REPORT

ON UNIT INVESTMENT COST INDICATORS
AND CORRESPONDING REFERENCE VALUES FOR
ELECTRICITY AND GAS INFRASTRUCTURE

ELECTRICITY INFRASTRUCTURE

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Document history

Version	Comment	Date
1	Original version. Available at: http://www.acer.europa.eu/Official_documents/Publications/UIC_Electricity_History/UIC%20Report%20%20-%20Electricity%20infrastructure.pdf	July 2015
1.1	Corrigendum The corrigendum replaces reference values in two tables and includes several minor formatting or typographical corrections. The main changes are set out in Appendix A.	August 2015

Electricity Infrastructure Unit Investment Costs

Report

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1 Introduction

This Report is the result of work carried out by NRAs cooperating in the framework of the Agency for developing a set of indicators and corresponding reference values for electricity infrastructure, as required under Article 11(7) of Regulation (EU) 347/2013 ("the Regulation"). The report is without prejudice to the development and the publishing by the NRAs of such indicators and reference values at individual Member State or regional level as NRAs may wish to develop and publish.

The Report contains separate volumes for electricity and gas infrastructure. This volume covers the set of indicators and corresponding reference values for the relevant electricity infrastructure: overhead lines, underground cables, subsea cables, onshore AC substations, and HVDC converters. The report also summarises the work methodology and the data sample.

The underlying information is historic data going back 10 years about the relevant electricity projects, as provided by Transmission System Operators (TSOs) and other developers. The data provided included incurred cost breakdowns and technical information about the assets.

The unit investment costs (UICs) in this volume are based on real € values referenced to 2014. The data is presented in quartile box-plots to transparently express the distribution of the data by unit whilst ensuring the confidentiality of cost data for individual assets. The units provided are those identified through the study as the most useful for UIC analysis, given the quantity of the data available. Cost breakdowns are also provided for several of the assets to indicate the rough composition of costs.

The indicators and the corresponding values should not be regarded as a substitute for the due diligence in each instance of an existing or planned investment in electricity infrastructure. The sample sizes and distributions should also be taken into account when using the UICs given.

It is important to underline that this report cannot be seen as legal advice, and neither the Agency nor any NRA can be held responsible for any consequence of the use of the UIC indicators and their reference values.

2 Background and Objectives

2.1 Legal basis

Pursuant to Article 11 (7) of the Regulation, 'national regulatory authorities… cooperating in the framework of the Agency shall establish and make publicly available a set of indicators and corresponding reference values for the comparison of unit investment costs for comparable projects of the infrastructure categories included in Annex II of the said Regulation'. For electricity these infrastructure categories are defined as follows:

(a) *high-voltage overhead transmission lines, 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;*

(b) *concerning in particular electricity highways; any physical equipment designed to allow transport of electricity on the high and extra-high voltage level, in view of connecting large amounts of electricity generation or storage located in one or several Member States or third countries with large-scale electricity consumption in one or several other Member States;*

(c) *electricity storage facilities used for storing electricity 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 designed for a voltage of 110 kV or more;*

(d) *any equipment or installation essential for the systems defined in (a) to (c) to operate safely, securely and efficiently, including protection, monitoring and control systems at all voltage levels and substations;*

(e) *any equipment or installation, both at transmission and medium voltage distribution level, aiming at two-way digital communication, real-time or close to real-time, interactive and intelligent monitoring and management of electricity generation, transmission, distribution and consumption within an electricity network in view of developing a network efficiently integrating the behaviour and actions of all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable electricity system with low losses and high quality and security of supply and safety;*

The Regulation also establishes that *'those reference values may be used by the ENTSO for Electricity and the ENTSO for Gas for the cost-benefit analyses carried out for subsequent 10- year network development plans.'*

2.2 Objectives

The main objective of the work undertaken by NRAs cooperating in the framework of the Agency is to compile a set of UIC indicators and corresponding reference values as required by the Regulation. The indicators are useful for the following purposes:

1. Preparation of the Ten-Year Network Development Plans (TYNDP)
2. PCI selection, where the indicators and the reference values could provide a reference point for the assessment of the project promoters' submissions
3. Development of better informed CBCA decisions, where the indicators and the values could be of help to NRAs when deciding on investment requests and considering cross-border cost allocation
4. Analyses associated with public financial assistance, where the indicators and the values could be informative for the agencies and the authorities in charge for the evaluation of proposals for grants to project promoters

In addition, the indicators may provide transparency regarding information about the levels of costs of electricity infrastructure in the European Union, as well as the structure of the costs, and the role of various factors affecting the costs.

2.3 Scope of the analysis

The work methodology for the preparation of this Report considers the variety of asset types and the large range of physical and non-physical cost drivers across Europe and therefore provides a solid basis for calculating UICs. In particular, the published unit investment cost indicators and their reference values have been developed by taking into account relevant cost categories which apply to most projects, with an assessment of cost drivers. Costs which are heavily dependent on particular contexts, such as financing costs, were left out of the scope of work.

Data on the historical costs of individual assets rather than projects was collected as projects could potentially include multiple assets which would complicate the analysis. Assets commissioned more than 10 years ago were left out of the analysis.

For certain asset categories defined in Annex II of the Regulation, only a limited number of assets have been built recently so that a meaningful empirical analysis was not possible. This relates to smart grid and storage investments. Further, NRAs did not have information and were not in the position to collect information on the cost of electricity storage facilities as storage does not fall into the regulated sphere of NRAs. Taking these restrictions into account, this study is limited to unit investment costs for overhead lines, underground cables, subsea cables, onshore AC substations, transformers and HVDC converters.

The analysis aims at achieving a balance between the level of detail and the robustness of the values provided. In this respect, the objective is not to have a large number of detailed case studies, but rather to derive UICs for the analysis of infrastructure projects.

Several assumptions had to be made when designing the data collection questionnaires regarding the factors which are likely to be the main cost drivers. To avoid leaving important cost drivers out of the scope of work, NRAs and ENTSO-E were consulted prior to the collection of data.

3 Work Methodology

3.1 Data collection

In order to collect the data necessary for analysis, a questionnaire was distributed to TSOs and other developers via their NRAs. TSOs and developers were requested to submit data for new assets belonging to one of five asset categories mentioned in chapter 1. Information on individual transformers was also provided as part of the AC substation asset category. Data was also requested for offshore substations and offshore HVDC converters, but there were insufficient returns to publish values for these assets.

TSOs were asked to submit the 20 most recent newly constructed assets, going back no more than 10 years. This was to ensure the data sample was not biased in favour of larger Member States and the time horizon did not reach too far back.

3.2 Types of data collected

Two forms of data were collected for each asset:

- Technical characteristics of the project to assess cost drivers
- Total costs divided into cost categories to assess cost breakdowns

The technical characteristics were assessed to identify reliable cost drivers in the data. Where more reliable cost drivers were found, the characteristics were used to produce the outputs in chapter 5.

For all asset categories, the total asset costs were divided in to the following cost categories:

1. Materials and assembly costs:
   - Materials and manufacturing
   - Installation and civil
   - Engineering and commissioning
2. Other costs
   - Project management
   - Regulatory requirements and consent
   - Studies and surveys

The categories were used to establish cost breakdowns for each asset type, in order to give an indication of how costs were composited per unit. The more detailed breakdown of these cost categories as given to TSOs is provided in the Annex.

3.3 Treatment of factors influencing the data

Treatment of taxes

All cost information was requested to be reported 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 costs were adjusted for inflation with 2014 as the base year. To facilitate this process, the NRAs provided their respective regulatory inflation rates for every year between 2005 and 2014. Where this was not provided, Eurostat data was used. These inflation rates were used to adjust the asset costs per member state, rather than using only one index for the EU.

Treatment of exchange rates

Where data was not reported in euros, the inflated data was converted to euros at the 2014 exchange rate. The approach reflects the real cost of the assets to consumers in non-euro countries, and avoids the outputs reflecting exchange rate volatility.

Treatment of outliers

Outliers were removed 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.

3.4 Assessment of appropriate UICs

For each asset group, the costs were tested for correlations with potential cost drivers. Those showing the strongest correlations were used to develop UICs. Where two cost drivers showed strong correlations in the same model, or where splitting the data by a second cost driver allowed for better UICs for the first cost driver, the data was split into categories of the second cost driver.

UICs are provided as mean and median averages. Variance is expressed in interquartile ranges (the lower quartile and the upper quartile values). Data is also presented in quartile box-plot charts, following the exclusion of outliers. These charts show the inner quartiles or the data distribution as two solid blocks, and the outer quartiles as lines extending from these two inner quartile blocks. UICs for small samples were only given if they showed reasonable UIC indicators with acceptably low variance, and if the sample size was sufficient to protect project anonymity.

Pie charts have been used to express how developers allocated the asset costs to a number of cost categories. However, these charts are only indicative since: they include only a subset of the asset data set where the requested data was provided, and for some assets these cost allocations were quite variable. The sample sizes were not sufficient for us to provide explanations or breakdowns of this variation.

4 Data Set

4.1 Sample size

The project database was populated with the historic data on completed electrical infrastructure assets, as provided by 25 NRAs (AT, BE, HR, CZ, DK, NL, EE, FI, FR, DE, GR, HU, IE, IT, LV, LT, LU, PL, PT, RO, SK, SI, SP, SE, UK) from their respective TSOs.

The sizes of the samples vary between assets. For overhead lines and AC substations, the samples are large. However, the samples were smaller for subsea cables and HVDC converters, and much smaller for offshore AC substations.

Table 1: Number of assets in the sample

Type of infrastructure	No. of Member States represented	Investment items
Overhead lines	14	91
AC substations	22	114

Underground cables	18	47
HVDC converters	8	14
Subsea cables	9	17
Offshore substations	3	4

Due to the small sample size for offshore substations, UICs could not be published for these assets on confidentiality grounds.

There was a high degree of variation regarding the quality of the cost category breakdowns. Various TSOs claimed that a breakdown of costs into the aforementioned categories was not possible as internal reporting structures did not allow for such a breakdown and/or projects were constructed by third parties and TSOs had no information on the actual breakdown of costs. Consequently, for the cost category assessments, it was only possible to use data from the assets that were appropriately disaggregated.

4.2 Geographical distribution

For two categories of assets, overhead lines and AC substations, and in a smaller extent for underground cables, the number of projects is uniformly distributed among Member States. For HVDC converters, and subsea cables the sample is unevenly distributed.

As expected, the concentration among countries of more specific assets such as HVDC converters and subsea cables is much stronger than for OHL and AC substations.

5 Set of Indicators and their Corresponding Reference Values

The following is the set of indicators and corresponding reference values for UICs in electricity infrastructure. All values are rounded to the nearest Euro (€), and are presented as anonymized UICs, in the most relevant units for each asset where the data permits.

5.1 Transmission network

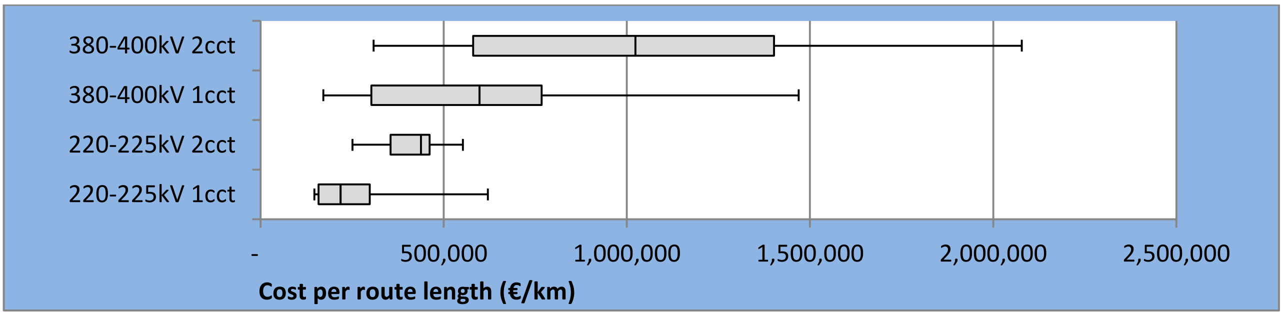
5.1.1 Overhead lines

Only AC cables were available in the sample. Voltage was the most significant cost-driver (at 95%). Costs per km increased with voltage and number of circuits, as shown in figure 1. The high degree of variation for 380-400kV assets was not explained by terrain difficulty, rating, or other asset characteristic information collected.

Table 2: UIC indicators for overhead lines

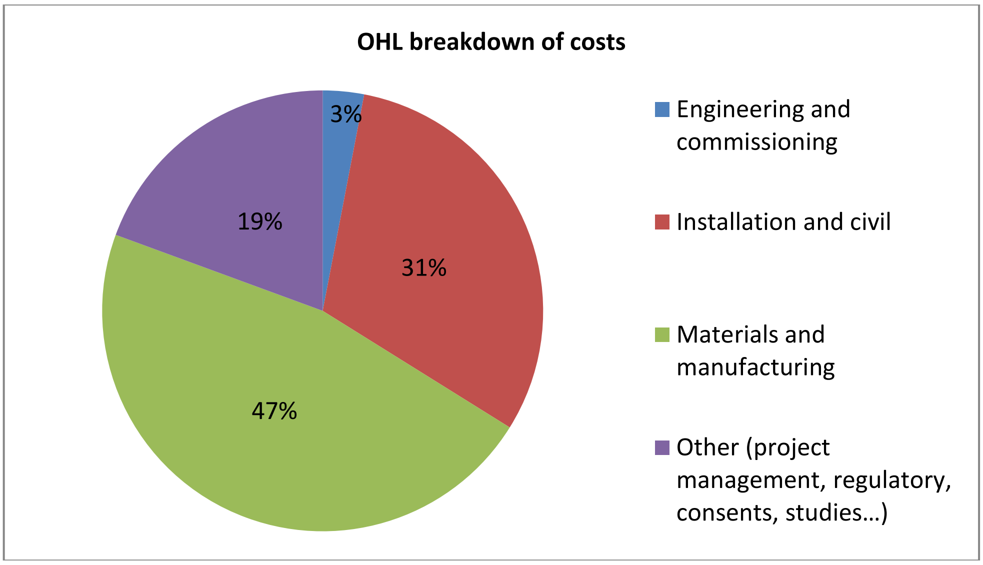
	Mean (€)	Min-max interquartile range (€)	Median (€)	No. of assets
Total cost[1] per circuit route length (km)				
380-400 kV, 2 circuit	1,060,919	579,771 – 1,401,585	1,023,703	39
380-400 kV, 1 circuit	598,231	302,664 – 766,802	597,841	32
220-225 kV, 2 circuit	407,521	354,696 – 461,664	437,263	15
220-225 kV, 1 circuit	288,289	157,926 -298,247	218,738	5

Figure 1: Overhead lines by circuit route length (km) by box-plot



[1] This is based on total asset costs, excluding financing costs

Figure 2: Overhead line cost breakdown



This cost breakdown is based on average values of the breakdowns for 79 assets.

5.1.2 Underground cables

Voltage and number of circuits, and cable rating were found to be significant cost drivers (at the 99% level). Costs increase as voltage and rating increase. However, most of the significance of rating was explained by voltage when they were tested in the same model. Moreover, dividing by rating did not improve the quality of the UICs. Thus, UICs are only given per km by voltage and number of circuits.

Table 3: UIC indicators for underground cables

Total cost	Mean (€)	Min-max interquartile range (€)	Median (€)	No. of assets
Per route length (km)				
380-400 kV, 2 circuit	4,905,681	3,557,853 – 5,895,748	5,729,628	5
220-225 kV, 2 circuit	3,314,047	3,982,813 – 4,115,441	4,063,557	6
220-225 kV, 1 circuit	2,224,630	1,920,846 – 2,444,014	2,260,036	20
150 kV, 2 circuit	1,511,846	885,759 – 1,891,647	886,109	5
150 kV, 1 circuit	695,704	454,208 – 816,016	782,212	10

All cables were AC. Insufficient data was available to assess DC cables.

Figure 3: Underground cables by route length (km) by quartile box-plots

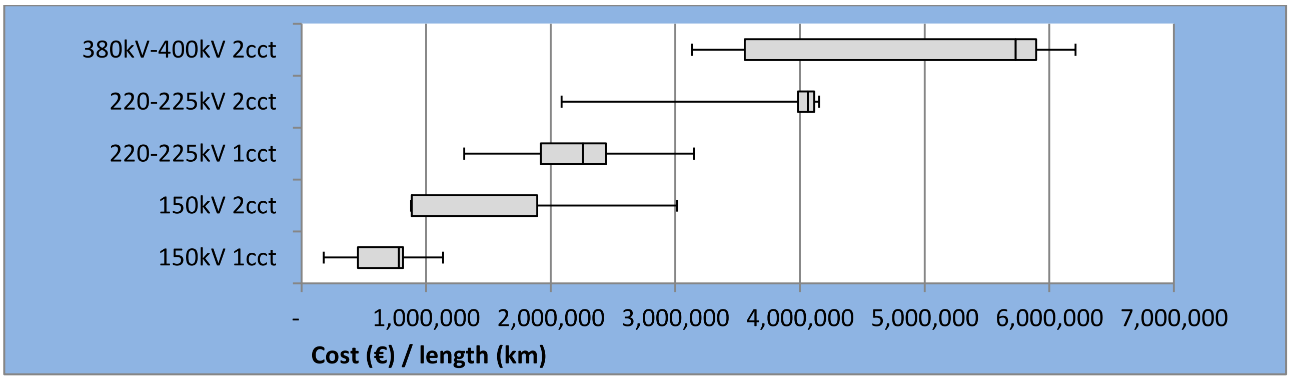
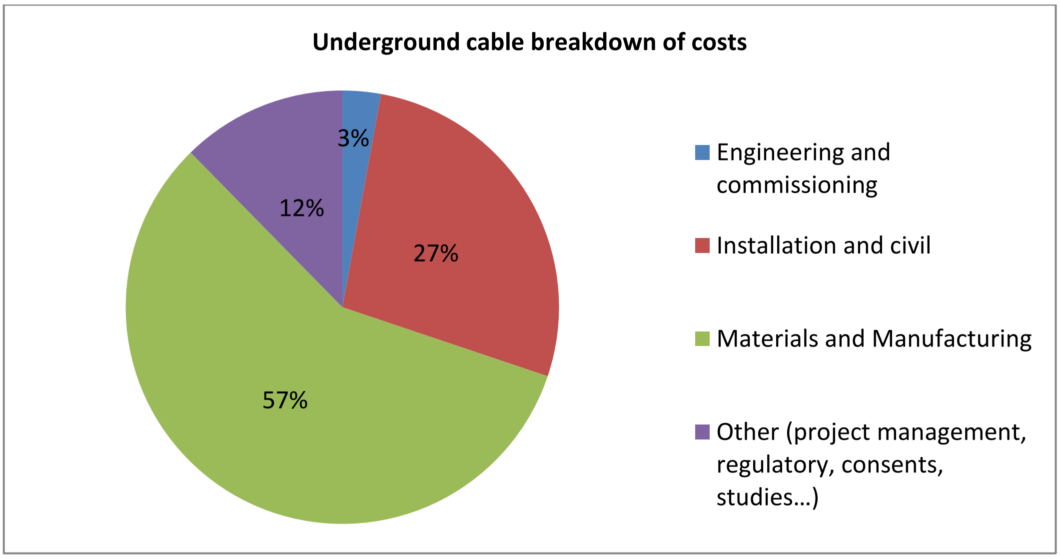


Figure 4: Underground cable cost breakdown



This cost breakdown is based on 27 assets.

5.1.3 Subsea cables

UIC indicators are split between AC and DC cables, given different technical requirements. The AC sample had a voltage range of 150-220 kV and the DC sample a voltage range of 250 to 500 kV. The UIC indicators were provided by length of distinct cable trench[2]. For DC cables, costs broadly increased with rating[3], although this was not clearly the case with AC cables. Costs were on average higher for cables with deeper cable laying depths. Further meaningful breakdowns could not be provided due to the size of the sample.

Table 4: UIC indicator for subsea cables

Total cost per route length (km)	Mean (€)	Min-max interquartile range (€)	Median (€)	No. of assets
All cables types	909,910	729,638 – 1,101,937	831,185	16
AC cables	1,143,966	1,095,474 – 1,245,183	1,140,989	6
DC cables	757,621	705,293 – 791,029	760,284	10

[2] That is, cable or series of cables laid in their own trench

[3] The DC sample had on average higher ratings than the AC sample.

Figure 5: Subsea cable cost per separate cable km by quartile box-plot

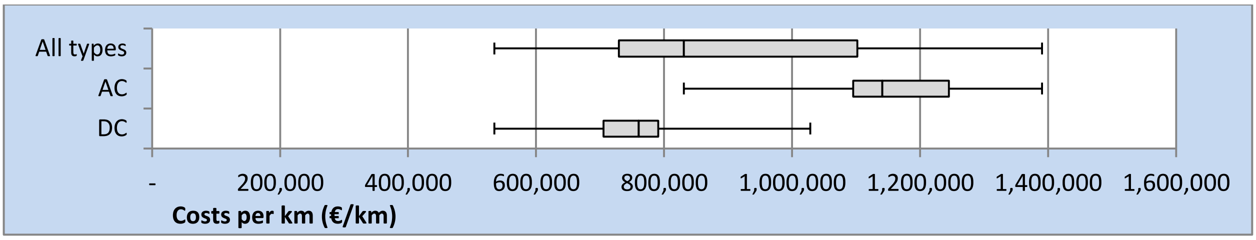
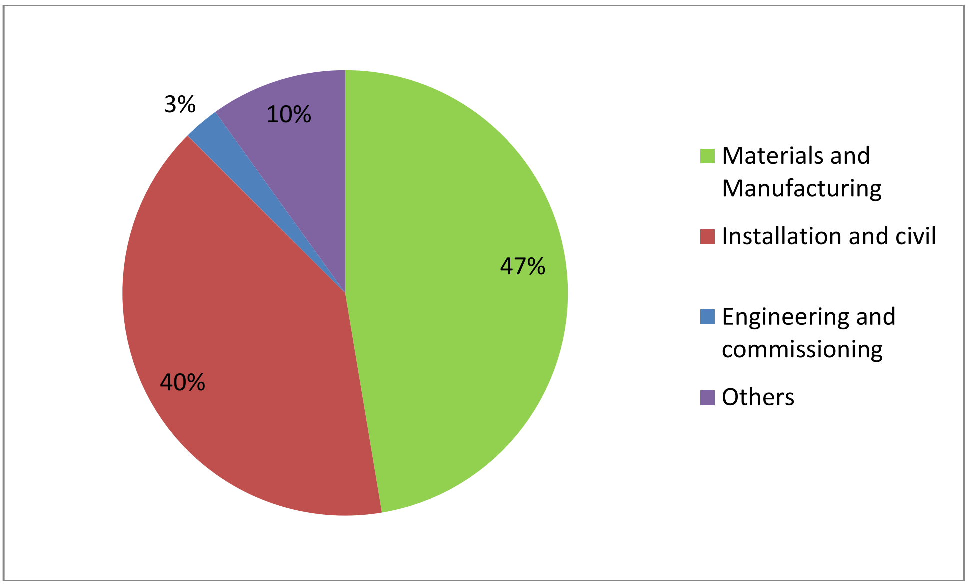


Figure 6: Subsea cable cost breakdown



This cost breakdown is based on only 7 assets and so is only a rough indication. However, the variation between the assets was relatively limited.

5.2 Associated equipment

5.2.1 AC substation (onshore)

Only substations where the substation-owner owned and included in their submission the costs of the main transformers were assessed.

Total substation rating was identified as the most significant cost driver (at 99% confidence)[4]. Busbar voltage was also a highly significant cost driver, as was the number of bays, and both remained highly significant when modelled together (all at 99% confidence). Voltage UICs are therefore also split between numbers of bays in the substation for Air Insulated Substations (AIS). Gas Insulated Substations (GIS) were assessed separately, without being split between the number of bays.

Table 5: UIC indicators for AC substations by rating

	Mean average UIC (€)	Min-max interquartile range (€)	Median (€)	No. of assets
Total cost per total rating (MVA)	38,725	26,436 – 52,078	35,500	99[2]

Figure 7: Substation total cost (€s) per total rating (MVA) by quartile box-plots

[4] Not all TSOs submitted data on rating, even where other transformer data was present. These were excluded from the rating analysis.

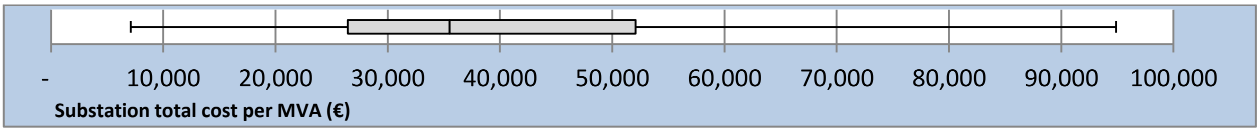
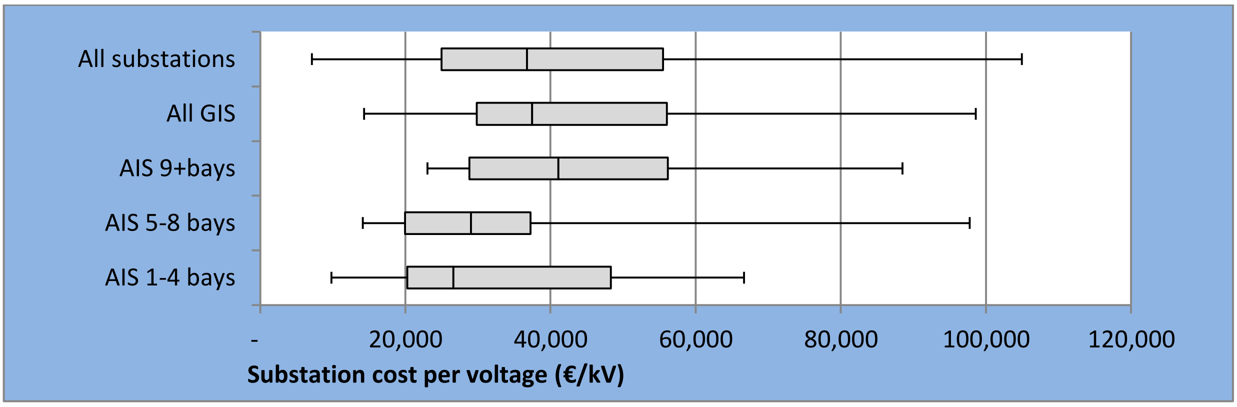


Table 6: UIC indicators for AC substations by voltage

Total substation cost per voltage (kV)	Mean average UIC (€)	Min-max interquartile range (€)	Median (€)	No. of assets
All substations	42,627	24,994 – 55,508	36,755	114
All GIS substations	46,237	29,837 – 56,017	37,449	18
AIS with 9+ bays	44,008	28,838 – 56,157	41,080	17
AIS with 5-8 bays	35,593	19,936 – 37,251	29,021	24
AIS with 1-4 bays	33,192	20,276 – 48,319	26,628	30

Figure 8: Substation total cost (€s) per kV by quartile box-plots



It was not possible to provide a cost breakdown for AC substations because complete and reliable cost category breakdowns were only provided for a limited number of assets.

5.2.2 Transformers

Data on transformers was collected as part of substations, but provided enough information for a separate analysis. The rating of transformers (MVA) was a highly significant cost driver (at the 99% confidence level). Both an average UIC per MVA rating and the costs of transformers within specified ranges of MVA ratings are given to demonstrate this close association.

Table 7: UIC indicators for individual transformers

Transformer cost	Mean average (€)	Min-max interquartile range (€)	Median (€)	No. of assets
Per MVA rating	9,903	6,865 – 12,709	9,500	99
Total transformer costs in rating ranges				
500-800 MVA	6,108,414	5,432,864 – 7,144,674	6,412,420	18
300-450 MVA	3,819,670	3,251,819 – 4,274,942	3,669,497	26
150-280 MVA	1,803,607	1,640,847 – 1,934,558	1,833,541	39

Figure 9: Transformer cost (€s) per total rating (MVA) by quartile box-plots

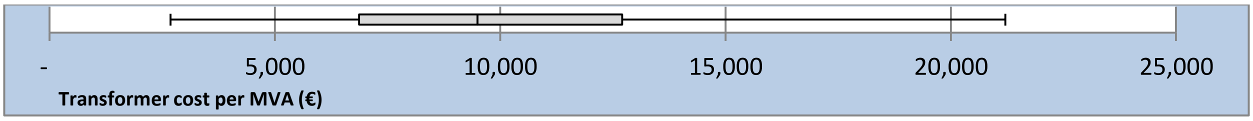
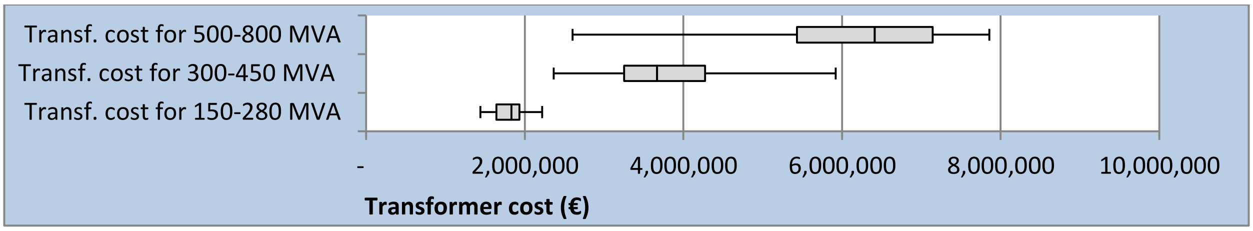


Figure 10: Transformer cost (€s) split into rating ranges by quartile box-plots



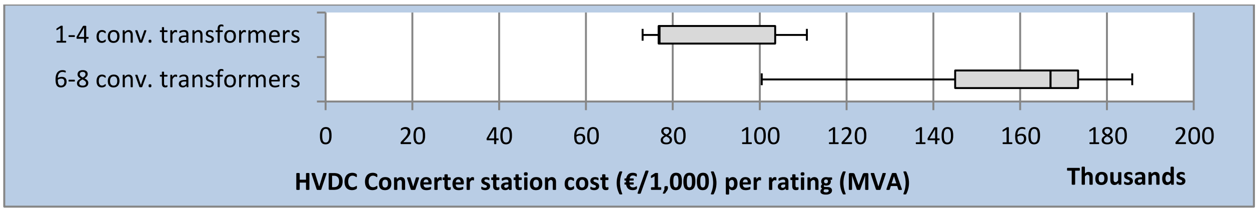
5.2.3 HVDC converter station

Correlations were identified between both rating (MVA) and the number of transformers in a station. Lower variation in the rating UIC was given when split into categories based on the number of converter transformers in the station. All assets in the 6-8 converter transformers category were CSC. There was an even mix of VSC and CSC in the 1-4 converter transformers category. VSC tended to have a higher cost per MVA than CSC within the 1-4 converters category, although this breakdown cannot be shown due to the size of the samples.

Table 8: UIC indicator for HVDC converter station

Total cost per rating (MVA)	Mean average (€)	Min-max interquartile range (€)	Median (€)	No. of assets
1-4 converter transformers	87,173	76,030 – 103,566	76,923	7
6-8 converter transformers	155,709	144,990 – 173,342	167,013	7

Figure 11: HVDC converter station total cost per rating (MVA) quartile box-plot



Costs provided in thousands of euros for ease of presentation.

It was not possible to provide a cost breakdown due to the small number of projects where a proper breakdown of costs was provided.

Appendix A: Changes from Version 1 to Version 1.1 (August 2015)

All the changes introduced to the document in Version 1.1 are listed below except for minor changes such as typographical errors or formatting.

Table 7: UIC indicators for individual transformers

Transformer cost min-max interquartile range (€) per MVA rating of 4,791 – 12,318 in the original version replaced with 6,865 – 12,709 in the current corrigendum version.

Table 8: UIC indicator for HVDC converter station

All the cost values in Table 8 replaced with the below values. Number of assets remains as in the original version.

Total cost per rating (MVA)	Mean average (€)	Min-max interquartile range (€)	Median (€)	No. of assets
1-4 converter transformers	87,173	76,030 – 103,566	76,923	7
6-8 converter transformers	155,709	144,990 – 173,342	167,013	7

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