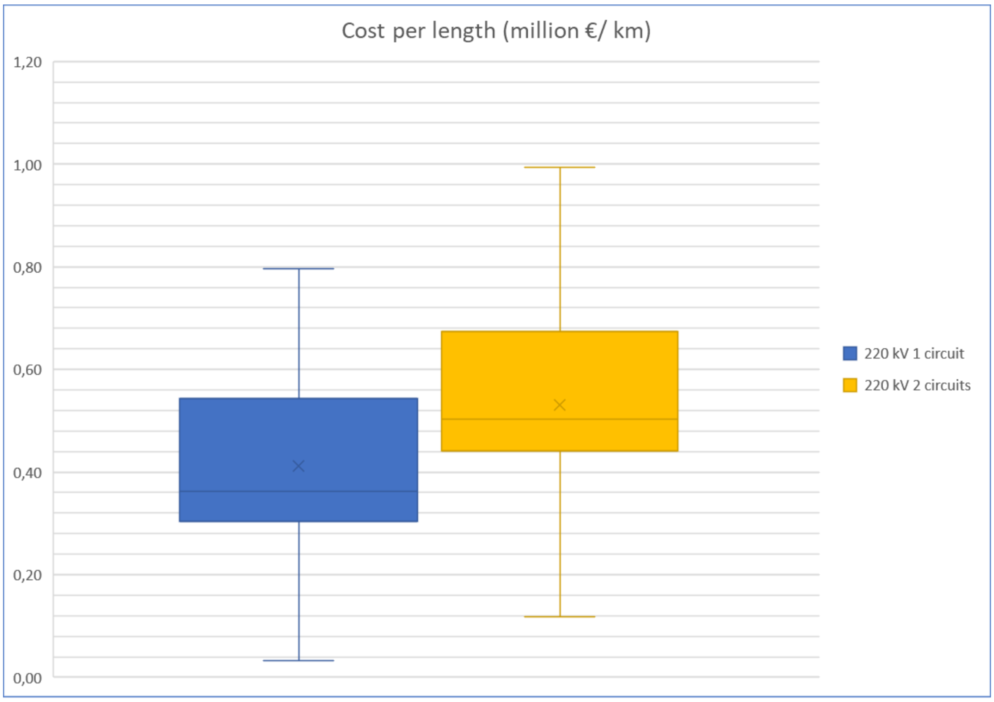

Figure 2. UIC indicators for overhead lines of 220 - 225 kV with 1 and 2 installed circuits; million EUR/km

Figure 3. UIC indicators for overhead lines of 380 - 400 kV with 1 and 2 installed circuits; million EUR/km

7.1.2. Underground cables

7.1.2.1. Definition of the asset

The primary goal of the UIC indicator report was to collect data and produce an indicator for **high and extra-high voltage underground transmission lines for a voltage of 150 kV or more**. The collected data was distributed into 5 subcategories: 110-150 kV (1 circuit), 110-150 kV (2 circuits), 220-225 kV (1 circuit), 220-225 kV (2 circuits) and 300-500 kV (1 circuit).

7.1.2.1. Definition of the UIC for the asset

The UIC was calculated as the total cost per kilometre of cable from analysed data sample. The analysed data sample is an outcome of the data treatment, where the collected data was adjusted for inflation and outliers were excluded. The items that did not meet the threshold of statistical significance (minimum 5 km in length). The remaining assets were distributed into subcategories and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.2.1. Data collection sample

Information was collected for 81 assets. 33 assets did not meet the technical thresholds of overall length or individually differed greatly from other collected data. The latter were considered and treated as outliers, as they were distinct as regards other technical specifics, but insufficient in number to form a separate group. Following the initial treatment, the sample was divided into subcategories based on the distribution of UICs with regards to respective voltage levels of individual assets. Each subcategory was then treated for statistical outliers, which were removed before the UIC indicator was calculated.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Underground cables	81	48	110 - 150 kV (1): 16 → 14 110 - 150 kV (2): 4 → 4 220 - 225 kV (1): 16 → 16 220 - 225 kV (2): 5 → 4 300 - 500 kV (1): 5 → 4	42

Certain technical specifications were submitted for all assets, such as route length, voltage levels and conductor rating and conductor cross section, while the submission rate of other technical specifications was not sufficient to draw a clear conclusion.

7.1.2.2. Reservations

Cable laying depth up to 30 meters below the ground did not have an impact on the investment cost based on the available data. However, this outcome may be a result of uneven numbers of assets across various depths or various origins of individual assets.

The UIC indicators for 2 circuit 110-150 kV and 220-225 kV lines were calculated from a sample of 4 assets. The small sample size may decrease the quality of the produced indicator and create a large indicator range.

7.1.2.3. Results and conclusion

The collected data demonstrates the major impact of the voltage level and the number of installed circuits on the investment cost of the transmission line project, which is shown in Table 4.

Table 4. UIC indicators for underground cables of various voltage levels; EUR/km

Asset subcategory (voltage level)	Mean	Interquartile range	Median	Number of assets	Period
110 - 150 kV 1 circuit	830 658	425 262 - 642 880	550 601	14	2015 - 2021
110 - 150 kV 2 circuits	2 232 070	846 865 - 3 064 750	1 679 545	4	2015 - 2020
220 - 225 kV 1 circuit	1 778 355	1 233 732 - 2 108 010	1 910 028	16	2014 - 2021
220 - 225 kV 2 circuits	4 401542	4 232 121 - 4 556 198	4 386 776	4	2016 - 2021
300 - 500 kV 1 circuit	1 308 952	1 045 741 - 1 394 246	1 131 035	4	2012 - 2020

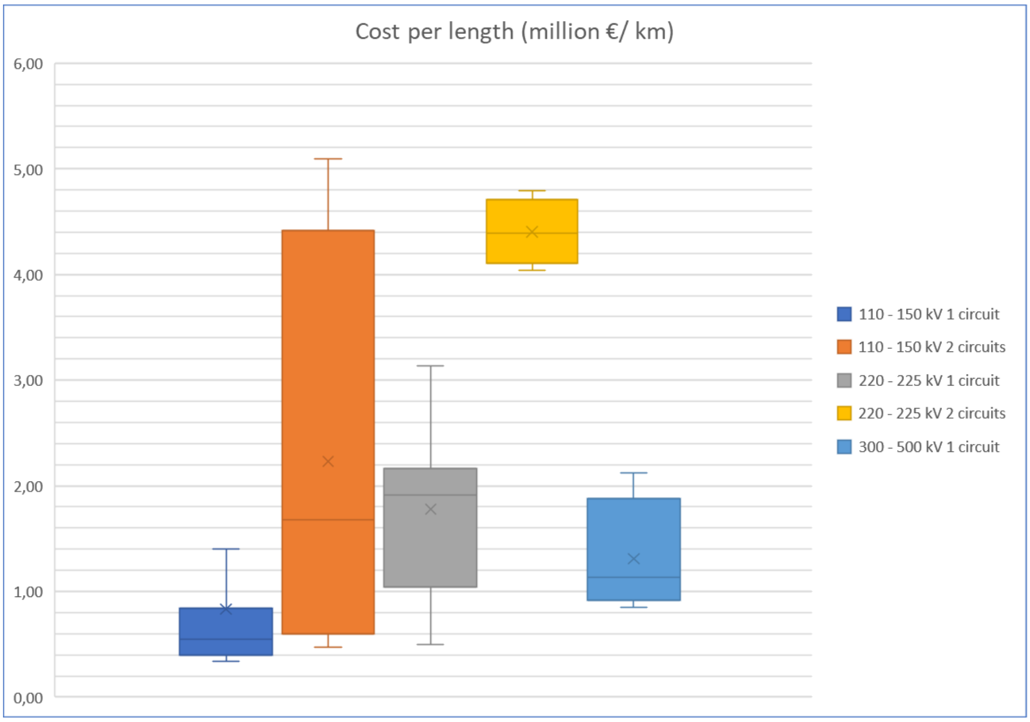

Figure 4. UIC indicators for underground lines of various voltage levels; million EUR/km

The subdivision of 110-150 kV and 220-225 kV voltage level subcategories into groups based on the installed number of circuits shows that the UIC increases substantially in relation to the number of installed circuits and, also the level of the total conductor rating of the cable.

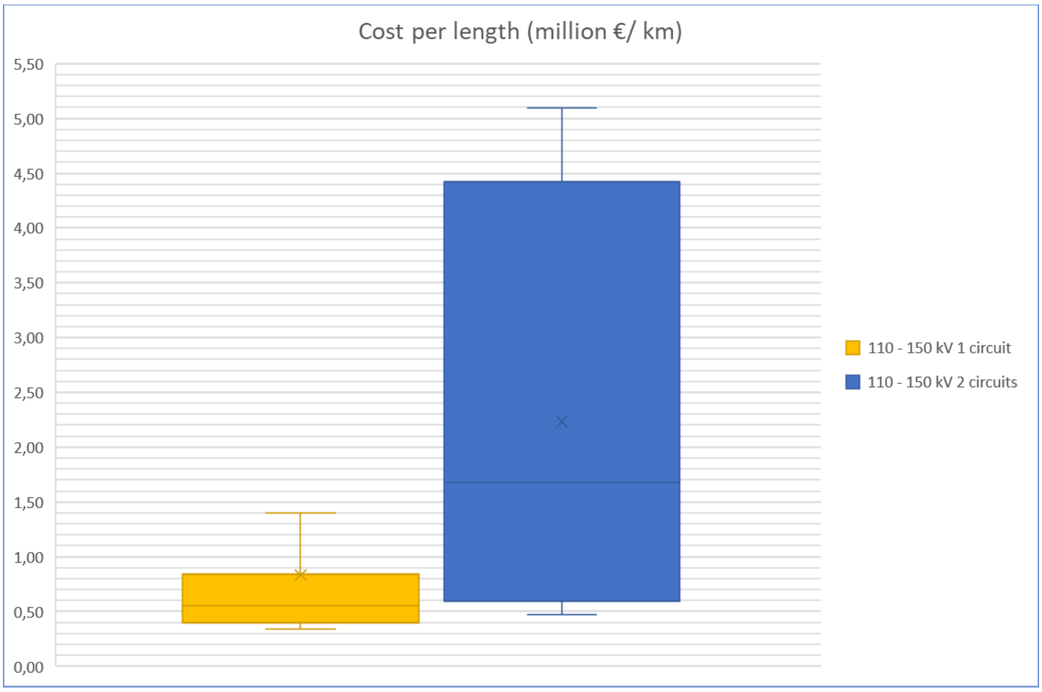

Figure 5. UIC indicators for underground cables of 110-150 kV voltage range with 1 and 2 installed circuits; million EUR/km

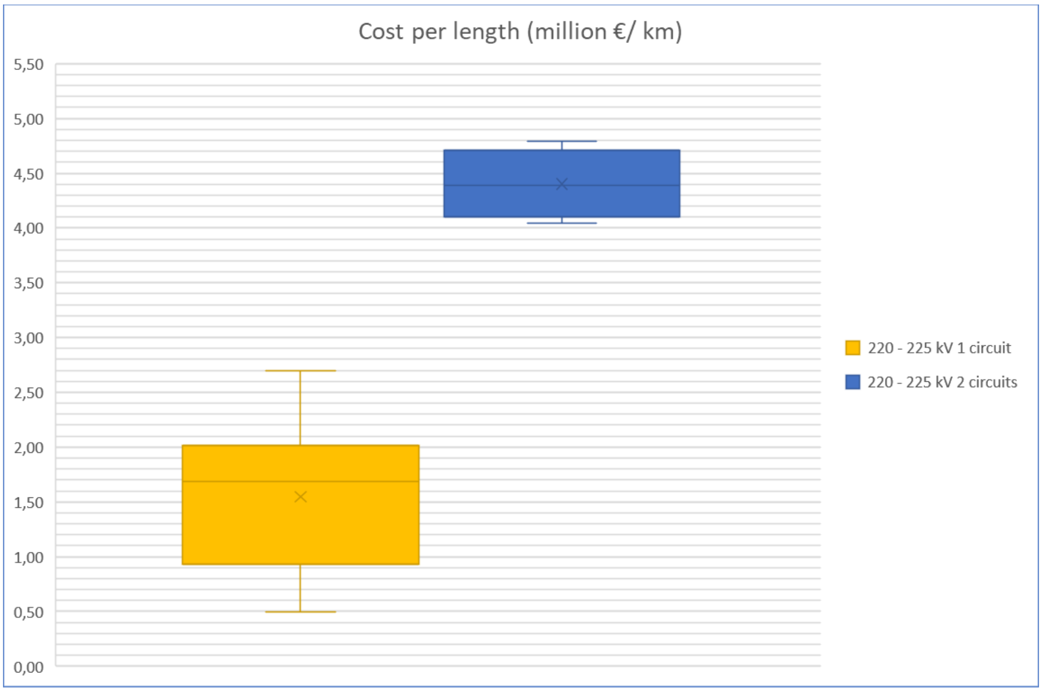

Figure 6. UIC indicators for underground cables of 220-225 kV voltage range with 1 and 2 installed circuits; million EUR/km

7.1.3. Submarine cables

7.1.3.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **submarine transmission cables if they are for a voltage of 150 kV or more**.

7.1.3.1. Definition of the UIC for the asset

The UIC was calculated as an average total cost per kilometre of cable from analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. The items that did not meet the threshold of statistical significance and the Regulation requirement were removed. The remaining data assets were distributed into batches and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.3.1. Data collection sample

Information was collected for 16 assets. 1 asset was identified as an outlier. The sample was not divided into subcategories as it was very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Submarine cables	16	16	16 → 15	15

7.1.3.2. Reservations

An asset with the investment year 2013 was included to improve the quality of the small size of the collected sample.

The differences in technical features present within the sample, were not catered to, due to the small size of the sample.

7.1.3.3. Results and conclusion

The results of UIC indicator calculation outline the impact of installing electric lines under water. The installation of submarine cables costs on average twice as much as the installation of overhead lines.

Table 5. UIC indicators for submarine cables of various voltage levels; EUR/km

AC/DC and voltage level	Mean	Interquartile range	Median	Number of assets	Period
All (132 - 500 kV)	1 647 297	912 100 - 2 477 987	1 263 091	15	2012-2020
AC (132 - 380 kV)	2 006 533	1 202 838 - 2 526 834	2 467 554	9	2015-2020
DC (300 - 500 kV)	1 108 442	903 376 - 1 257 822	1 085 783	6	2012-2019

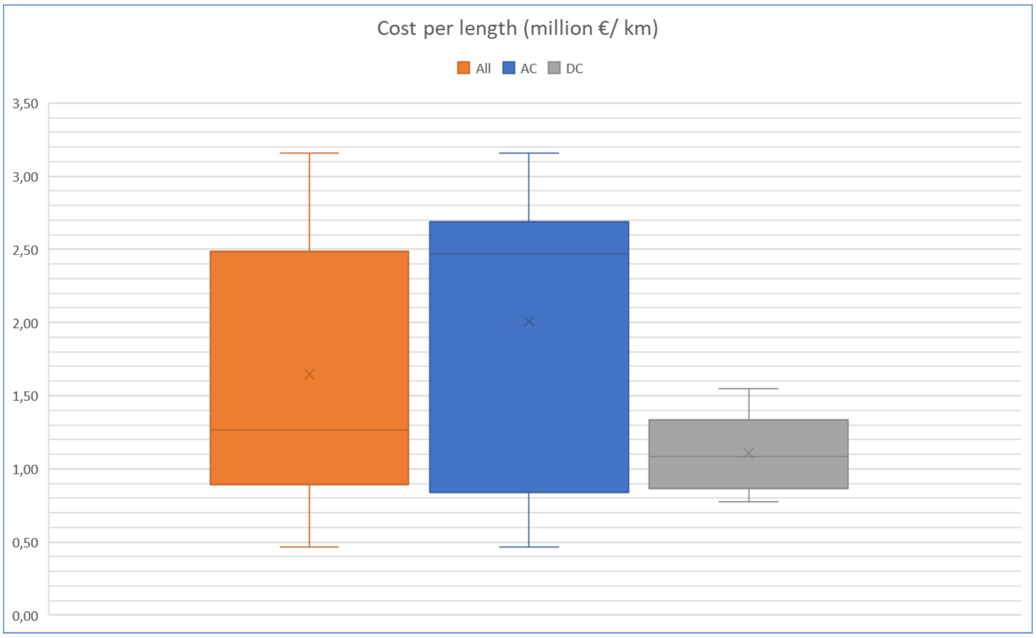

Figure 7. UIC indicators for submarine cables; million EUR/km

The cables located offshore were divided into submarine cables discussed in this section and offshore transmission cables discussed in Section 7.1.4. The cost levels in these asset categories varies. The abundance of technical specifications data and the variability of some technical specification between individual assets does not allow for reliable determination of the cause.

There is no distinction based on voltage level due to the small sample size.

7.1.4. Offshore transmission cables

7.1.4.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **cables for transmission of offshore renewable electricity from offshore generation sites**.

7.1.4.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per kilometre of cable from analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. The assets that did not meet the threshold of statistical significance and the Regulation requirement were removed. The remaining data assets were distributed into batches and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.4.3. Data collection sample

Information was collected for 7 assets. All assets met the technical thresholds - overall length and voltage level. The sample was not divided into subcategories, as it is very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Offshore transmission cables	7	7	7	7

7.1.4.4. Reservations

The differences in technical features present within the sample, were not catered to, due to the small size of the sample.

7.1.4.5. Results and conclusion

Lines connecting offshore electricity generation from renewable sources cost almost three times more than submarine cables, as shown in Table 5 and Table 6.

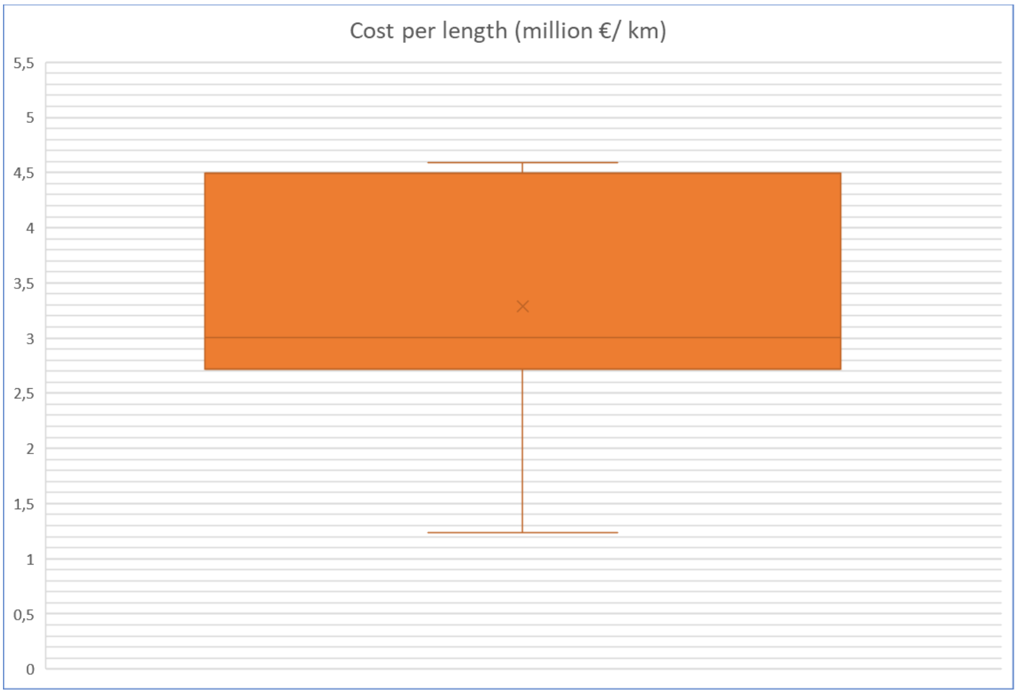

Figure 8. UIC indicators for offshore transmission cables; million EUR/km

Table 6. UIC indicators for offshore transmission cables of various voltage levels; EUR/km

Voltage level	Mean	Interquartile range	Median	Number of assets	Period
150 - 320 kV	3 289 318	2 761 303 – 4 338 720	3 002 706	7	2016 - 2020

7.1.5. Onshore AC substation

7.1.5.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **installations essential for the transmission lines and energy storage equipment to operate safely, securely and efficiently**. AC substations fall under this category.

7.1.5.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per asset from analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. Collected cost data was examined with regard to the technical features of individual assets. The assets were distributed into batches based on the number of bays and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.5.3. Data collection sample

Information was collected for 182 assets. The sample was divided into subcategories based on the distribution of investment cost with regards to the respective number of bays of individual assets. Each subcategory was then treated for statistical outliers, which were removed before the UIC indicator was calculated.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Onshore AC substation (UIC/station)	182	182	0-5 bays: 89 → 77 6-9 bays: 67 → 62 10-60 bays: 26 → 23	162
Onshore AC substation (UIC/kV)		129	New AIS: 51 → 48 New GIS: 32 → 26 Refurbished/Upgrade AIS: 35 → 33	107

Onshore AC substation (UIC/MVA)	48	New AIS: 20 → 19 New GIS: 9 → 8 Refurbished/Upgrade AIS: 17 → 16	43
Onshore AC substation (UIC/bay)	113	220 – 275 kV: 49 → 48 300 – 330 kV: 4 → 4 380 – 400 kV: 58 → 58	110

7.1.5.4. Reservations

> *UIC Report 2015 calculated the UIC indicator as a ratio of AC substation cost to its total substation voltage rating and busbar voltage level. This exercise provides multiple indicators based on different parameters of an AC substation allowing the reader to consider several determining cost-drivers when estimating asset cost.*

In contrast to the substation rating and busbar voltage level information, the number of transformers, number of bays, type of substation and project status (new/refurbishment/upgrade) were collected for a large number of assets. Therefore, subcategories were initially created based on these parameters.

A universal unit of the UIC indicator for AC substation is difficult to define due to the wide variety of parts, compositions, and sizes of individual AC substations. The diverse nature of the asset combined with incomplete data for individual collected assets led to the conclusion that the UIC indicator for this category should be expressed as a set of indicators in various units. The grouping of assets and calculation of these costs for projects sharing specific technical or management features produces a more specific cost indicator.

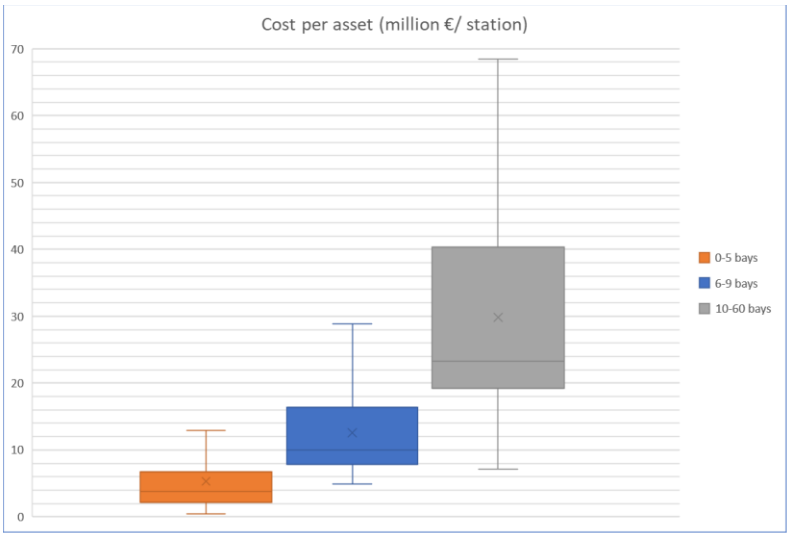

Figure 9. UIC indicators for AC substations; million EUR/asset

7.1.5.5. Results and conclusion

The collected data allows for the following conclusions with regards to the investment cost of an AC substation based on number of bays, project type (new/refurbishment/upgrade) and insulation.

Table 7. Cost indicators for AC substations; EUR/substation

Number of bays, project type and status*	Mean	Interquartile range	Median	Number of assets	Period
0 – 5 bays	5 306 824	2 195 367 – 6 697 045	3 841 483	**77**	**2012 - 2022**
AIS New	11 712 678	3 588 860 – 16 906 920	6 692 165	24	2014 - 2021
AIS Updated / Refurbished	3 401 125	2 116 075 – 4 300 494	2 789 344	28	2014 - 2021

Number of bays, project type and status*	Mean	Interquartile range	Median	Number of assets	Period
GIS New	13 618 810	5 401 601 - 15 986 439	9 401 507	9	2012 – 2022
GIS Updated / Refurbished	4 447 601	1 990 954 – 6 396 787	2 405 165	13	2014 - 2020
6 – 9 bays	12 586402	7 881 849 – 16 408 890	9 953 660	**62**	**2014 - 2021**
AIS New	12 141 284	8 179 079 - 16 680 967	9 943 449	24	2014 – 2021
AIS Updated / Refurbished	15 377 882	6 807 332 - 23 436 225	11 803 321	14	2013 – 2021
GIS New	9 820 774	7 815 435 – 11 529 678	9 553 581	21	2014 – 2021
10 – 60 bays	29 845 349	19 261 193 – 40 333 298	23 270 198	**23**	**2014 - 2021**
New	43 572 497	22 719 818 – 58 867 151	30 601 253	13	2014 - 2022
Updated / Refurbished	29 246 382	20 876 264 – 41 916 536	24 459 022	10	2016 – 2020

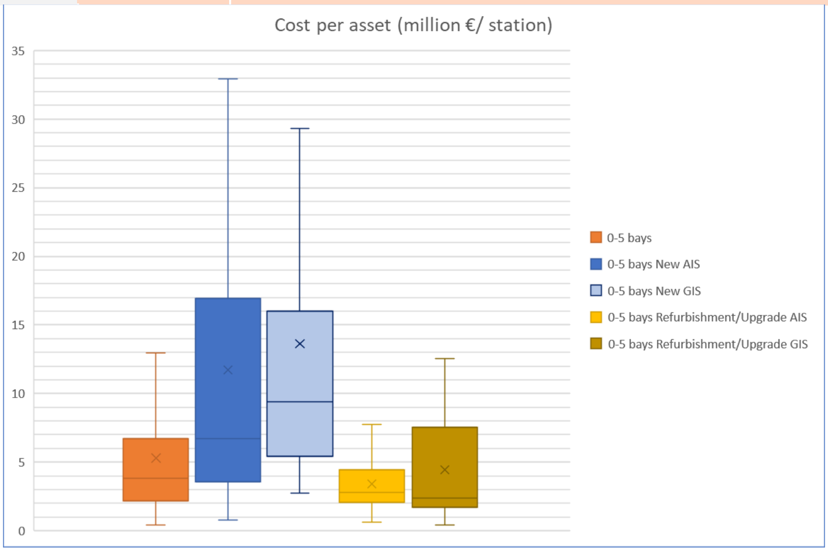

Figure 10. UIC indicators for AC substations with 0-5 bays of various types, new and upgraded/refurbished; million EUR/station

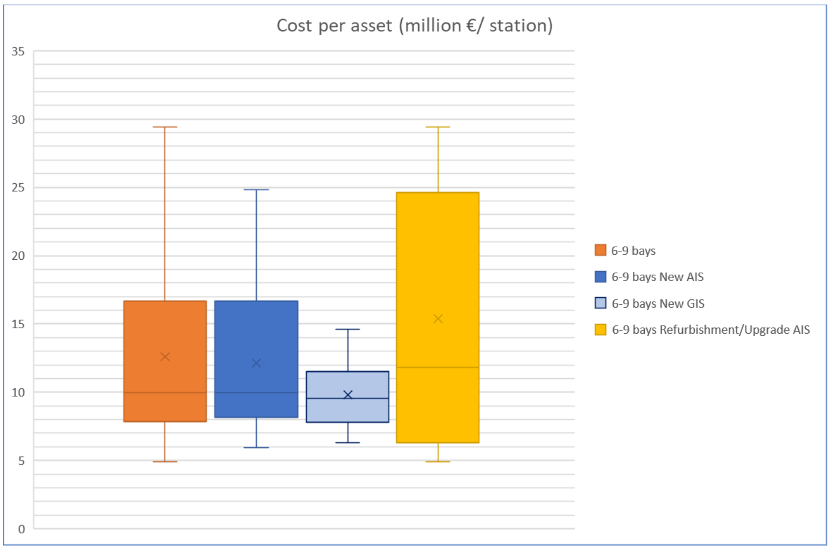

Figure 11. UIC indicators for AC substations with 6-9 bays per type, new and upgraded/refurbished; million EUR/station

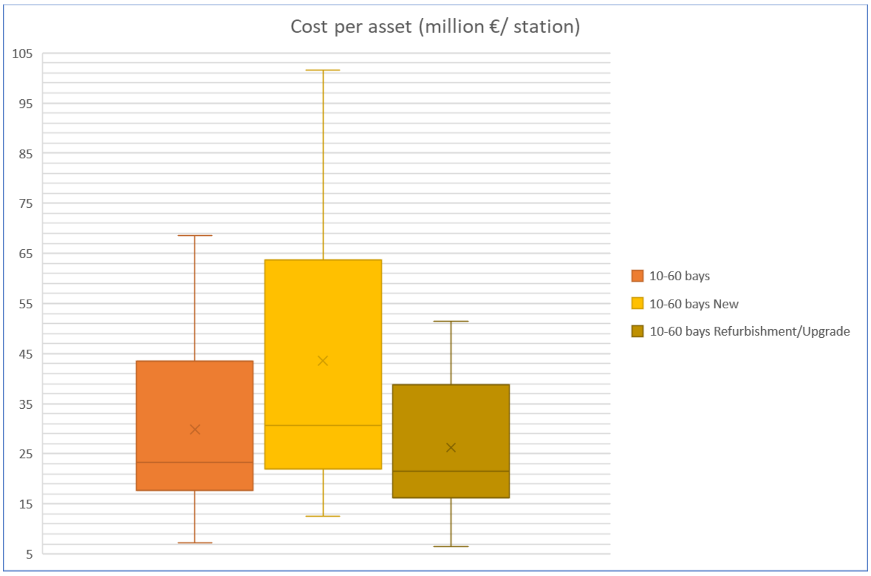

Figure 12. UIC indicators for AC substations with 10-60 bays, new and upgraded/refurbished; million EUR/station

The collected data allows for the following conclusions with regards to the unit investment cost of an AC substation based on voltage rating and busbar voltage level.

Table 8. UIC indicators for AC substations of various types; EUR/kV

Asset subcategory (voltage level)	Mean	Interquartile range	Median	Number of assets	Period
All	31 248	16 683 – 43 449	25 047	**118***	**2012 - 2022**
AIS New	31 720	18 519 – 43 615	23 969	48	2014 - 2021
AIS Updated / Refurbished	27 566	12 328 – 45 260	19 219	33	2014 - 2021
GIS New	35 105	27 676 – 42 305	33 743	26	2013 – 2021

*Numbers of assets are not sums of number of assets in subcategories, as there are assets that do not belong into any presented subcategory but are not numerous enough to create a separate subcategory.

Table 9. UIC indicators for AC substations of various types; EUR/MVA

Asset subcategory (voltage rating)	Mean	Interquartile range	Median	Number of assets	Period
All	68 823	37 576 – 93 130	64 701	**44***	**2014 - 2021**
AIS New	65 884	43 409 – 81 888	63 470	19	2014 – 2021
AIS Updated / Refurbished	50 828	23 459 – 70 733	37 054	16	2013 – 2021
GIS New	123 678	93 484 – 133 738	109 818	8	2013 – 2021

*Numbers of assets are not sums of number of assets in subcategories, as there are assets that do not belong into any presented subcategory but are not numerous enough to create a separate subcategory.

Table 10. UIC indicators for AC substations of various busbar voltage levels; EUR/bay

Asset subcategory (voltage rating)	Mean	Interquartile range	Median	Number of assets	Period
220 – 275 kV	1 206 055	837 306 - 1 516 905	1 133 288	48	2014 - 2021
300 – 330 kV	1 210 624	1 045 029 - 1 374 792	1 209 197	4	2017 - 2021
380 – 400 kV	3 382 029	1 152 582 - 5 238 417	2 435 831	58	2014 – 2022

7.1.6. Substation transformers

7.1.6.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **installations essential for the transmission lines and energy storage equipment to operate safely, securely and efficiently**. Transformers which are a part of AC substations fall under this category.

7.1.6.2. Definition of the UIC for the asset

The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. Collected cost data was examined for its relation to technical features of individual assets. The assets were distributed into batches based on the transformer rating and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.1.6.3. Data collection sample

Information was collected for 57 assets. The sample was divided into subcategories based on the transformer voltage level. Each subcategory was then treated for statistical outliers, which were removed before the UIC indicator was calculated.

Asset category	Raw data sample	Data sample with abundant information	Data sample after removal of outliers (by subcategories)	Final size of data sample
Transformer	57	41	150/60: 3 → 3 220/66: 13 → 12 330: 3 → 3 400/110: 15 → 15 400/220: 7 → 7	40

7.1.6.4. Reservations

Similar voltage level assets were merged into one subcategory to create a more reliable basis for UIC calculation. The subcategory 220/66 contains transformers labelled with the voltage levels 220/66 and 225/63. The subcategory 400/110 contains transformers labelled with the voltage levels 400/110 and 400/120/33. The subcategory 400/220 contains transformers labelled with the voltage levels 400/220 and 400/225.

7.1.6.5. Results and conclusion

The collected data allows for the following conclusions with regards to the investment cost of a transformer.

Table 11. UIC indicators for transformers; EUR/transformer

Asset subcategory (voltage level)	Mean	Interquartile range	Median	Number of assets	Period
150/60	1 212 256	1 097 683 – 1 269 543	1 097 683	3	2020
220/66	1 536 088	1 339 940 – 1 719 934	1 592 333	12	2015 - 2021
330	2 445 181	2 419 231 – 2 495 452	2 493 821	3	2019 - 2020
400/110	4 355 615	3 633 138 – 4 728 917	4 345 275	15	2014 - 2021
400/220	4 631 216	2 944 268 – 6 815 760	3 847 493	7	2014 - 2018

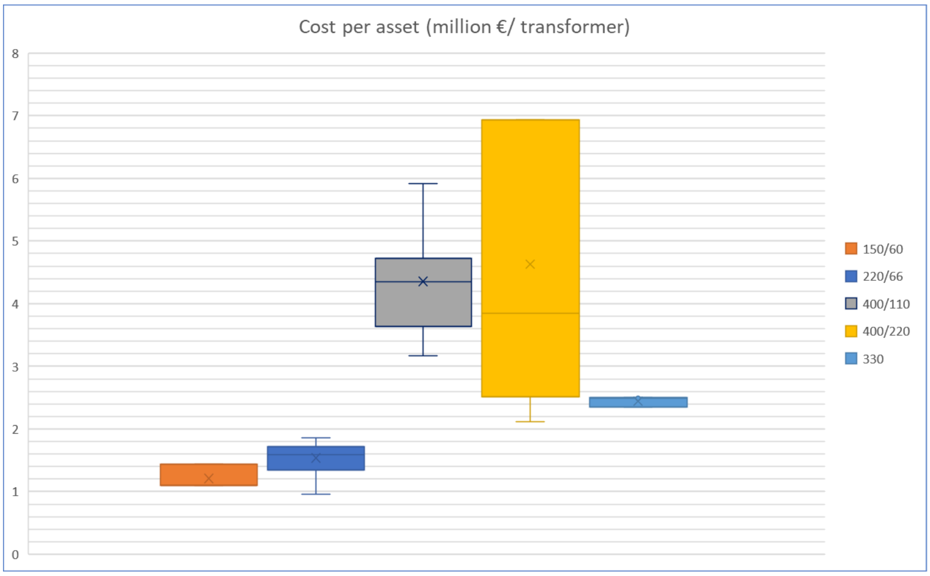

Figure 13. Comparison of UIC for transformers per voltage level; million EUR/transformer

The collected data allows for the following conclusions with regards to the unit investment cost of a transformer based on the transformer rating.

Table 12. UIC indicators for transformers; EUR/MVA

Asset subcategory (transformer rating)	Mean	Interquartile range	Median	Number of assets	Period
150/60	63 767	51 256 – 88 790	88 790	3	2020
220/66	97 686	82 656 – 108 702	100 262	12	2015 - 2021
330	23 413	20 309 – 26 127	22 636	3	2019 - 2020
400/110	76 830	57 388 – 92 827	79 991	15	2014 - 2021
400/220	28 182	22 749 – 34 460	29 653	7	2014 - 2018

7.1.7. Offshore AC substations

7.1.7.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **installations essential for the transmission lines and energy storage equipment to operate safely, securely and efficiently**. Offshore AC substations fall under this category.

7.1.7.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per asset from analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. Despite the technical specifics of individual assets, the sample was treated as one group.

7.1.7.3. Data collection sample

Information was collected for 6 assets. The sample was not divided into subcategories as it is very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Offshore AC substation	6	6	6	6

7.1.7.4. Reservations

The differences in technical features that are present within the sample, were not catered to, due to the small size of the sample.

A universal unit of the UIC indicator for AC substation is difficult to define due to the wide variety of parts, compositions and sizes of individual AC substations. The diverse nature of the asset combined with incomplete data for individual collected assets led to the conclusion that the UIC indicator for this category should be expressed as an indicator of the overall investment cost for an AC substation. The grouping of assets and the calculation of these costs for projects sharing specific technical or management features produces a more specific cost indicator.

7.1.7.5. Results and conclusion

The collected data allows for the following conclusions with regards to the investment cost of an AC substation.

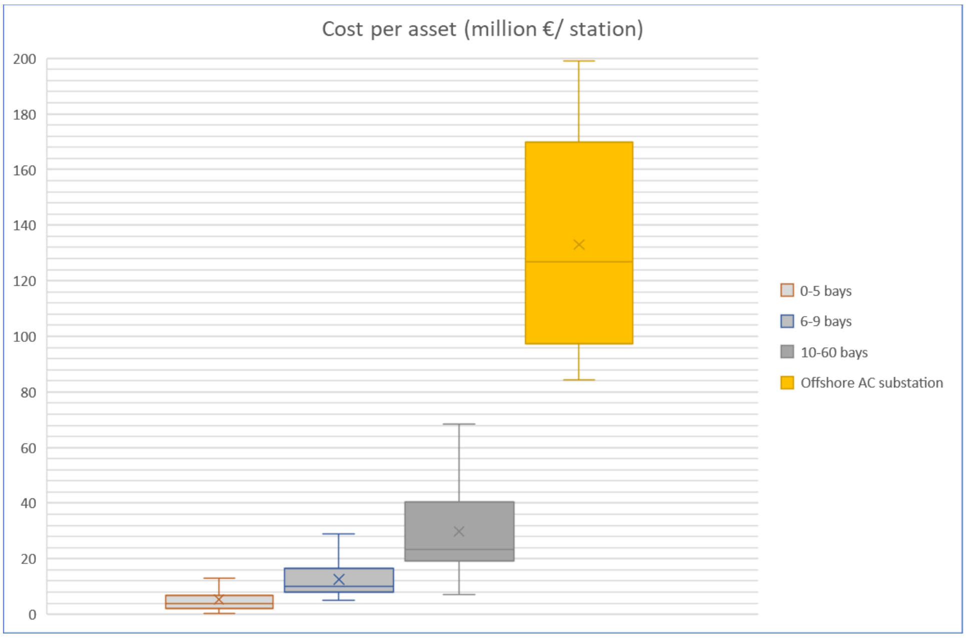

Figure 14. Comparison of UIC for offshore AC substations with UIC of onshore substations

Table 13. UIC indicators for offshore AC substations; EUR/substation

Asser category	Mean	Interquartile range	Median	Number of assets	Period
Offshore AC substation	133 069 592	104 727 891 – 154 825 154	126 730 605	6	2016 - 2020

7.1.8. Offshore DC substations

No information was collected for the asset categories falling under this infrastructure category.

7.1.9. HVDC converters

7.1.9.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **installations essential for the transmission lines and energy storage equipment to operate safely, securely and efficiently**. HVDC converters fall under this category.

7.1.9.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per kV of AC voltage level for the analysed data sample. The analysed data sample is an outcome of the data treatment, where the collected data was adjusted for inflation and outliers were excluded.

7.1.9.3. Data collection sample

Information was collected for 11 assets. The sample was not divided into subcategories as it is very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
HVDC converter	11	11	11 → 9	7

7.1.9.4. Reservations

The differences in technical features that are present within the sample were not catered to, due to the small size of the sample.

The sample of HVDC converters contained two assets that differed widely from the majority of assets in the sample by stored capacity. Therefore, the UIC of these assets also differed from the rest of the sample, which only includes converters with the storable capacity of no more than 6 000 kWh.

7.1.9.5. Results and conclusion

The following conclusions were drawn based on the collected data with regards to the investment cost of an HVDC converter.

Table 14. UIC indicators for HVDC converters; EUR/kWh

Asset category	Mean	Interquartile range	Median	Number of assets	Period
HVDC converter	150 331	127 193 - 192 723	147 380	7	2012 - 2020

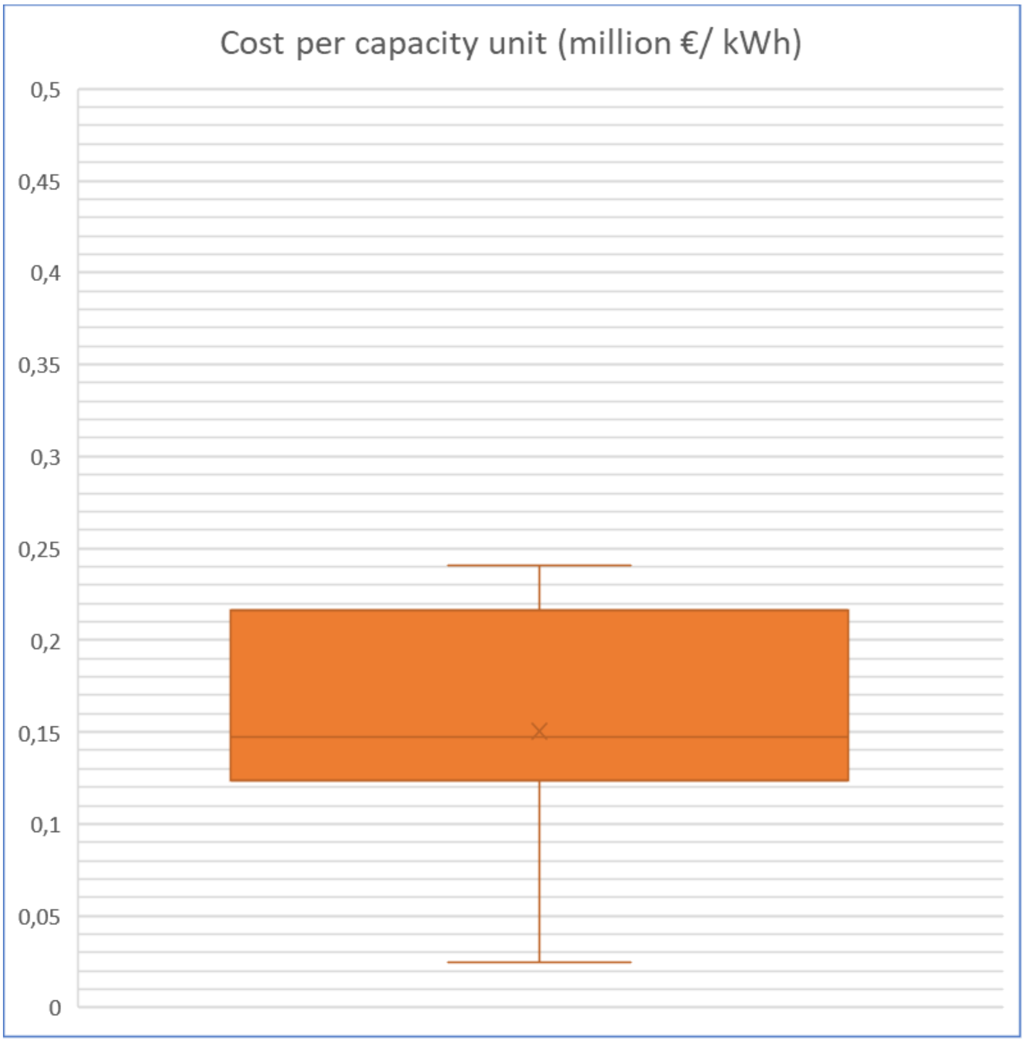

Figure 15. UIC indicators for HVDC converters; million EUR/ kWh

7.1.10. SSSC – smart electricity grid equipment

7.1.10.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **digital systems and components integrating information and communication technologies** (ICT), **aiming to ensure a more efficient and intelligent electricity transmission and distribution network.** Static Synchronous Series Compensators (SSSC) fall under this category.

7.1.10.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost of assets in the analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded.

7.1.10.3. Data collection sample

Information was collected for 15 assets. The sample was not divided into subcategories, as the sample is very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
SSSC	15	15	15	15

7.1.10.4. Reservations

A universal unit of the UIC indicator for SSSC equipment is difficult to define due to incomplete data for individual collected assets. The UIC indicator for this category is expressed as an indicator of investment cost per rated reactive power unit of the submitted asset.

7.1.10.5. Results and conclusion

The following conclusions were drawn based on the collected data with regards to the investment cost of a SSSC.

Table 15. UIC indicators for SSSC; EUR/MVA

Voltage batch	Mean	Interquartile range	Median	Number of assets	Period
SSSC	29 989	18 319 - 40 007	24 954	15	2015 - 2018

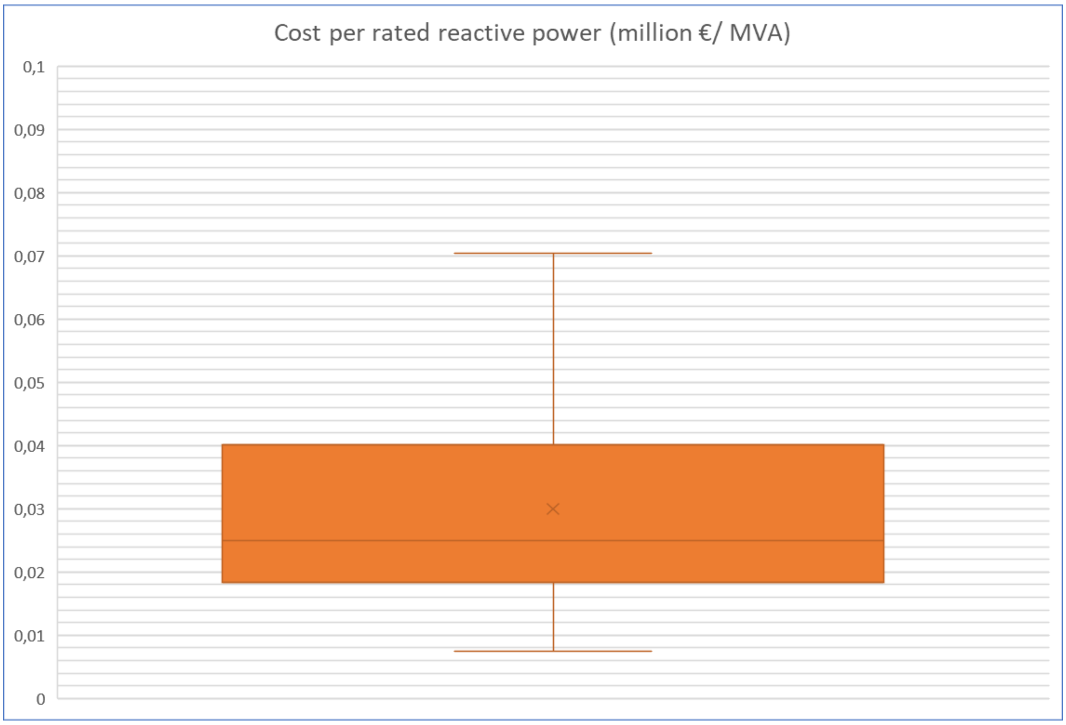

Figure 16. UIC indicators for SSSC equipment of smart electricity grid; million EUR/ MVA

7.1.11. Synchronous condenser – smart electricity grid equipment

7.1.11.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **digital systems and components integrating information and communication technologies** (ICT), **to ensure a more efficient and intelligent electricity transmission and distribution network.** Synchronous condensers fall under this category.

7.1.11.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost of assets in the analysed data sample. The analysed data sample is an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded.

7.1.11.3. Data collection sample

Information was collected for 5 assets. The sample was not divided into subcategories as the sample size is very small. Data for other smart electricity grid equipment was submitted. However, their abundance was not sufficient to be analysed and presented.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
SSSC	5	5	5	5

7.1.11.4. Reservations

A universal unit of the UIC indicator for synchronous condensers equipment is difficult to define due to incomplete data for individual collected assets. The UIC indicator for this category is expressed as an indicator of overall investment cost for the submitted asset.

7.1.11.5. Results and conclusion

The following conclusions were drawn based on the collected data with regards to the investment cost of a synchronous condenser.

Table 16. UIC indicators for synchronous condensers; EUR/asset

Asset category	Mean	Interquartile range	Median	Number of assets	Period
Synchronous condenser	46 598 500	36 462 537 – 51 040 792	50 682 030	5	2020 - 2021

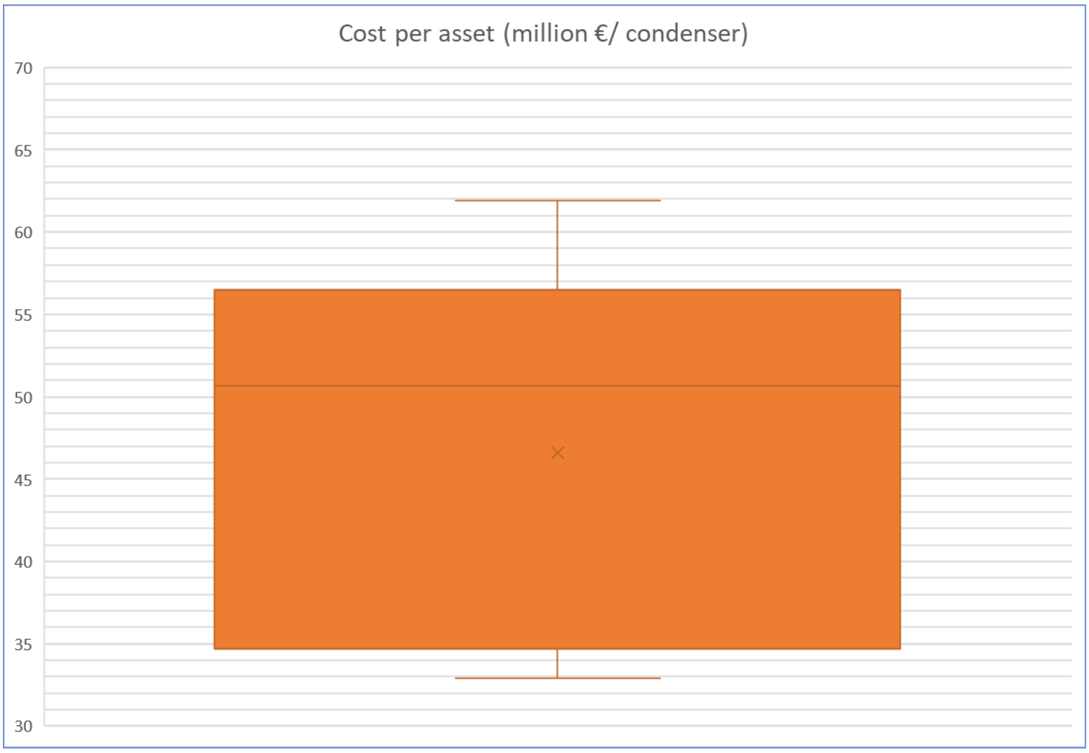

Figure 17. UIC indicators for synchronous condensers equipment of smart electricity grid; million EUR/ asset

7.2. Infrastructure for low-carbon gas blending and smart gas grid

Integration of low-carbon gases into natural gas infrastructure requires the adaptation of natural gas assets. This section presents the collected information and calculated UIC results related to the assets contributing to this infrastructure: compression stations and chromatographs.

7.2.1. Compression stations

7.2.1.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **installation to enable and facilitate the integration of a plurality of low-carbon and particularly renewable gases**, including biomethane or hydrogen, into the gas network. Compression stations fall under this category as they are an essential aspect of the transmission and distribution network.

7.2.1.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per MW of installed power from analysed data sample. The analysed data sample was an outcome of a data treatment, where the collected data was adjusted for inflation and outliers were excluded. Assets were distributed into batches and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.2.1.1. Data collection sample

Information was collected for 11 assets. The sample was not divided into subcategories, as the sample size is very small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Compression station	11	10	<1MW: 6 → 6 10-50 MW: 4 → 4	10

7.2.1.2. Reservations

The data submitted in categories for low-carbon gas blending and smart gas grid infrastructure were merged for the purposes of comparison. The assets that accommodate some rates of low-carbon gases were not submitted together with the specific information and, represent the equipment belonging to natural gas infrastructure and smart gas grid compression stations.

Insufficient data was received for all technical types (gas/electric) to produce a robust indicator for each individual type. Therefore, the indicator for compression stations with a capacity of 10-50 MW expresses approximate values for a compression station at large.

7.2.1.3. Results and conclusion

The following conclusions were drawn based on the collected data with regards to the investment cost of compression stations accommodating various rates of low-carbon gases:

Table 17. UIC indicators for compression stations of various capacities; EUR/MW

Capacity (Megawatts)	Mean	Interquartile range	Median	Number of assets	Period
< 1MW	14 511 488	10 868 266 - 18 270 710	16 045 933	6	2020 - 2022
10 – 50 MW	4 273 702	4 252 137 - 4 300 369	4 283 908	3	2020 - 2021

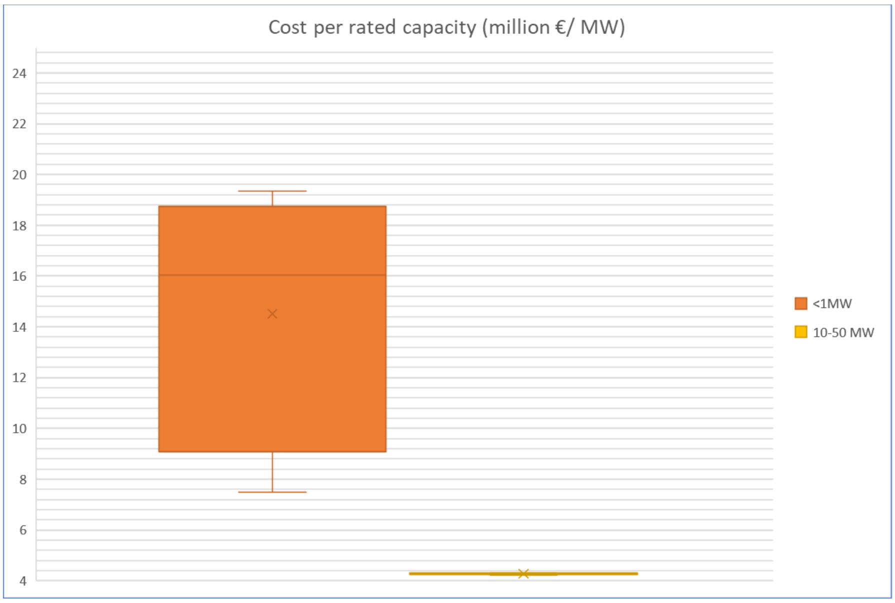

Figure 18. UIC indicators for compression stations of various capacities; million EUR/MW

7.2.2. Chromatograph - advanced metering equipment

7.2.2.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **equipment enabling and facilitating the integration of a plurality of low-carbon and particularly renewable gases**, such as technologies to enable the interactive and intelligent monitoring and metering. Chromatographs accommodating hydrogen fall under this category, as an essential aspect of transmission and distribution network.

7.2.2.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per submitted asset. Analysed data sample was an outcome of data treatment, where the collected data was adjusted for inflation and outliers were excluded. Assets were not distributed into subcategories and outliers were identified as specified in Section 4.4 Data treatment and analysis.

7.2.2.3. Data collection sample

Information was collected for 3 assets. The sample was not divided into subcategories as the sample size is small.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Advanced metering equipment	3	3	3	3

7.2.2.4. Reservations

A universal unit of the UIC indicator for advanced metering equipment is difficult to define due to limited data for individual collected assets and the small size of the sample. The UIC indicator for this category is expressed as an indicator of the overall investment cost for the submitted asset. All assets originate in the same Member State.

7.2.2.5. Results and conclusion

The collected data allows for the following conclusions with regards to the investment cost of advanced metering equipment:

Table 18. UIC indicators for advanced metering equipment contributing to the smart gas grid; EUR/asset

Asset category	Mean	Interquartile range	Median	Number of assets	Period
Metering equipment	125 647	113 543 – 136 598	123 341	3	2022

7.3. Hydrogen category

Hydrogen category included data inquiries for pipelines and related equipment, such as compression stations, and large-scale storage facilities. One asset was submitted in the pipeline asset category. To shed light on the cost of hydrogen transport infrastructure, the asset was combined with hydrogen-ready natural gas pipelines and UIC for this category was calculated.

7.3.1. Hydrogen-ready pipelines

7.3.1.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for **pipelines for the transport, of hydrogen, including repurposed natural gas infrastructure**. Data collection provided the opportunity to draw a picture of hydrogen transport investment cost.

7.3.1.2. Definition of the UIC for the asset

The UIC was calculated as an average total cost per kilometre of pipeline from analysed data sample. The analysed data sample is an outcome of the data treatment, where the collected data was adjusted for inflation and outliers were excluded. The items were treated for outliers as specified in Section 4.4 Data treatment and analysis.

7.3.1.1. Data collection sample

Information was collected for 5 assets capable to transport hydrogen without the need to mix it with another gas. The sample was not divided into subcategories, as the sample size is very small and consists of pipelines with the same diameter – 40 inch.

Asset category	Raw data sample	Data sample after threshold treatment	Data sample after removal of outliers (by subcategories)	Final size of data sample
Hydrogen-ready pipeline	5	5	5 → 5	5

7.3.1.2. Reservations

The number of assets collected in the asset category for hydrogen pipelines was 1 as per the table in Section 6.1.1. However, assets in the asset category for gas/ biomethane / hydrogen blending include multiple pipelines able to carry hydrogen at 100% rate. Therefore, it was concluded that the sample of hydrogen-ready pipelines (not designed specifically for hydrogen) will serve for the calculation of UIC indicator for hydrogen-ready pipelines.

7.3.1.3. Results and conclusion

Hydrogen-ready pipeline assets were combined with one hydrogen pipeline asset provided in the data collection and allowed for calculation of a UIC indicator for a transmission pipeline carrying hydrogen.

Table 19. UIC indicators for hydrogen-ready pipelines of 40-inch diameter; EUR/km

Asset category	Mean	Interquartile range	Median	Number of assets	Period
Hydrogen-ready pipeline	2 271 347	2 215 636 – 2 299 253	2 243 542	4	2017 – 2021

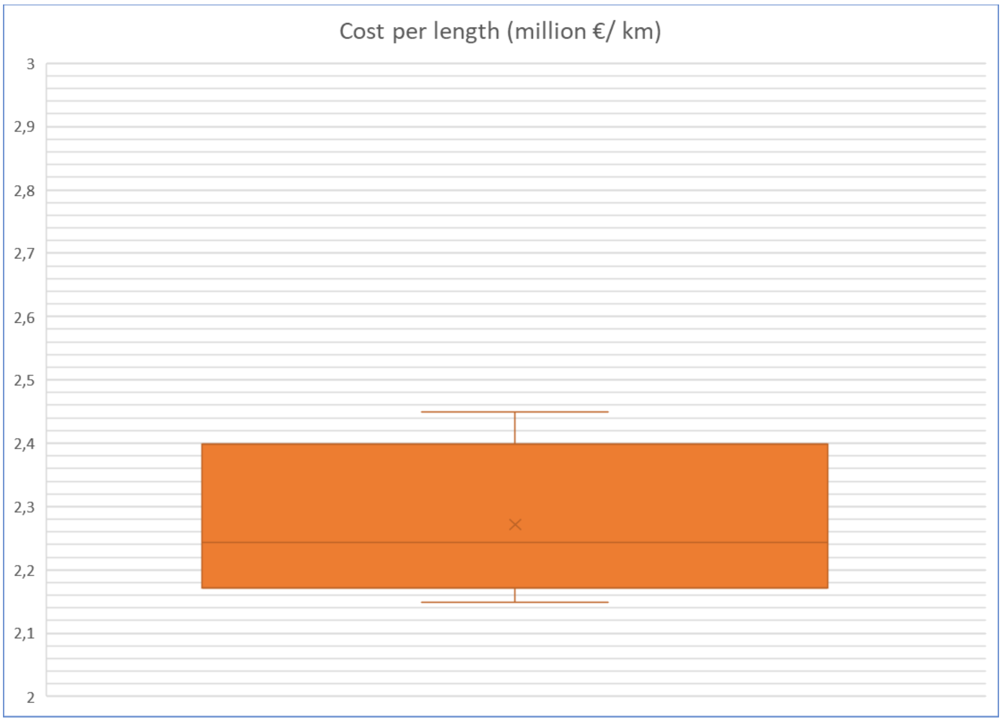

Figure 19. UIC indicator for pipelines carrying hydrogen of 40” diameter; million EUR/km

7.4. Electrolyser facilities category

No information was collected for the asset categories falling under this infrastructure category. The results of additional research into the topic are presented in Section 8.4 Large-scale electrolyser facilities.

7.5. Carbon dioxide category

No information was collected for the asset categories falling under this infrastructure category. The results of additional research into the topic are presented in Section 8.5 Carbon dioxide infrastructure.

8. UIC indicators for new infrastructure categories

8.1. Methodology

8.1.1. Scope of the research

The methodology utilized to produce UIC indicators for the new energy infrastructure categories was **research into available studies** and **publicly available data**, reaching beyond the data that was collected in the scope of ACER's data collection exercise for the purpose of the calculation of UICs for the UIC Report 2023, which was based on already commissioned projects.

Since **it was expected** that for the new energy infrastructure categories the data collected by ACER **will be very limited** (due to the limited number of implemented projects), the research serves **as an alternative source of information** for the calculation of indicative UICs for these new energy infrastructure categories.

The scope of the research **focuses on four infrastructure categories**, for which a limited data was collected from ACER's data collection process: (1) **Hydrogen infrastructure**, (2) **Electrolyser facilities**, (3) **Carbon dioxide infrastructure** and (4) **Smart gas grids infrastructure**. Each of these new energy infrastructure categories was further **divided into infrastructure assets** (or sub-categories), for which the research sought to collect the data from available studies (see the list of these assets/sub-categories below in Section *8.1.2 Definition of new energy infrastructure categories and* assets/sub-categories*)*.

The four main infrastructure categories can be divided into numerous sub-categories, for which, however, it **may be difficult** to collect sufficient cost data from publicly available studies, since different studies may vary in terms of the granularity of the information. Therefore, in order to define assets/sub-categories for each infrastructure category, it was agreed that **they must be significant** from the perspective of the size of the investment and from the perspective of **being critical** for the infrastructure network.

For example, for the purpose of hydrogen and carbon dioxide infrastructure, large high-capacity hydrogen and carbon dioxide storages were included as assets/sub-categories in the research, while small tank storages were not considered on the basis of low capacity and low investment value. **For electrolyser facilities**, only large electrolysers of capacities above 50 MW were considered, despite their long-standing existence and the operation of small electrolyser facilities. **As for smart gas grid**, metering appliances were considered, despite their lower individual investment costs due to their high impact on the network if rolled out widely.

8.1.2. Definition of new energy infrastructure categories and assets/sub-categories

As stated above, the four new energy infrastructure categories **were split** into assets/sub-categories, for which the research collected data and estimated the UICs.

The **TEN-E Regulation** foresees collection of cost data for hydrogen infrastructure and smart gas grid categories as part of the UIC Report 2023. As these infrastructure categories contain assets that are not yet widely operational in the EU, or not strictly defined as part of the infrastructure category, additional investigation of each category's current status was necessary.

In addition to the scope defined by the TEN-E Regulation for UIC Report 2023, **future UIC data collections** should also include **large electrolysers** (50+ MW) and **carbon dioxide infrastructure**, which currently exist worldwide, but their penetration or required specification (electrolyser facility capacity) is limited in the EU. Thus, no meaningful cost indicator can be calculated based on existing public information on implemented projects.

Therefore, all the above new energy infrastructure categories were included in the research. The following table summarizes the categories and the assets/sub-categories considered by this research:

Infrastructure category	Asset/sub-category
Electricity infrastructure	• Electric batteries
Hydrogen	• Hydrogen pipelines • Hydrogen compression stations • Hydrogen storage in depleted fields or other geological formations
Electrolyser facilities	• Electrolysers of at least 50 MW capacity, complying to GHG emission savings requirements
Carbon dioxide	• Dedicated CO_2 pipelines • CO_2 storage facilities

8.1.3. Research process and report structure

Following the definition of the scope of the research, the **search and collection of publicly available studies** was conducted (the sources used in the research are summarised in Section *A.2 Appendix – research sources*). The studies were then **analysed** to identify the current state of affairs in individual new energy infrastructure categories and to **identify indicator cost data** that can be used as inputs into the estimation of the UICs for individual defined assets/sub-categories.

The research and its results are summarised in the following sections. The document is **split into four main sections** for each of the new energy infrastructure category, and within each of these sections, there are **subsections for individual assets/sub-categories**.

Each subsection for individual assets/sub-categories is further **divided into the following parts**:

1) **Definition of the asset** – briefly summarising the asset/sub-category that is subject to the research.

2) **Definition of the UIC for the asset** – defining the UIC that the research attempts to calculate for the given asset/sub-category, for example, UIC per km of length of hydrogen pipeline, or UIC per MW of capacity of an electrolyser, including the proposed calculation formula.

3) **Summary of the research** – briefly summarising the current state of affairs, existing or potential projects, cost drivers, available data and similar. The summary includes also a review of the existing commissioned projects if reliable cost information about such projects commissioned since 2014 was available.

4) **Cost discussion** – summarising the identified cost data in various studies related to the asset/sub-category.

5) **Conclusion** – summarising the result of the research and providing the indicative UIC for the asset/sub-category, where the data allows for such estimation. The conclusions are reached if a quantified indicator can be provided resulting from the research. Due to the immaturity of the studied assets/sub-categories, or wide dispersion of the UICs (for example, across different countries), the UIC indicator could not always be provided. In those cases, a cost discussion was used to present estimates from various sources and their limitations or cost-driving factors for each individual asset.

8.1.4. Sources used in the research

Research papers, publications, studies, online articles and other sources of information served as a basis for estimating unit investment cost of new assets. A summary of these sources is attached in A.2A.2 Appendix – research sources .

8.2. Electricity infrastructure

This section reports on the new assets included in the data collection. The results of the data collection provide cost information estimates for installations projected for commissioning by 2026 and 2028.

8.2.1. Electric batteries

8.2.1.1. Definition of the asset

The assets submitted as electric batteries are **energy storage facilities**, in individual or aggregated form, used for storing energy on a permanent or temporary basis in above-ground or underground infrastructure or geological sites, provided they are **directly connected to high-voltage transmission lines and distribution lines designed for a voltage of 110 kV or more**.

8.2.1.2. Definition of the UIC indicator for the asset

The goal of the research was to **determine the UIC indicator per MW of installed power** for collected electric batteries:

$$\boldsymbol{Electric\ battery\ UIC\ indicator\ (EUR/MW)} \\ = \sum(\boldsymbol{Total\ cost\ of\ electric\ battery\ (EUR)})/(\boldsymbol{Total\ installed\ power\ (MW)})$$

8.2.1.3. Summary of the research

No additional research was performed.

8.2.1.4. Cost discussion

No additional research was performed.

8.2.1.5. Conclusion

The collected data allows for the following conclusions with regards to the estimated investment cost of electric batteries:

Table 20. UIC indicators for electric batteries per installed power; EUR/MW

Asset category	Mean	Interquartile range	Median	Number of assets	Period
Electric battery storage	696 545	645 719 – 756 706	705 970	4	2026 - 2028

8.3. Hydrogen infrastructure

This section of the report explores the **current state and cost of hydrogen infrastructure** in the EU and the world. It provides the details and results of UIC calculations if underlying information is publicly available.

A comprehensive network for **hydrogen transport** and **storage** includes transportation routes, i.e. **pipelines**, and large-scale **storage facilities** in geological formations or depleted fields, in addition to production of green hydrogen addressed in Section 8.4 Large-scale electrolyser facilities. **In Section 8.4**, a brief introduction is given on the overall importance of hydrogen as a **key future backbone** of the European energy system.

This section is divided **into two main sub-sections** for the following assets/sub-categories:

1) Hydrogen pipelines
2) Hydrogen compression stations
3) Hydrogen storage in depleted fields or geological formations

8.3.1. Hydrogen pipelines

8.3.1.1. Definition of the asset

A hydrogen pipeline is infrastructure used for the **transportation of hydrogen** via a pipe, similarly to the transport of natural gas via the gas transport network. It may connect an electrolyser or other hydrogen production facility with the final destination for its use, sometimes accumulating into a hub. Hydrogen flows through 4 500 km of pipelines globally[6], of which 2 570 km and 1 560 km are in the USA[7] and Europe[8] respectively.

8.3.1.2. Definition of the UIC indicator for the asset

The goal of the research was to **determine the UIC indicator per km of length** for various diameters of the pipeline as follows:

$$\mathit{Hydrogen\ pipeline\ UIC\ indicator}\ (EUR/km) = \frac{M * \sum \mathit{Total\ cost\ of\ low\ carbon\ gas\ pipelines}\ \ (EUR) + \sum \mathit{Total\ cost\ of\ H\_2\ \ pipelines}\ (EUR)}{\sum \mathit{Length\ of\ low\ carbon\ and\ H\_2\ \ pipelines}\ (km)}$$

- Where M is a coefficient equal to 1,1 as explained in the following section.

8.3.1.3. Research summary

Hydrogen pipelines are today predominantly **owned and operated by private industrial companies** that use hydrogen in industrial processes. The largest hydrogen hubs operators in Europe[9] - Air Liquide and Linde - **do not publish** information about the cost of individual projects. Projects vary from the perspective of major cost drivers, such as **diameter** of pipelines, used **material** and total **length** of the pipeline or scale of the project. Differences in installation and material expenditures **across various geographic areas** add another level of potential inaccuracy to a result produced by calculating the UIC indicator based on available information. Since information about a sufficient number of individual comparable projects **is not publicly available**, it was concluded that **common features between hydrogen and natural gas pipelines** would be used to estimate the UIC indicator for hydrogen based on the costs of natural gas pipelines network.

Several studies explored the **similarities and differences** between hydrogen and natural gas pipelines, stating a **coefficient that can be applied** to the costs of the natural gas pipelines to estimate the cost of hydrogen pipelines. The coefficient was chosen based on the overlap of two different sources: a *study by Transition Accelerators* and the *Technical Targets for Hydrogen Delivery* by the US Department of Energy.

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[6] Hydrogen Council, McKinsey & Company; Hydrogen Insights Report September 2022
[7] 1600 miles; DOE; Hydrogen Pipelines; viewed 22.12.2022; https://www.energy.gov/eere/fuelcells/hydrogen-pipelines
[8] Fuel Cells and Hydrogen Observatory; Hydrogen Pipelines map; viewed 26.01.2023 https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-pipelines
[9] Fuel Cells and Hydrogen Observatory; Hydrogen Pipelines map; viewed 26.01.2023 https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-pipelines

The latter used the **assumption of a 10% cost difference** between hydrogen and gas pipelines in its Hydrogen Delivery Scenario Analysis Model (HDSAM)[10], and a **multiplication factor of 1.1** is used in the study from Transition Accelerators[11] to adjust technical, material and labour cost of gas pipelines to calculate the cost of a hydrogen pipeline. The collected cost information on clean gas pipelines served as a basis for the calculation of UIC indicators provided in Section 8.3.1.5.

8.3.1.4. Cost discussion

The study by *Transition Accelerators* justifies the multiplicator **with the following reasons**:

> *"The increased costs are due to: (1) more stringent inspections of the welds, and (2) leak-free seals on the isolation and control valves. These cost correlations can be divided into four categories, i.e. material cost, labour cost, right of way cost and miscellaneous cost […] and assuming that H2 embrittlement will not be an issue in steel pipelines."*[12]

The *US Department of Energy* stated that it "determined [the value of multiplicator] by consultations with stakeholders and industry and analyses of industry data performed at ANL"[13]. **An alternative multiplier value** is proposed by the 2004 publication[14] from the Institute of Transportation Studies (University of California). The study suggests a factor of **1.5 for material** and **1.25 for labour costs**.

The ongoing debate about technical and regulatory feasibility may help further adjust the multiplicator. A study assessing technical requirements of hydrogen[15] focuses on the choice of material suitable for the nature of hydrogen gas, while another study suggests that, instead of technical issues, **regulatory adjustment in network standards** need to be considered[16] to lower the investment cost per unit.

8.3.1.5. Conclusion

The data collection did not provide the expected abundance of cost data for various diameters of pipelines, but it did provide information on assets that are ready to carry hydrogen without mixing with natural gas. Therefore, the UIC indicator for hydrogen-carrying pipelines was calculated based on data collected for pipelines for gas / biomethane / hydrogen blending and hydrogen pipeline. The results are presented in Section 7.3.1 Hydrogen-ready pipelines.

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[10] DOE; Technical Targets for Hydrogen Delivery; viewed 22.12.2022 https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-delivery

[11] Transition accelerators; TECHNICAL BRIEF Khan, M.A., Young, C. and Layzell, D.B. (2021). The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379

[12] Transition accelerators; TECHNICAL BRIEF Khan, M.A., Young, C. and Layzell, D.B. (2021). The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379

[13] DOE; Multiyear Research, Development, and Demonstration Plan – Delivery Section; 2015

[14] Parker, Nathan; Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs; Institute of Transportation Studies (University of California); 01.12.2004

[15] Histories - EU; Summary report on steels K55, L80 including H2S containing atmosphere and a quenched reference material; 2021

[16] Fekete, James; Sowards, Jeffrey; Amaro, Robert; Economic impact of applying high strength steels in hydrogen gas pipelines; International Journal of Hydrogen Energy - Volume 40, Issue 33; 2015

8.3.2. Hydrogen compression station

8.3.2.1. Definition of the asset

The goal of the UIC indicator report was to collect data and produce an indicator for the assets contributing to transportation of hydrogen. Hydrogen compression stations are essential for the transportation of large volumes of hydrogen. The main focus of estimating the cost of compression stations at the infrastructural level is on the power necessary to compress hydrogen.

8.3.2.2. Definition of the UIC for the asset

The main focus of estimating the cost of compression stations on the infrastructural level is on the power necessary to compress hydrogen. Therefore, the goal of the research was to **determine the UIC indicator per kW of rated power capacity** as follows:

$$\textit{Unit cost of compression station}\left(\frac{EUR}{kW}\right) = \textit{Unit cost of compressor}\left(\frac{C\$}{kW}\right) * \textit{Installation factor} * \textit{Indirect cost} * \textit{Exchange rate} * \textit{Inflation rate factor}$$

Where:

- Unit cost of compressor = 3 083,3 C$
- Installation factor = 2 (for the pipeline compressors)
- Indirect cost = 40% of direct cost of installation
- Exchange rate = 0,6733 (C$ to EUR; Average of 2019)
- Inflation rate factor (EU 27; 2022) = 1,0919

8.3.2.3. Research summary

The research started with a review of price offerings by compressor manufacturers. The Pure Energy Centre announced that the price of a hydrogen compressor ranged between EUR 46 500 – 140 000[17] (£40 000 - £120 000[18]) in 2021 depending on the size and power intake of the compressor. The cost of large compressors will be higher. A technical brief by Transition Accelerator[19] proposed a methodology of capital expenditure of hydrogen compressor based on cost assumptions from the Chemical Engineering Plant Cost Index (CEPCI)[20]. The results of the paper were used to calculate unit investment cost indicator according to the formula presented in Section 8.3.2.2.

8.3.2.4. Cost discussion

Research[21] in this area suggests that more compressors / more compression stages are necessary for hydrogen in order to achieve the same level of pressure when compared with natural gas, while the distance between individual stations, which translated into the density of installations, is the same or higher. However, a research paper by Zabrzeski et al.[22] presents the argument that a gas mixture containing a higher share of hydrogen is related to its level of compression to a longer distance/ or necessitates a lower number of recompressions for the same distance than natural gas alone. DeSantis et al.[23] present compression investment cost per mile of pipeline. The cost of compression stations in natural gas pipeline network is, according to their research, twice the cost of compression in a hydrogen pipeline network due to the lower number of recompression stations required.

8.3.2.5. Conclusion

The formula proposed by Transition Accelerators and adjusted for EUR currency and inflation represents the basis for the following indicator of unit investment cost for pipeline compression stations: **EUR 6 346.97 / kW.**

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[17] ECB exchange rate GBP to EUR 2021 average: 1:1,1636

[18] Pure Energy Centre; Hydrogen Products Pure Energy Centre – Hydrogen Compressor; 2021 https://pureenergycentre.com/hydrogen-products-pure-energy-centre/hydrogen-compressor/

[19] Khan, M.A., Young, C., and MacKinnon, C. and Layzell, D. (2021). The Techno-Economics of Hydrogen Compression. Transition Accelerator Technical Briefs Vol. 1, Issue 1, Pg. 1-36. ISSN 2564-1379

[20] Chemengonline; The Chemical Engineering Plant Cost Index; viewed 14.03.2023 https://www.chemengonline.com/pci-home

[21] ANL; Overview of Interstate Hydrogen Pipeline Systems; Environmental Science Division; November 2007

[22] Ł Zabrzeski et al; Hydrogen-Natural Gas mixture compression for transporting via high-pressure gas pipelines 2019 IOP Conf. Ser.: Earth Environ. Sci. 214 012137

[23] Daniel DeSantis, Brian D. James, Cassidy Houchins, Genevieve Saur, Maxim Lyubovsky; Cost of long-distance energy transmission by different carriers; iScience; Volume 24, Issue 12, 2021, 103495, ISSN 2589-0042,

However, this uniform indicator does not reflect compression ratio requirements, pipeline diameter, technical type of the compressor and other factors that determine final investment cost of a compression station.

8.3.3. Hydrogen storage in depleted fields or geological formations

8.3.3.1. Definition of the asset

Hydrogen storage is an infrastructure where **large volumes of hydrogen can be stored** for a certain period of time to balance the demand and supply of hydrogen. Storing hydrogen is **similar to storing natural gas**. Small volumes of hydrogen can be stored in storage tanks if cooled, pressurized, and kept at a specific pressure and temperature.

On the other hand, **geological formations**, such as aquifers, salt caverns or depleted fields can be used to **store large volumes of hydrogen**. Examples of underground storage of hydrogen alone **are rare**, while storing hydrogen in a combination with other gases is more common as per the review of *Underground hydrogen storage options* by Gaffney Cline[24]. The initial goal of the research was to determine the investment cost indicator per unit of mass of the stored hydrogen.

8.3.3.2. Definition of the UIC for the asset

The goal of the research was to **determine the UIC indicator per kg of the overall mass of stored hydrogen** for various storage types as follows:

$$Hydrogen\ storage\ UIC\ \left(\frac{EUR}{kg}\right) = \frac{Total\ cost\ (EUR)}{Mass\ of\ stored\ H_2(kg)}$$

$$= \frac{Total\ cost\ (EUR)}{Volume\ \ (m^3) * Density(\frac{kg}{m^3})}$$

8.3.3.3. Research summary

The research started with an **overview of the existing hydrogen storage facilities**. It led to the **Hybrit** pilot which is being developed in Sweden. It is estimated Hybrit will cost **EUR 23 million**[25] and will provide 100 to 120 thousand cubic meter of storage in a rock cavern[26]. Available space under the projected pressure of 250 bars can accommodate between 1.78 and 2.15 tonnes of H2 (if kept at 20°C)[27]. Published information together with the assumptions permitted the calculation of an **estimated UIC** according to the following formula:

$$UIC\ (EUR/kg) = \frac{Total\ cost\ (EUR)}{Volume\ (m^3) * Density\ [250bar, 20°C]}$$

Following the review of existing projects, the research continued by **screening available publications** from recent years comparing the existing projects and their costs. The study by *Gaffney Cline* points to the limitation of a general cost indicator due to the **variability of unit cost** depending on overall size and other conditions of the site. Multiple assumptions in studies that serve as a basis for the calculation by *Gaffney Cline* may add another layer of potential inaccuracy when estimating the UIC. INES[28] (Initiative Energien Speichern) presented their estimates of hydrogen storage formation or refurbishment of existing natural gas storage.

8.3.3.4. Conclusion

Publicly available information does **not permit a reliable calculation of the UIC indicator**, as the existing projects **vary widely in technology, total volumes, share of already utilized capacity**, etc.

Thus, the following figures only **provide an approximate indication** of the cost range across various types of storage:

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[24] Gaffney Cline; Underground Hydrogen Storage; 2022

[25] 250 million SEK; ECB exchange rate 2021 SEK to EUR = 10,88:1

[26] Hybrit Development; SSAB, LKAB and Vattenfall building unique pilot project in Luleå for large-scale hydrogen storage investing a quarter of a billion Swedish kronor; 07.04.2021; viewed 09.01.2023 https://www.hybritdevelopment.se/en/april-7-2021-hybrit-ssab-lkab-and-vattenfall-building-unique-pilot-project-in-lulea-for-large-scale-hydrogen-storage-investing-a-quarter-of-a-billion-swedish-kronor/

[27] Converter website: https://cmb.tech/

[28] INES; Store hydrogen – that much is certain (WASSERSTOFF SPEICHERN – SOVIEL IST SICHER Transformationspfade für Gasspeicher); 2022

1. Estimated UIC of the Hybrit, a project under construction in Sweden, **ranges between 10.7 and 12.9 EUR/kg**.
2. According to the study by *Gaffney Cline*, storing 1 912 t of hydrogen requires an investment cost as follows:
    a. **EUR 48.5 / kg** in a salt cavern,
    b. **EUR 17.5 / kg** in a depleted gas field and
    c. **EUR 18.3 / kg** in an aquifer[29].
3. A study by INES estimated the cost of newly-built storage in a cavern at **EUR 9 / kg**.

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[29] 51,5 USD; 18,4 USD; 19,3 USD; ECB exchange rate 2022 USD to EUR = 1,053:1
Gaffney Cline; Underground Hydrogen Storage; 2022

8.4. Large-scale electrolyser facilities

This chapter of the report explores the **current status and cost of electrolyser facilities** with emphasis on large installations in Europe and globally. It provides the details and results of UIC calculations **if underlying information is publicly available**.

The European Green Deal foresees the **transition of the current energy system** to energy production from renewable sources. The **intermittent nature** of solar and wind power supply will be compensated for by other sources. This compensation is needed in the event of insufficient immediate production or for storage, **when power is in over- and undersupply**.

The most prevalent manner of storing electricity today are electric batteries and pumped storage hydropower, however, their features such as self-discharge or geographic limitations mean that they are not universally suitable, for example, for long-term storage of large energy volumes or for bulk demand on the shoreline far from elevated areas.

Hydrogen is a **potential medium for long-term and bulk storage** method thanks to several of its features. **First**, hydrogen can be produced using clean electric power, without the use of fossil fuels. **Second**, it can be transformed back to electricity. **Third**, its nature, similar to currently used liquid fuels, permits the use of existing infrastructure or well-established knowledge for hydrogen storage and transportation, at least in part. A similar application is being considered by the *EU strategy for transportation*[30], which further amplifies the necessity of a hydrogen network, including its transport and large storage capacity.

8.4.1.1. Definition of the asset

Electrolyser facility is a hydrogen production facility that utilizes an **excess power supply** provided by renewable power sources and **uses electrolysis** to **transform water into hydrogen,** which also produces oxygen as a by-product. Electrolysis in industrial processes has a **century-long global history**, yet the cost of hydrogen storage and "gas-to-power" conversion is **as yet insufficiently competitive** compared to traditional sources of electricity production.

This may be due in part to the **smaller size** and **uniqueness** of currently operating installations. According to several studies and expert estimates, electrolysis has the potential for **cost reduction** if the focus is targeted towards the learning curve and regular **installations are sized up**. *EU Hydrogen Strategy*[31] stipulates numerous actions that must be taken in order for the strategy to be successful. Investing heavily in **large production facilities** of green hydrogen is one such action.

8.4.1.2. Definition of the UIC for the asset

The goal of the research was to **determine the UIC indicator per MW** of input power supply for 40+ MW electrolysers as follows:

$$\textit{Large electrolyser UIC indicator}\ (EUR/MW) = \bar{x}\left(\textit{UIC from individual research papers}\ \left(\frac{EUR}{MW}\right)\right)$$

8.4.1.3. Current state of large installations

The scale of electrolyser capacity until relatively recently was **only a few megawatts**. In recent years, electrolyser facility capacity **in the tens of MW** have come online. However, their **number is limited** and information about their investment costs **are scarce**.

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[30] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Sustainable and Smart Mobility Strategy – putting European transport on track for the future; COM/2020/789 final

[31] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A hydrogen strategy for a climate-neutral Europe; COM/2020/301 final

Several sources[32] rate the **Baofeng** project as the largest currently operating electrolyser facility. The capacity is estimated at 30 MW by most sources. The next in line are two 20 MW facilities: **Bécancour** facility by AirLiquide[33] and **Zhangjiakou** facility created a joint venture of Shell and Zhangjiakou City Transport Construction Investment Holding Group. One of the largest facilities in Europe is an electrolyser in the Wunsiedler Energiepark with a capacity of 8.75 MW and is a joint venture between Siemens Smart and Wunsiedler municipal utility[34].

8.4.1.4. Research summary

Information about the overall cost of the largest existing installations is scarce. Information can be obtained from online news articles. But **such information is often not confirmed by a reliable source** or the manufacturer. A rare piece of information about the Wunsiedler Energiepark reveals a cost[35] of **8.75 MW to be EUR 20 million**. This would mean that the unit cost is **EUR 2.28 million / MW**.

McPhy, a French electrolyser manufacturer, stated a unit cost of **EUR 0.7 million / MW**, not specifying the type of electrolyser technology[36]. Preliminary information on the planned large installation was collected if available and is presented, in Section 8.4.1.5.

Alternative cost indications can be found in various academic sources. The most recent and complex are the meta-studies from *Forschungszentrum Jülich GmbH* (Saba, 2017)[37], the *Oxford Institute for Energy Studies* (OIES)[38], *Bloomberg*[39] and a bottom-up study from *Fraunhofer*[40].

Saba collected information from the past studies, primarily **relying upon expert estimations**. The values were then converted to EUR and adjusted for inflation up to 2017. Costs for alkaline installations between 2014 and 2015 were between **EUR 0.9 and 1.1 million / MW**. The average of these values adjusted for 2021 indicates a unit cost of EUR 1.095 million / MW. As the study was published in 2017, the information for more recent years are only future estimates that differ widely as regards the methodology used to obtain the estimate.

OIES estimates the unit cost of a 1 MW **alkaline electrolyser** facility to be between **EUR 0.48 million / MW and EUR 0.8 million / MW** for 1 MW installations in 2019. For a **PEM facility** of the same size, the cost would be between **EUR 0.6 and 1.3 million / MW**.[41]

Bloomberg published information based on **its own research** showing a **wide gap between** the cost of building an alkaline electrolyser in **China and the West**. While the investment cost in the West is estimated at **EUR 1.02 million / MW** in 2021, the same installation can be built for **EUR 0.25 million / MW in China**.

Fraunhofer used a different approach from the above studies but **produced similar results**. The bottom-up calculation of cost based on the cost of components points to an investment cost of **EUR 0.95 million / MW and**

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[32] Rechargenews; World's largest green hydrogen project, with 150MW electrolyser, brought online in China https://www.rechargenews.com/energy-transition/record-breaker-world-s-largest-green-hydrogen-project-with-150mw-electrolyser-brought-on-line-in-china/2-1-1160799 taken over from BloombergNEF, 2021
Shell – official company website;
https://www.shell.com/media/news-and-media-releases/2022/shell-starts-up-hydrogen-electrolyser-in-china-with-20mw-product.html

[33] Air Liquide – official company website; Air Liquide inaugurates the world's largest low-carbon hydrogen membrane-based production unit in Canada; 26.01.2021; viewed 22.12.2022
https://www.airliquide.com/group/press-releases-news/2021-01-26/air-liquide-inaugurates-worlds-largest-low-carbon-hydrogen-membrane-based-production-unit-canada

[34] Siemens – official company website; Siemens realisiert in Wunsiedel eine der größten CO 2-freien Wasserstoffproduktionen Deutschlands (Siemens completes one of the largest hydrogen productions free of CO_2 in Germany); 09.07.2022
https://press.siemens.com/global/de/pressemitteilung/siemens-realisiert-wunsiedel-eine-der-groessten-co2-freien-wasserstoffproduktionen

[35] Hydrogen Central; Hydrogen, Bavaria – Largest Electrolysis Plant Goes into Operation; 14.09.2022; viewed 09.01.2023 https://hydrogen-central.com/hydrogen-bavaria-largest-electrolysis-plant-goes-operation/#:~:text=Hydrogen%2C%20Bavaria%20%E2%80%93%20largest%20electrolysis%20plant%20goes%20into%20operation.,from%20solar%20and%20wind%20power.

[36] Le Figaro; L'hydrogène vert va-t-il boulverser la géopolitique de l'énergie; Anna Chelvyalle;10.05.2022

[37] Saba, Muller, Robinius, Stolten; The investment costs of electrolysis - A comparison of cost studies from the past 30 years; 2017

[38] OIES; Cost-competitive green hydrogen: how to lower the cost of electrolysers?; January 2022;

[39] Bloomberg; China Leading Race to Make Technology Vital for Green Hydrogen; Dan Murtaugh; 21.09.2022; viewed 09.01.2023
https://www.bloomberg.com/news/articles/2022-09-21/china-leading-race-to-make-technology-vital-for-green-hydrogen?leadSource=uverify%20wall

[40] Fraunhofer; Cost Forecast for Low-Temperature Electrolysis; 2021

[41] OIES; unit cost of PEM (667–1,450 USD/kW) and alkaline (540-900 USD/kW)
ECB conversion rate: USD to EUR 2019 average 1:1.1195

EUR 0.98 million / MW for alkaline and PEM respectively. These costs apply to installations with **a capacity of 5 MW**. The study also predicts that large installations will be able to decrease unit investment costs per unit.

8.4.1.5. Cost discussion

Another preliminary indicator for the estimation of costs of large installations is the **released cost estimates** for planned projects. An electrolyser facility powered by renewable energy has been announced by **Saudi Arabia,** which will be a part of the Neom project. According to Bloomberg, the electrolyser is projected to cost USD 5 billion [42] (EUR 4.7 billion). The article also states that **120 Thyssenkrupp AG electrolysers** will be used. These prefabricated electrolyser modules will probably have a capacity of 20 MW[43]. The total capacity would be 2 400 MW with a **unit cost equal to EUR 1.96 million / MW**.

To continuously improve the estimate of unit investment cost for large-scale projects, information about the planned projects **can be indicative**. The **HyDeal** European mega-venture is planning to bring online **67 GW of electrolyser capacity**. **Hydrogen Holland 1** is another large project which will build 200 MW of electrolyser capacity[44]. Egypt and Oman have also announced plans to build electrolysers with a capacity of 100 MW and 400 MW capacity respectively.

While the cost of electrolysis is **predicted to decrease** by many sources used in this research, there are also factors pointing to an increase. Investment cost reduction will likely be the **result of improving technology**, and the **maturing** of new technologies will diversify electrolysis sources. **Economies of scale** may further contribute to the decreasing cost.

However, there are other **inevitable consequences** of electrolyser manufacturing ramp-up. First and foremost, both mature electrolysis technologies (alkaline and PEM) **require metals**. Alkaline electrolysers require nickel, while PEM technologies use platinum and iridium. These metals are distributed around the world, but are only **found in large concentrations** in Russia and regions which **do not permit seamless distribution** to the market.[45]

Secondly, **European and national regulation** seeking to cutting dependencies on imports of industrial production may affect the cost of building electrolysers. Conditions for new facilities coming online (such as restricted access non-local electricity) may **become an inevitable cost** item for large-scale installations and favour certain regions over others, which will **push up costs**. Similar effects are likely to be produced by regulation or taxation of imports if the push for independence persists.

8.4.1.6. Conclusion

The UIC of large-scale electrolyser facilities is at the centre of several studies. Fraunhofer, Saab and OIES focused on **estimates for large installations costs**. The averages of the figures suggested by the research publications presented in Section 8.4.1.4. are **summarised in the following table**:

Capacity range **Technology**	**1-5 MW**	**40-200 MW**	**No indication of total capacity**
Alkaline	0.745	**0.537**	0.790
PEM	0.956		

Table 21. UIC indicator for electrolyser facilities; in million EUR/MW

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[42] Bloomberg; Saudi Arabia to start building green hydrogen plant in Neom; Vivian Nereim; 17.03.2022; viewed 09.01.2023 https://www.bloomberg.com/news/articles/2022-03-17/saudi-arabia-to-start-building-green-hydrogen-plant-in-neom?leadSource=uverify%20wall

[43] Thyssenkrupp; Hydrogen from large-scale electrolysis; 2019 https://ucpcdn.thyssenkrupp.com/_legacy/UCPthyssenkruppBAISUhdeChlorineEngineers/assets.files/products/water_electrolysis/tk_19_0820_hydrogen_broschuere_2019_03.pdf

[44] CNBC; Shell to build Europe's largest renewable hydrogen plant to help power Dutch refinery; Anmar Frangoul; 07.07.2022; viewed 10.01.2023 https://www.cnbc.com/2022/07/07/shell-to-build-europes-largest-renewable-hydrogen-plant.html

[45] Stiftung Wissenschaft und Politik; Electrolysers for the Hydrogen Revolution; 2022

Capacity ranges indicated in the table divide the data points **into small-scale facilities** (1-5 MW)**, large-scale facilities** (40-200 MW), and **other general UIC figures for which there is a lack of more specific indication of the facilities' total capacity**. The data for **alkaline** electrolysers was more abundant, and the collected data points for **PEM** electrolysers **were not sufficient** to produce an indicator.

There are multiple **limitations** to the calculated UIC indicator:

- The calculation is **not** based on the cost of constructed and operational projects.
- The methodologies across the studies **differ**.
- The UIC of individual projects **varies widely depending on their geographic location**[46] as estimated UICs are often largely based on cost levels typical in Asia.
- **Only alkaline-type facilities were considered for indicator calculations for large-scale electrolysers**, as the cost estimates were available in contrast to large-scale PEM electrolysers.
- Estimates for Wunsiedler Park and NEOM were not included in the calculation **due to the deviation from the average of other figures** from the research and the relatively low capacity of Wunsiedler Park.

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[46] According to Bloomberg, a UIC in Europe is estimated to be three times higher than a UIC in Asia.

8.5. Carbon dioxide infrastructure

This chapter of the report explores the **current state and cost of the carbon dioxide network infrastructure** in Europe and globally. It provides the details and results of UIC calculations if underlying information is publicly available.

Current carbon dioxide reduction efforts have led to the planning and construction of **storage facilities** and **transportation routes** to **sequestrate and deposit carbon** from the atmosphere. The infrastructure needed to store carbon dioxide includes **pipelines** (onshore and offshore), **ships**, **liquefaction facilities** and **final storage depositories**.

This research focuses on **pipelines and large-scale storage** in depleted fields or geological formations. The initial target was to find information and, if possible, based on the available data, calculate the UIC of these assets.

The section is divided **into two main sub-sections** for the following assets:

1) Carbon dioxide pipelines
2) Carbon dioxide storage in depleted fields or geological formations

8.5.1. Carbon dioxide pipelines

8.5.1.1. Definition of the asset

A carbon dioxide pipeline is infrastructure used for the **transportation** of carbon dioxide via a pipe, similarly to the transport of natural gas via the gas transport network. Carbon dioxide was transported in approx. 9 000 km of pipelines in 2022[47]. Increasingly, **carbon dioxide is being sequestrated** to facilitate storage for environmental reasons.

Historically, carbon dioxide has been utilised for the enhancement of oil recovery and as a feedstock for some industrial processes. The concentration of carbon dioxide pipelines **is therefore higher in areas** where oil is extracted. Similarly, cost data as well as experience with building pipelines carrying carbon dioxide comes primarily from the USA, which has a high concentration of carbon dioxide pipelines along the Gulf of Mexico.

8.5.1.2. Definition of the UIC for the asset

The multipliers (M), that are the result of the research described in Section 0 Identified data issues and deficiencies, **were applied** to the collected cost information for **clean gas infrastructure** according to the **diameter of the pipeline** (x). The factors serve as multipliers for the entirety of gas pipeline investment costs. An indicator based on this assumption was **calculated using the following formula**:

$$\textit{Carbon dioxide pipeline UIC indicator}\ (EUR/km) = \frac{\sum \textit{Total cost of low carbon gas pipelines}\ (EUR)}{\sum \textit{Total length of low carbon gas pipelines}\ (km)} * M(x)$$

If x= 12.75 then M= 1,00
If x= 16 then M= 1,12
If x= 24 then M= 1.25
If x= 30 then M= 1.25
If x= 36 then M= 1.25
If x= 42 then M= 1.25

8.5.1.3. Research summary

Arguments for hydrogen pipelines are also **valid for carbon dioxide pipelines**. Different projects **vary in major cost drivers**, such as the diameter of pipelines, used material and total length of the pipeline or scale of the project. **Differences in installation** expenditures across various states and outdatedness (for pipelines used for

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[47] IEA; CO_2 Transport and Storage – Infrastructure Deep Dive; September 2022

the enhancement of oil recovery) add another level of **potential inaccuracy** to a result produced by calculating a UIC indicator based on available information.

For all the above reasons the research was oriented **towards finding a coefficient** linking the cost of natural gas pipelines and carbon dioxide pipelines with the final goal of calculating the UIC indicator.

A comprehensive study by the *National Energy Technology Laboratory*[48], within the US Department of Energy, suggested a factor of **1-1.25 based on the diameter** of the pipeline for the calculation of the cost for pipeline transporting carbon dioxide. Despite the limitations related to different labour and material cost ratios and permitting differences, a multiplier of the natural gas pipeline cost provides **the most reliable estimate** in an environment where there is a lack of relevant information from Europe.

8.5.1.4. Cost discussion

Older publications may also provide a basis for establishing the unit cost for pipelines for carbon dioxide. The unit cost for an onshore pipeline, according to a report by the *Zero Emissions Platform*[49], **was between EUR 0.82 million / km to EUR 1.9 million / km** in the year of publication (which is unknown) **depending on the overall length** of the pipeline, its **diameter,** and **the volumes** of gas to be transported.

8.5.1.5. Conclusion

The cost information on infrastructure assets integrating low-carbon gases (presented in Section **Error! Reference source not found.**) served as the basis for the calculation of estimated UIC indicators for carbon dioxide pipelines of 2 diameter groups. The results are presented in the following table:

Diameter subcategory	Mean
Diameter 12-16	2 101 781
Diameter 36-48	4 040 957

8.6. Carbon dioxide storage in depleted fields or geological formations

8.6.1. Definition of the asset

Carbon dioxide storage is infrastructure where **large volumes of carbon dioxide can be stored**, either temporarily or indefinitely. Carbon dioxide capture and storage has been developed for commercial purposes in

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[48] T.C. Grant, D. Morgan, US DOE/National Energy Technology Laboratory, M. Godec, R. Lawrence, Advanced Resources International, J. Valenstein, R. Murray, Booz Allen Hamilton; NETL CO2 Injection and Storage Cost Model; 2012

[49] Zero emissions platform; The Costs of CO_2 Transport - Post-demonstration CCS in the EU

the past and its development continues today, also as a result of environmental and climate concerns due to the need to capture and store CO2 to decrease the volume of CO2 emissions released into the atmosphere.

8.6.2. Definition of the UIC for the asset

The goal of the research was **to determine the UIC indicator per kg of mass** for various storage types as follows:

$$\textit{Carbon dioxide injection UIC}\,(EUR/kg) = (\textit{Total cost}\,(EUR))/(\textit{Mass of annually injected}\,CO_2\,(kg))$$

8.6.3. Research Summary

Between 7[50] and 11[51] projects **are operational** and provide storage **in Europe**. These projects differ in purpose, technology and the era in which they became operational. **Only 4 storage capacities** in Europe have been put into operation **in the past decade** and 3 of them are pilot or demonstration projects.

Northern Lights is a pilot carbon dioxide storage project being developed in Europe. This joint venture of European international oil companies estimates the **upfront costs to be EUR 592.2 million**[52]. The annual injection capacity is projected **at 5 million tons**[53] of carbon dioxide per annum. Therefore, the unit investment cost **is estimated to be EUR 0.118 / kg of annual injection capacity**.

The Zero Emissions Platform performed a study[54] of the cost of storage in saline aquifers and depleted oil fields which confirmed the assumption that the unit cost per total volume of the storage facility **varies widely** according to the **size** and **type** of storage. Although the cost results in the study provide a meaningful basis for cost observation, they cannot be translated into current prices, and therefore are not of any value for this report, as the publication dates of the report are unknown.

8.6.4. Conclusion

The research **did not result in a sufficient amount and quality of cost data**. Operational projects differ widely in cost-driving features and new technologies to store carbon dioxide are being developed and pilot-tested. Therefore, a meaningful **indicator cannot be calculated** based on the available data at the time of this report.

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[50] Nikolaos Koukouzas, Marina Christopoulou, Panagiota P. Giannakopoulou, Aikaterini Rogkala, Eleni Gianni, Christos Karkalis, Konstantina Pyrgaki, Pavlos Krassakis, Petros Koutsovitis, Dionisios Panagiotaras and Petros Petrounias; Current CO2 Capture and Storage Trends in Europe in a View of Social Knowledge and Acceptance. A Short Review; Energies; 2022

[51] Global CCS Institute; Public database of CCS facilities – filtered for Europe; 12.01.2023 https://co2re.co/FacilityData

[52] 700 million USD; Offshore-energy; Offshore Energy; Norway approves plan for Northern Lights project; Bojan Lepic; 09.03.2021; viewed 10.01.2023 https://www.offshore-energy.biz/norway-approves-plan-for-northern-lights-project/#:~:text=The%20licensee%20%E2%80%93%20Equinor%20%E2%80%93%20has%20estimated,operation%20period%20of%2025%20years.
ECB 2021 average exchange rate = 0.8460

[53] Northern Lights; Northern Lights concludes well drilling operations; 10.11.2022 https://norlights.com/news/northern-lights-concludes-well-drilling-operations/

[54] Zero Emissions Platform; The Costs of CO2 Storage

9. Cost breakdowns, annual cost distribution and comparison with the UIC in 2015

This chapter presents additional conclusions based on the collected data about individual assets. The sections of this chapter do not always follow the same structure, as the abundance and conclusiveness of data varied across assets.

Cost breakdowns were calculated if 3 or more assets provided full cost breakdown information. Only assets considered in the UIC analysis (within thresholds and without outlier status) indicators were included in the sample for cost breakdown calculation.

A cost distribution on an annual basis was calculated if 3 or more assets were assigned the same investment year and there was sufficient abundance of data for more than at least 2 non-consecutive years. Only assets considered in the UIC analysis (within thresholds and without outlier status) indicators were included in the sample for cost breakdown calculation.

A comparison of the UIC indicator results drew attention to the results in the subcategories that were defined in the same way as in 2015 and 2023 UIC Report. Additionally, occasional disparities in approach also led to notable results, such as the nature of 380 kV electric lines.

9.1. Electricity infrastructure category

9.1.1. Overhead lines

9.1.1.1. Cost breakdown

The provided cost breakdowns point to the installation and civil works costs as a major cost driver for overhead lines, comprising an average 57% of the total costs. The share is higher for lower voltage level lines at 64% for 220 kV lines, while installation and civil works in 400 kV lines comprise 46%. The disparity between the voltage level cost structure is related to the share of labour costs of total costs. On average, 5.3% of total costs of 220 kV lines project are labour costs, while 400 kV lines spend 29.1% of total costs on labour. The origin of the project seems to play a significant role as regards the overall share of labour costs.

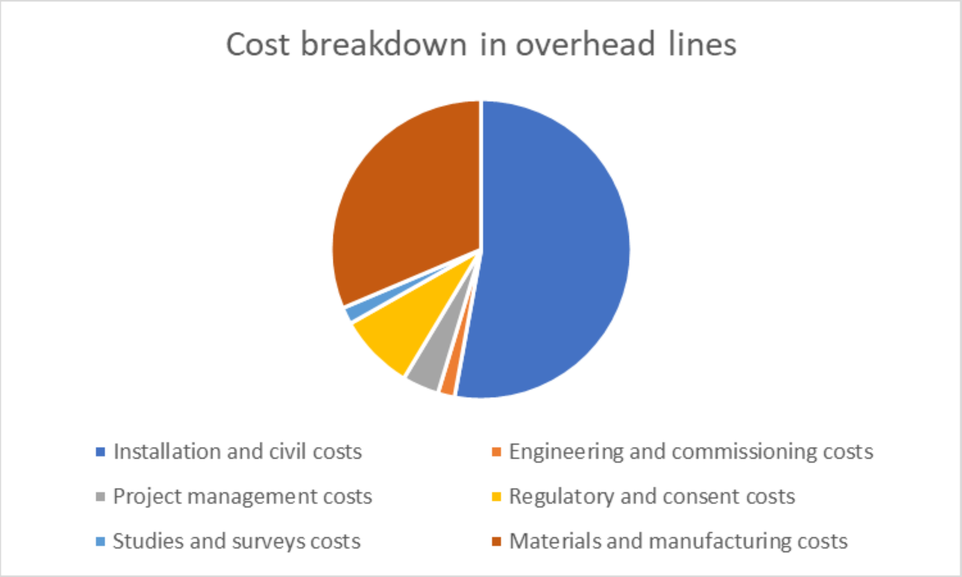

Figure 20. Cost breakdown in overhead lines; in %

9.1.1.2. Annual distribution

Cost developments over several years is provided for 2-circuits lines with voltage levels of 220 kV and 400 kV. The sample of 220 kV lines points to extreme unit cost reductions between 2018 and 2019. Although the extreme cost reduction shown in **Error! Reference source not found.** suggests this outcome may be questionable to a degree, the origin of the individual cost data does not suggest this irregularity is origin-driven.

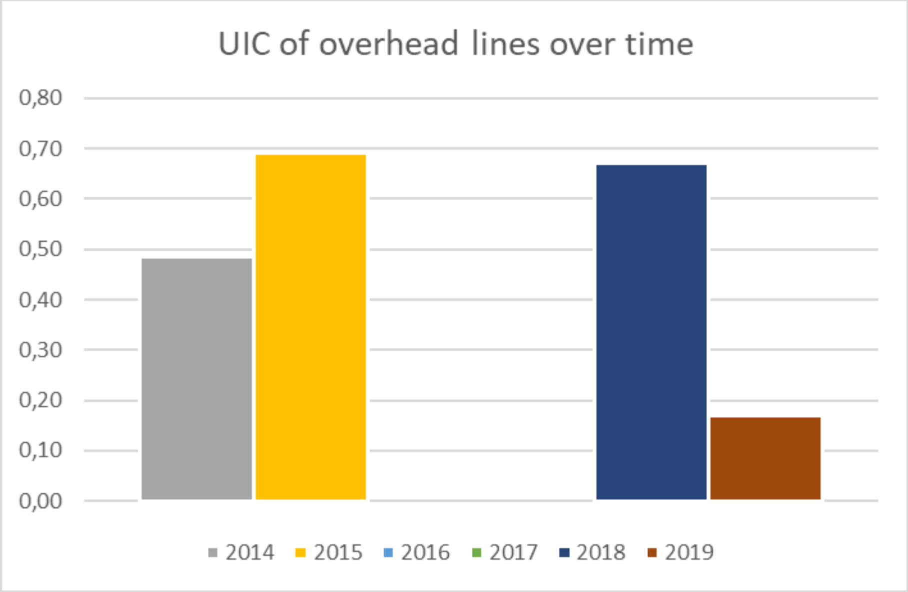

Figure 21. Average UIC of overhead lines (220 kV and 2 circuits) per annum; in million EUR/km

The general trend as regards the development of the indexed unit investment cost of 400 kV lines suggest that the cost is rising. Yet, origin of the assets commissioned in individual years has large impact on the final average unit cost.

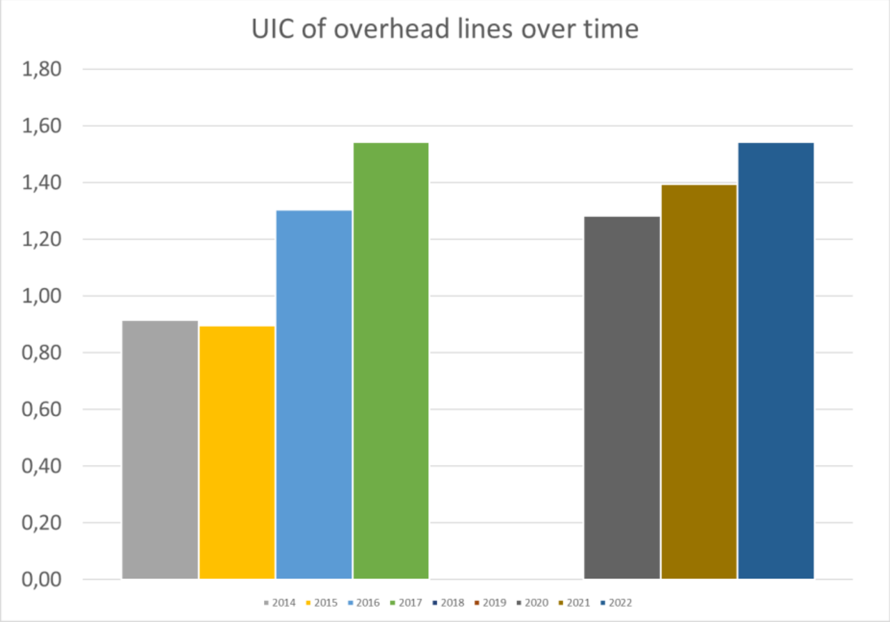

Figure 22. Average UIC of overhead lines (400 kV and 2 circuits) per annum; in million EUR/km

9.1.1.3. Comparison with UIC in 2015

The comparison of UIC indicators from 2015 with the indicators presented in this report generally confirms the expected trend of increasing nominal cost due to inflation between 2015 and 2023. The trend is contradicted for 380 – 400 kV lines, which may be a result of differences in data samples between 2015 and 2023.

Table 22. Comparison of UIC indicator results for overhead lines between 2015 and 2023; in EUR/km

2015	Mean	Median	Mean	Median	2023
220 - 225 kV 1 circuit	288 289	218 738	411 887	362 180	220 - 225 kV 1 circuit
220 - 225 kV 2 circuit	407 521	437 263	530 500	502 843	220 - 225 kV 2 circuits
380 - 400 kV 1 circuit	598 231	597 841	465 287	396 856	380 - 400 kV 1 circuit
380 - 400 kV 2 circuit	1 060 919	1 023 703	1 260 970	1 050 044	380 - 400 kV 2 circuits

9.1.2. Underground cables

9.1.2.1. Cost breakdown

The provided cost breakdowns point to installation and civil costs as a major cost driver of overhead lines, comprising on average 55% of total costs. The overwhelming majority of the sample used as the basis for cost breakdown calculation is comprised of 220 kV lines with one installed circuit. 220 kV lines projects spend on average 3.73% of total costs on labour. All labour cost data is taken from assets installed in France, therefore, the labour cost share may be very different in other EU Member States.

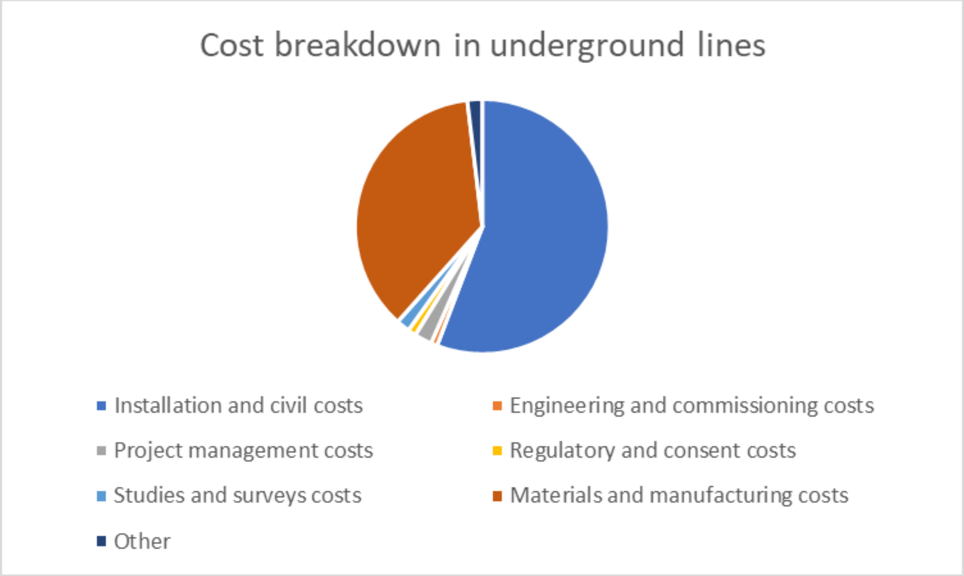

Figure 23. Cost breakdown in underground cables; in %

9.1.2.2. Annual distribution

The sample of 1 circuit 110-150 kV lines suggests a marked increase in UIC over time. However, this change in cost level can be explained by a larger cross section of the assets from 2018[55] compared to the assets from previous years.

9.1.2.3. Comparison with UIC in 2015

The comparison of UIC indicators from 2015 with the indicators presented in this report further points to the irregularity of 380 kV lines in specific states. All 380 kV from specific states cable assets collected in the current collection were outliers of the sample, as their number was too small to form a separate subcategory. Therefore, the cost level in the last row is much lower than the cost level from the UIC Report 2015.

Table 23. Comparison of UIC indicator results for underground cables between 2015 and 2023; in EUR/km

2015	Mean	Median	Mean	Median	2023
150 kV 1 circuit	695 704	782 212	830 658	550 601	110 - 150 kV 1 circuit
150 kV 2 circuit	1 511 846	886 109	2 232 070	1 679 545	110 - 150 kV 2 circuits
220 - 225 kV 1 circuit	2 224 630	2 260 036	1 778 355	1 910 028	220 - 225 kV 1 circuit
220 - 225 kV 2 circuit	3 314 047	4 063 557	4 401 542	4 386 776	220 - 225 kV 2 circuits

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[55] 2018 is the assigned investment year of the assets.

9.1.3. Submarine cables

9.1.3.1. Annual distribution

The sample points to the reduction of UIC over time as per **Error! Reference source not found.**. However, this change in cost level can be explained by the type of assets installed in individual years. Half of the sample used to calculate UIC for 2016[56] had 2 circuits, while samples from later years only contained 1-circuit assets.

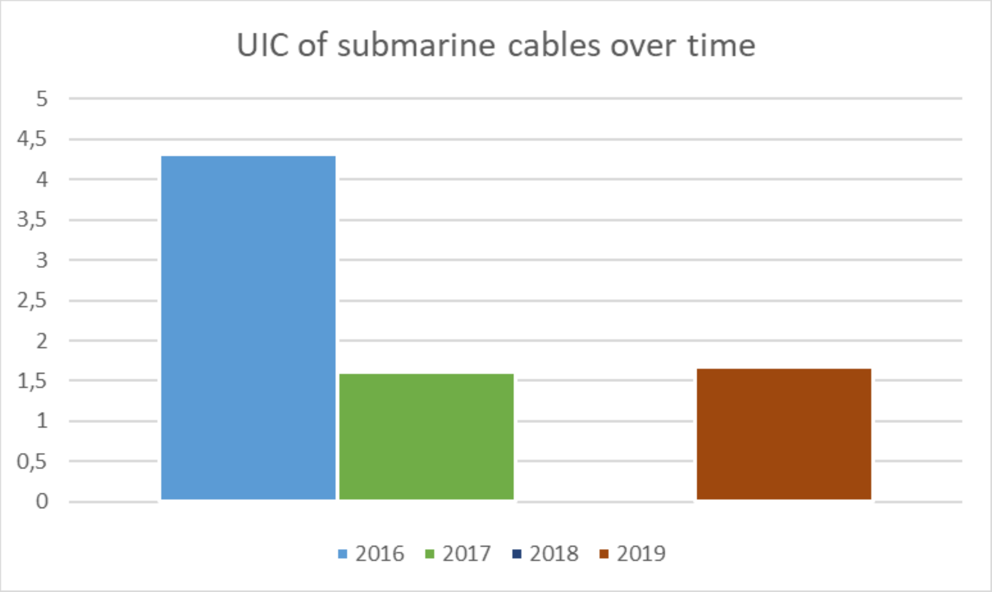

Figure 24. Average UIC of submarine cables per annum; million EUR/km

9.1.3.2. Comparison with UIC in 2015

The higher cost level in the current UIC exercise may be explained by inflation coupled with the sample containing higher number of AC cable assets than the sample used for calculation of the UIC indicator for all cable types in the UIC Report 2015.

Table 24. Comparison of UIC indicator results for submarine cables between 2015 and 2023; in EUR/km

2015	Mean	Median	Mean	Median	2023
All cable types	909 910	831 185	1 647 297	1 263 091	132 - 500 kV
AC cables	1 143 966	1 140 989	2 006 533	2 467 554	AC cables
DC cables	757 621	760 284	1 108 442	1 085 783	DC cables

9.1.4. AC substations

9.1.4.1. Cost breakdown

A major pattern seen for all subcategories of AC substations is the dominant impact of installation and civil costs along with the materials and manufacturing cost as a percentage of the total cost. This ranges between 33% and 56% and 31% and 51% respectively. The ratio between installation / civil and materials / manufacturing appears not to correlate with a single technical aspect, such as the number of bays, status (new or refurbished or upgraded) or type of substation (AIS or GIS). Labour cost ranges between 8% and 16% without any clear pattern tied to a technical parameter.

9.1.4.2. Annual distribution

The granularity of the collected data does not allow for a meaningful analysis of UIC indicator development over time.

9.1.4.3. Comparison with UIC in 2015

The granularity of the collected data does not allow for a meaningful comparison of UIC indicators from 2015 and 2023.

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[56] 2018 is the assigned investment year of the assets.

Table 25. Comparison of UIC indicator results for AC substations between 2015 and 2023; units in table

2015	Mean	Median	Mean	Median	2023
All (EUR/ MVA)	38 725	35 500	31 248	25 047	**All (EUR/ MVA)**
All (EUR/kV)	42 627	37 449	68 823	64 701	**All (EUR/kV)**

9.1.5. Transformers

9.1.5.1. Annual distribution

The sample points to a possible increase of UIC over time, which may be explained by price inflation.

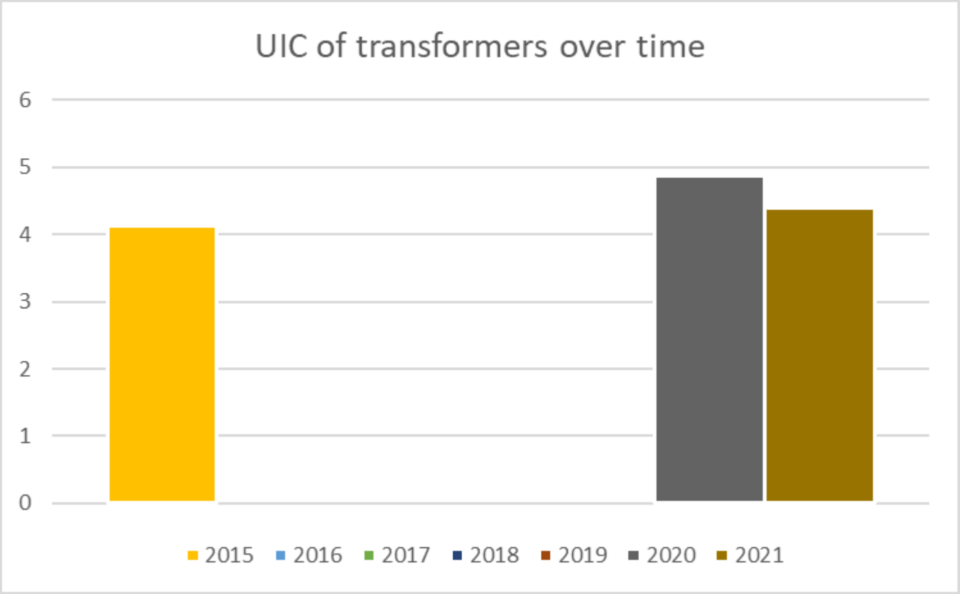


Figure 25. Average UIC of 400/110 transformers per annum; million EUR/transformer

9.2. Infrastructure for low-carbon gas blending and smart gas grid

9.2.1. Compression stations

9.2.1.1. Cost breakdown

The provided cost structure show that the materials and manufacturing dominate the cost of compression stations, with an average 50% of total costs in compression stations not exceeding 1 MW of power capacity. Installation and civil costs comprise 14.1% and engineering costs follow with a 13% share. Labour costs usually make up around 38% of total costs.

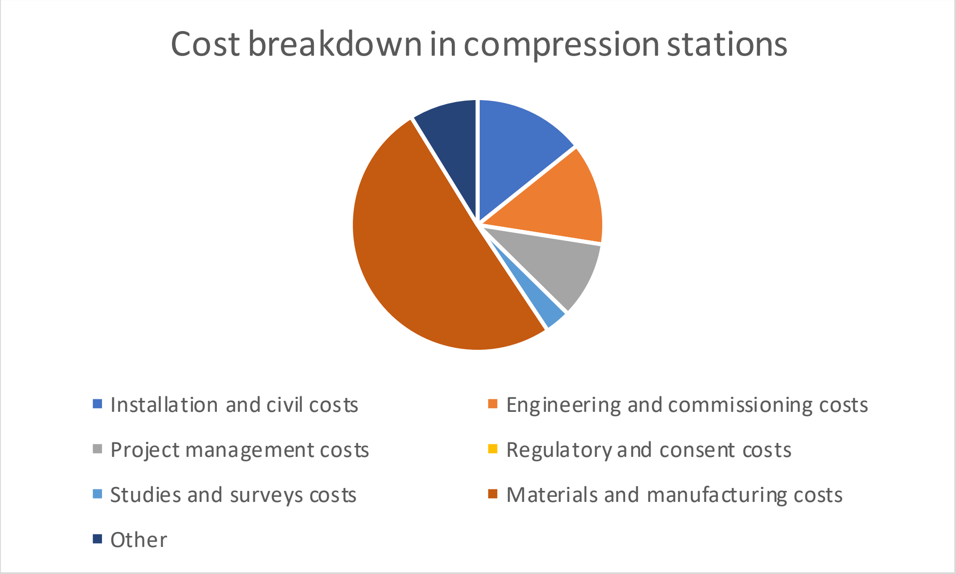


Figure 26. Cost breakdown in compression stations (<1MW); in%

End of the report

Appendix A. - Appendices

A.1. Appendix – Inflation rates

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Belgium	0.5	0.6	1.8	2.2	2.3	1.2	0.4	3.2	10.3
Bulgaria	-1.6	-1.1	-1.3	1.2	2.6	2.5	1.2	2.8	13.0
Czech Republic	0.4	0.3	0.6	2.4	2	2.6	3.3	3.3	14.8
Denmark	0.4	0.2	0	1.1	0.7	0.7	0.3	1.9	8.5
Germany	0.8	0.7	0.4	1.7	1.9	1.4	0.4	3.2	8.7
Estonia	0.5	0.1	0.8	3.7	3.4	2.3	-0.6	4.5	19.4
Ireland	0.3	0	-0.2	0.3	0.7	0.9	-0.5	2.4	8.1
Greece	-1.4	-1.1	0	1.1	0.8	0.5	-1.3	0.6	9.3
Spain	-0.2	-0.6	-0.3	2	1.7	0.8	-0.3	3	8.3
France	0.6	0.1	0.3	1.2	2.1	1.3	0.5	2.1	5.9
Croatia	0.2	-0.3	-0.6	1.3	1.6	0.8	0	2.7	10.7
Italy	0.2	0.1	-0.1	1.3	1.2	0.6	-0.1	1.9	8.8
Cyprus	-0.3	-1.5	-1.2	0.7	0.8	0.5	-1.1	2.3	8.1
Latvia	0.7	0.2	0.1	2.9	2.6	2.7	0.1	3.2	17.2
Lithuania	0.2	-0.7	0.7	3.7	2.5	2.2	1.1	4.6	18.9
Luxembourg	0,7	0,1	0	2.1	2	1.6	0	3.5	8.2
Hungary	0	0.1	0.4	2.4	2.9	3.4	3.4	5.2	15.3
Malta	0.8	1.2	0.9	1.3	1.7	1.5	0.8	0.7	6.1
Netherlands	0.3	0.2	0.1	1.3	1.6	2.7	1.1	2.8	11.6
Austria	1.5	0.8	1	2.2	2.1	1.5	1.4	2.8	8.6
Poland	0.1	-0.7	-0.2	1.6	1.2	2.1	3.7	5.2	13.2
Portugal	-0.2	0.5	0.6	1.6	1.2	0.3	-0.1	0.9	8.1
Romania	1.4	-0.4	-1	1.1	4.1	3.9	2.4	4.1	12.0
Slovenia	0.4	-0.8	-0.2	1.6	1.9	1.7	-0.3	2	9.3
Slovakia	-0.1	-0.3	-0.5	1.4	2.5	2.8	2	2.8	12.1
Finland	1.2	-0.2	0.4	0.8	1.2	1.1	0.4	2.1	7.2
Sweden	0.2	0.7	1.1	1.9	2	1.7	0.7	2.7	8.1

Source: Eurostat

A.2. Appendix – research sources

A.2.1. Research papers and publications

Title	Author	Publication year	Additional information
Hydrogen Insights Report September 2022	Hydrogen Council, McKinsey & Company	2022	
Technical Targets for Hydrogen Delivery	Department of Energy		
The Techno-Economics of Hydrogen Pipelines	Khan, M.A., Young, C. and Layzell	2021	Transition Accelerator Technical Briefs Vol. 1, Issue 2 D.B.; Pg. 1-40
Multi-Year Research, Development, and Demonstration Plan – Delivery Section	Department of Energy	2015	
Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs	Parker, Nathan; Institute of Transportation Studies (University of California)	2004	
Summary report on steels K55, L80 including H2S containing atmosphere and a quenched reference material	Hystories - EU;	2021	
Economic impact of applying high strength steels in hydrogen gas pipelines	Fekete, James; Sowards, Jeffrey; Amaro, Robert;	2015	International Journal of Hydrogen Energy - Volume 40, Issue 33
Overview of Interstate Hydrogen Pipeline Systems	ANL; Environmental Science Division	2007	
Hydrogen-Natural Gas mixture compression for transport via high-pressure gas pipelines	Ł Zabrzeski et al. 2019	2019	IOP Conf. Ser.: Earth Environ. Sci. 214 012137
The Techno-Economics of Hydrogen Compression	Khan, M.A., Young, C., and MacKinnon, C. and Layzell, D.	2021	Transition Accelerator Technical Briefs Vol. 1, Issue 1, Pg. 1-36. ISSN 2564-1379
Cost of long-distance energy transmission by different carriers	Daniel DeSantis, Brian D. James, Cassidy Houchins, Genevieve Saur, Maxim Lyubovsky;	2021	iScience; Volume 24, Issue 12, 103495, ISSN 2589-0042
Underground Hydrogen Storage	Gaffney Cline	2022	
Store hydrogen – that much is certain	INES	2022	Original title: Wasserstoff speichern – soviel ist sicher
Hydrogen from large-scale electrolysis;	Thyssenkrupp	2019	
The investment costs of electrolysis - A Comparison of cost studies from the past 30 years	Saba, Muller, Robinius, Stolten	2017	

Title	Author	Publication year	Additional information
Cost-competitive green hydrogen: how to lower the cost of electrolysers?	OIES	2022	
Cost Forecast for Low-Temperature Electrolysis	Fraunhofer	2021	
Electrolysers for the Hydrogen Revolution	Stiftung Wissenschaft und Politik	2022	
CO_2 Transport and Storage – Infrastructure Deep Dive	IEA	2022	
NETL CO2 Injection and Storage Cost Model	M. Godec, R. Lawrence, T.C. Grant, D. Morgan; US DOE/National Energy Technology Laboratory	2012	
The Costs of CO_2 Transport - Post-demonstration CCS in the EU	Zero emissions platform		
Current CO_2 Capture and Storage Trends in Europe in a View of Social Knowledge and Acceptance. A Short Review;	Nikolaos Koukouzas, Marina Christopoulou, Panagiota P. Giannakopoulou, Aikaterini Rogkala, Eleni Gianni, Christos Karkalis, Konstantina Pyrgaki, Pavlos Krassakis, Petros Koutsovitis, Dionisios Panagiotaras and Petros Petrounias; Energies	2022	
The Costs of CO_2 Storage	Zero emissions platform		
Supporting Country Fiches accompanying the report Benchmarking Smart Metering Deployment in the EU-28	Directorate General for Energy	2019	

A.2.2. Online articles

Title	Author	Publication date	Link
The Chemical Engineering Plant Cost Index	Chemengonline;	viewed 14.03.2023	https://www.chemengonline.com/pci-home
Hydrogen Products Pure Energy Centre – Hydrogen Compressor	Pure Energy Centre	2021	https://pureenergycentre.com/hydrogen-products-pure-energy-centre/hydrogen-compressor/
SSAB, LKAB and Vattenfall building a unique pilot project in Luleå for large-scale hydrogen storage investing a quarter of a billion Swedish kronor	Hybrit Development	07.04.2021	https://www.hybritdevelopment.se/en/april-7-2021-hybrit-ssab-lkab-and-vattenfall-building-unique-pilot-project-in-lulea-for-large-scale-hydrogen-storage-investing-a-quarter-of-a-billion-swedish-kronor/)
World's largest green hydrogen project, with a 150MW electrolyser, brought online in China	Rechargenews	2021; viewed 04.01.2023	https://www.rechargenews.com/energy-transition/record-breaker-world-s-largest-green-hydrogen-project-with-150mw-electrolyser-brought-on-line-in-china/2-1-1160799 taken over from BloombergNEF, 2021
Shell starts up hydrogen electrolyser in China with 20 MW production capacity	Shell – official company website	28.01.2022; viewed 04.01.2023	https://www.shell.com/media/news-and-media-releases/2022/shell-starts-

Title	Author	Publication date	Link
			up-hydrogen-electrolyser-in-china-with-20mw-product.html
Air Liquide inaugurates the world's largest low-carbon hydrogen membrane-based production unit in Canada	Air Liquide – official company website	26.01.2021; viewed 22.12.2022	https://www.airliquide.com/group/press-releases-news/2021-01-26/air-liquide-inaugurates-worlds-largest-low-carbon-hydrogen-membrane-based-production-unit-canada
Siemens realisiert in Wunsiedel eine der größten CO_2-freien Wasserstoffproduktionen Deutschlands	Siemens – official company website	09.07.2021; viewed 04.01.2023	https://press.siemens.com/global/de/pressemitteilung/siemens-realisiert-wunsiedel-eine-der-groessten-co2-freien-wasserstoffproduktionen
Hydrogen, Bavaria – Largest Electrolysis Plant Goes into Operation	Hydrogen Central	14.09.2022; viewed 09.01.2023	https://hydrogen-central.com/hydrogen-bavaria-largest-electrolysis-plant-goes-operation/#:~:text=Hydrogen%2C%20Bavaria%20%E2%80%93%20largest%20electrolysis%20plant%20goes%20into%20operation.,from%20solar%20and%20wind%20power.
L'hydrogène vert va-t-il boulverser la géopolitique de l'énergie	Anna Chelvyalle; Le Figaro	10.05.2022	
China Leading Race to Make Technology Vital for Green Hydrogen	Dan Murtaugh; Bloomberg	21.09.2022	
Saudi Arabia to start building green hydrogen plant in Neom	Vivian Nereim; Bloomberg	17.03.2022	https://www.bloomberg.com/news/articles/2022-09-21/china-leading-race-to-make-technology-vital-for-green-hydrogen?leadSource=uverify%20wall https://www.bloomberg.com/news/articles/2022-03-17/saudi-arabia-to-start-building-green-hydrogen-plant-in-neom?leadSource=uverify%20wall
Shell to build Europe's 'largest' renewable hydrogen plant to help power Dutch refinery	Anmar Frangoul; CNBC	07.07.2022	https://www.cnbc.com/2022/07/07/shell-to-build-europes-largest-renewable-hydrogen-plant.html
Public database of CCS facilities – filtered for Europe	Global CCS Institute	12.01.2023	https://co2re.co/FacilityData
Norway approves plan for Northern Lights project	Bojan Lepic; Offshore-energy	09.03.2021	https://www.offshore-energy.biz/norway-approves-plan-for-northern-lights-project/#:~:text=The%20licensee%20%E2%80%93%20Equinor%20%E2%80%93%20has%20estimated,operation%20period%20of%2025%20years.
Northern Lights concludes well drilling operations	Northern Lights	10.11.2022	https://norlights.com/news/northern-lights-concludes-well-drilling-operations/
Smart Gas Meter Project in France	GRDF	Viewed 10.01.2023	https://www.grdf.fr/grdf-en/smart-gas-meter-france
Aemetis, Inc.: Aemetis Completes 7-mile Pipeline to Transport Biogas from Five Dairy Digesters to RNG Production Facility	Bloomberg	26.01.2022	https://www.bloomberg.com/press-releases/2022-01-26/aemetis-inc-aemetis-completes-7-mile-pipeline-to-

Title	Author	Publication date	Link
			transport-biogas-from-five-dairy-digesters-to-rng-production-facility

A.3. Calculator model

A calculator model in Excel format is part of the deliverables of this project. This model is an underlying document for the unit investment cost presentation and estimate of future values (taking into account inflation estimates). It consists of

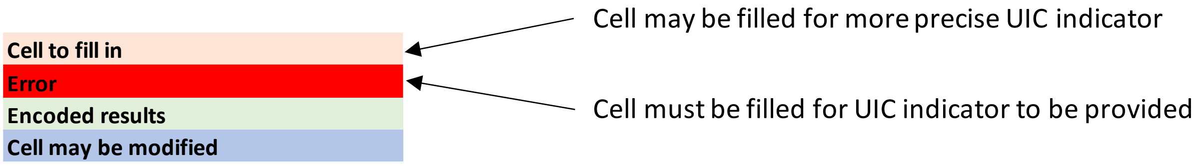
- The main presenting sheets (‘Cover’; ‘Presentation’),
- Modifiable supporting sheets (‘Inflation’),
- Hardcoded supporting sheets (which are hidden).

A.3.1. Model methodology

The first step in the development of this model was the calculation of presented values based on collected data and UIC indicators reference values as presented in Chapter 7. This data was then consolidated in the sheet ‘Results’, which is hidden. Results for individual assets were linked to the table presenting UIC indicators in the column ‘UIC value (2023)’ using a selection of assets from the first table and a secondary selection of a subcategory in the second table in the sheet ‘Presentation’. The current value of the UIC, which is presented together with UIC 2023, is adjusted for inflation based on values published by Eurostat. Future UIC projections use forecasts published by the ECB. The ECB and other institutions provide other inflation forecasts. Thus, the suggested inflation values in the sheet ‘Inflation’ can be replaced by the user with specific inflation values. Hidden sheets are ‘Results’ and ‘Key’. The sheets are locked, as they are necessary for the functioning of the model.

A.3.2. Model guideline

The sheet 'Presentation' provides the results for an asset selected by the users. Please select infrastructure and asset categories in the first table. The selection of a subcategory in the same table may be necessary in order to provide the UIC indicator. If this is the case, the cell will turn red. UIC indicators are presented in the third table. The cell colour indicates, whether the cell can, must or cannot be filled in order to produce results.



Cell may be filled for more precise UIC indicator

Cell must be filled for UIC indicator to be provided