PEER REVIEW OF "COST OF CAPACITY FOR CALIBRATION OF BELGIAN CRM" STUDY

A report to Elia

OCTOBER 2020

AFRY

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1 EXECUTIVE SUMMARY

The new Belgian Capacity Remuneration Mechanism (CRM) is about to be introduced with the first capacity auction set to take place in October 2021. Elia and CREG have been working on the design parameters, including the fixed cost estimates for existing units. These costs are used for the purposes of defining the relevant price caps for existing capacity providers.

A study undertaken by Fichtner, and completed in April 2020, provides for cost estimates for new entrant technologies and existing/operating technologies in Belgium. We (AFRY) have been requested to review these cost estimates and provide for a further independent view, and to provide for estimates for the annual avoidable fixed costs of pumped storage units.

The Fichtner specific O&M cost estimates for existing peaking units is broadly reasonable, but on the upper end of the spectrum for turbojet units

Our review of the Fichtner analysis has highlighted the following:

- the EPC cost suggested by Fichtner appears to be on the low side, and we would recommend that this is set at 180% of the total equipment cost;
- on the other hand, the annual operating cost put forward by Fichtner appears to be rather conservative, and we would expect this to be significantly lower;
- the resulting specific O&M cost appears to be reasonable for frame GTs and aero-derivatives, but on the upper end of the spectrum for turbojet units.

Table 1 shows our estimates for the specific fixed O&M cost. These are based n an assumed 800h of operation and 150 starts per annum. More restricted operation would most likely mean lower maintenance costs and the fixed O&M would be lower than that presented below.

Table 1 – Specific O&M cost for existing Belgian OCGTs

Unit	Capacity (MW)	Type	Commercial operation date	Specific fixed O&M cost (€/kW/a)		
				Fichtner	AFRY	AFRY (excl. grid charge)
Angleur 3 - TG31	25	Frame type	1978	25.40	40.68	40.19
Angleur 3 - TG32	25	Frame type	1978	25.40	40.68	40.19
Angleur 4 - TG41	63	Aero	2012	18.49	19.08	18.59
Angleur 4 - TG42	63	Aero	2012	18.49	19.08	18.59
Ham - HAM31	56	Aero	2006	19.38	19.08	18.59
Ham - HAM32	56	Aero	2006	19.38	19.08	18.59
Cierreux	18	Turbojet	1960's	33.83	29.49	29.00
Beerse	32	Turbojet	1960's	28.94	23.07	22.58
Zelzate	18	Turbojet	1960's	33.83	29.49	29.00
Aalter	18	Turbojet	1960's	33.83	29.49	29.00
Zedelgem	18	Turbojet	1960's	33.83	29.49	29.00
Noordschote	18	Turbojet	1960's	33.83	29.49	29.00
Zeebrugge	18	Turbojet	1960's	33.83	29.49	29.00

We are in agreement with the Fictner CCGT specific O&M cost estimates; however, assuming a more limited operating profile for existing CCGTs would result in lower annual maintenance costs

Our assessment of the Fichtner existing CCGT cost estimates suggests that these are reasonable assuming 'baseload' operation. We do however, recognise that existing CCGTs in Belgium are operating in a more mid-merit fashion. This could then reduce the need for major maintenance, and the corresponding costs could be lower.

Table 2 shows our specific O&M cost estimates for existing CCGTs in Belgium. We present our cost estimates assuming both baseload and mid-merit operation, and including and excluding electricity transmission charges.

Table 2 – Specific O&M cost for existing Belgian CCGTs

				Specific fixed O&M cost (€/kW/a)				
Unit	**Capacity (MW)**	**Type**	**Commercial operation date**	Fichtner	AFRY (8000h)	AFRY (4000h)	AFRY (8000h, no elec)	AFRY (4000h, no elec)
T-Power	425	1x1	2011	41.41	41.39	34.55	36.46	29.62
Seraing	485	2x1	1994	40.21	42.10	34.53	37.16	29.59
Amercoeur	451	1x1	2010	40.58	40.26	33.81	35.32	28.88
Marcinelle	405	1x1	2011	41.73	42.36	35.18	37.42	30.24
Saint-Ghislain	350	1x1	2000	43.14	45.52	37.21	40.59	32.28
Drogenbos	460	2x1	1993	40.65	43.22	35.24	38.28	30.30
Knippergroen	315	1x1	2010	44.13	48.06	38.83	43.12	33.89
Ringvaart	357	1x1	1998	43.14	45.07	36.93	40.13	31.99
Herdersbrug	480	2x1	1998	40.21	42.31	34.66	37.38	29.73
Zandvliet	384	1x1	2005	42.19	43.47	35.90	38.53	30.96
Inesco	138	1x1	2007	53.99	56.46	46.35	51.52	41.42

There is a strong degree of variation in pumped storage annual O&M costs, and believe that 19 €/kW is a reasonable estimate for Belgian plants

Our review of different public data sources (from power utilities as well as authorities) combined with our inhouse knowledge suggests annual fixed O&M cost for PSP in the range of 10 to 30 €/kWh. There may, however, be a significant difference between small and large PSP plants, and recommend the use of an average cost of 19 €/kW for the purposes of defining a typical fixed O&M value for a pumped storage plant in Belgium.

2 Introduction

2.1 Introduction and background

With the planned introduction of a Capacity Remuneration Mechanism (CRM) in Belgium from 2025, and capacity auctions set to take place in October 2021, Elia (along with CREG) has been working on the design parameters. One key consideration is the gross (and net) cost of new entry and the fixed cost estimates for existing units. These costs are used for the purposes of defining the relevant price caps for new and existing capacity providers.

A study undertaken by Fichtner (hereafter called the 'Fichtner study'). provides for cost estimates for new entrant technologies and for existing/operating technologies in Belgium. The Fichtner study was completed in April 2020. Subsequently Elia organised a public consultation regarding a set of inputs to be used in the calibration process with the cost estimates in Fichtner report being a focal point.

The objective of this project is to provide Elia with an independent peer review of sections of the Fichtner report. The focus of this report is:

- Section 4.2 on the detailed cost calculation for shortlisted existing technologies; and
- Section 4.3 on results for the existing units in Belgium.

We have also been asked to provide estimates for the annual avoidable fixed costs for pumped storage assets in Belgium.

2.2 Structure of this report

This report is structured as follows:

- Section 3 describes our review of the Fichtner study (Section 4.2 and Section 4.3 of the Fichtner report), and our assessment of the annual avoidable fixed costs for existing units;
- Section 4 presents our independent estimates of the annual avoidable fixed costs for a pumped storage asset in Belgium.

2.3 Conventions

All monetary values quoted in this report are in Euros (€) in real 2019 prices, unless otherwise stated.

Plant efficiencies throughout this report are defined at the Higher Heating Value (HHV) basis. Fuel prices are similarly quoted on a gross (HHV) basis.

2.3.1 Sources

Unless otherwise attributed the source for all tables, figures and charts is AFRY Management Consulting.

3 FIXED COSTS FOR EXISTING UNITS

3.1 Approach and methodology

Our general approach, as agreed with Elia, is as follows:

- extract the values from the Fichtner study;
- opine on whether the numbers proposed by Fichtner are reasonable or unreasonable, alongside supporting justification; and
- in cases where a number is considered to be unreasonable, provide a counter proposal with supporting justification.

Any justification provided is also supported by publicly referenced sources wherever possible. It is only when no such sources are publicly available that we revert to using our own in-house knowledge and experience.

For the avoidance of doubt, AFRY has not held any discussions with Fichtner for the purposes of preparing this independent report.

3.1.1 Definition of fixed O&M cost

The fixed O&M cost is considered to include the following components[1]:

- fixed operating costs including personnel costs, administrative costs, electricity and gas transmission charges (where applicable);
- the O&M insurance for general liability, machine breakdown and interruption of operation of a power plant;
- fixed maintenance costs including intra-year maintenance and a provision for major overhauls that do not necessarily take place on a yearly basis.

3.1.2 Technologies considered

Section 4.3 of the Fichtner study present the results of the detailed cost calculations for the following existing technologies in Belgium:

- Open cycle gas turbines (OCGTs);
- Combined cycle gas turbines (CCGTs); and
- Combined heat and power (decentralised).

[1] Elia document "Explanatory note for the Public consultation on the scenario's, sensitivities and data for the CRM parameter calculation for the Y-4 Auction with Delivery Period 2025-2026", dated May 2020

Elia has confirmed that combined heat and power (decentralised) technology shall not be considered further on the basis that such installations are expected to derive a significant part of their revenues from sources other than electricity (e.g. from the value of produced heat), and the respective 'missing money' will be more limited[2]. The focus of this review has therefore been on existing OCGT and CCGT technologies in Belgium.

3.1.3 Publicly referenced sources

The following sources have been used in the preparation of this report:

- "COST OF NEW ENTRANT PEAKING PLANT AND COMBINED CYCLE PLANT IN I-SEM," dated August 2018 prepared by Pöyry Management Consulting ("Pöyry 2018").
- "PJM Cost of New Entry Combustion Turbines and Combined-Cycle Plants with June 1, 2022 Online Date" dated April 2018 prepared by the Brattle Group ("Brattle 2018");
- Independent Consultant Study to Establish New York ICAP Demand Curve Parameters for the 2021/2022 through 2024/2025 Capability Years – Final Report" dated Sept 2020 prepared by Analysis Group, Inc. and Burns & McDonnell ("Analysis 2020");
- COST ESTIMATES FOR THERMAL PEAKING PLANT FINAL REPORT" dated June 2008 prepared by Parsons Brinckerhoff New Zealand Ltd ("Parson Brinckerhoff 2008")
- the Gas Turbine World Handbook for the year 2019 ("GTW 2019").

3.2 Review of Section 4.2 of the Fichtner study

Section 4.2 of the Fichtner Study states that "*…this section provides a detailed cost calculation for the shortlisted existing technologies in Belgium*."

We note there is no actual detailed cost calculation provided in Section 4.2. In particular:

- Section 4.2.1, which relates to the fixed O&M costs, lists the components that are included in the fixed O&M costs, without providing for any calculation methodology or breakdown for each cost component.
- there are no "numbers" that can be extracted from Section 4.2 for us to comment on.

The more detailed cost calculation is actually included in Section 4.3, and this is discussed below.

[2] Elia document "Explanatory note for the Public consultation on the scenario's, sensitivities and data for the CRM parameter calculation for the Y-4 Auction with Delivery Period 2025-2026", dated May 2020

3.3 Review of section 4.3 of the Fichtner study – OCGTs

3.3.1 Fichtner study estimates

First, we have extracted the numbers for the different existing OCGTs from Section 4.3.1 of the Fichtner study. These are presented in the table below.

Table 3 – Fichtner estimates for existing OCGTs

Unit name	Capacity (MW)	Configuration	Year of construction	Annual fixed O&M costs (€/a)	Specific Annual Fixed O&M costs (€/kW/a)
Angleur 3	50	OCGT	-	1,270,000	25.40
Angleur 4	126	OCGT	-	2,330,000	18.49
Ham	112	OCGT	2006	2,170,000	19.38
Cierreux	18	Turbojet	-	609,000	33.83
Beerse	32	Turbojet	-	926,000	28.94
Zelzate	18	Turbojet	-	609,000	33.83
Aalter	18	Turbojet	-	609,000	33.83
Zedelgem	18	Turbojet	-	609,000	33.83
Noordschote	18	Turbojet	-	609,000	33.83
Zeebrugge	18	Turbojet	-	609,000	33.83

Source: Table 15 of the Fichtner study

We note the following when it comes to the units included in the above table:

- the "turbojet" units identified in the table above, installed between 1963 and 1968, are of the aircraft jet engine type (make is unknown and we have assumed Rolls Royce Avon turbojet or similar);
  - these engines use kerosene as their fuel[3];
- the Angleur 3 plant was originally a 117 MWe combined cycle power plant, comprising two gas turbine, two heat recovery boilers and one steam turbine, built in 1978, and the plant was converted to open cycle in 2013;
  - the gas turbines are rated at 25 MWe each (TG31 and TG32)[4];

[3] Experience in Belgium with Aircraft Jet Engine Peaking Units, H. BOSQUET and J. REMEYSEN, presented at the ASME gas turbine conference & products show, Brussels, Belgium, May 24- 28 1970

[4] https://edfluminus.edf.com/edf/la-centrale-electrique-d-angleur

- the Angleur 4 plant, commissioned in 2012 comprises two Rolls Royce Trent 60 aeroderivative type gas turbines. The Trent 60 gas turbine was derived from the Rolls-Royce Trent aero engine for the Boeing 777;
  - the gas turbines at Angleur are of the dual fuel type. The gas turbines are rated for 63 MWe each (TG41 and TG42)[5];
- the Ham plant, commissioned in 2006, comprises two Rolls Royce Trent 60 aeroderivative type gas turbines. The plant is designed to burn natural gas only;
  - the gas turbines are rated for 56 MWe each (HAM31 and HAM32)[6];

The capacities quoted in the Fichtner table are at ISO conditions (15°C and 60% relative humidity).

We believe it would have been more appropriate for Fichtner to have listed the individual gas turbines units for the Angleur and Ham facilities, as these are individually dispatchable units.

It is not clear if the capacity figures in the above table are quoted on a "clean and new" basis or "average degraded" basis. Average degraded net plant capacities are typically used for reports of this nature to reflect expected operations over the life of the relevant asset. New and clean output is typically degraded by 2% to arrive at an average degraded figure.

3.3.2 Review of Fichtner estimates for Angleur 4 units

Section 4.3.1 of the Fichtner study states that "*the numbers provided in Table 15 are estimated by Fichtner (Fichtner 2020) based on the data provided for the individual units, the methodology presented (i.a. in Section 4.2) and Fichtner's experience as a technical consultant).*" Fichtner 2020 is described within the Fichtner study as "*Internal data, calculations and interviews with experts. Stuttgart*". These reference data have not been provided to us for review.

In the absence of any information to the contrary, we consider it reasonable to assume that Fichtner estimated the fixed O&M costs for the existing plants in Belgium in the same way that they estimated the fixed O&M costs for the gross CONE calculation.

The table below contains an estimate of fixed O&M costs for the Angleur 4 gas turbine units using the methodology used by Fichtner for the gross CONE calculation (as set out in Section 3.3.3 of the Fichtner study).

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5 https://www.rolls-royce.com/media/press-releases-archive/yr-2012/120515-plant-in-belgium.aspx
6 https://www.powerengineeringint.com/world-regions/europe/peak-practice-choosing-a-brand-new-engine-for-variable-load-generation/

Table 4 – Fichtner Gross CONE calculation methodology applied to the Angleur 4 units

Parameter	Units	Value	Remark
Plant	-	Angleur 4	
Gas turbine model		Trent 60	
Fuel type		Gas/oil (dual) [7]	
Rated output	MWe	63	
EPC cost			
Equipment supply	€/kW	323	**GT World 2019**
Construction	€/kW	80.84	**25% of equipment supply**
Engineering	€/kW	16.168	**5% of equipment supply**
Total	€/kW	420.368	
Plant capacity	kW	63,000	
EPC cost	€	26,483,184	
Fixed O&M			
Fixed operating costs	€/a	926,911	**3.5% of EPC cost**
Operating insurance	€/a	132,416	**0.5% of EPC cost**
Fixed maintenance	€/a	132,416	**0.5% of EPC cost**
Total	€/a	1,191,743	
Specific fixed O&M cost	€/kW/a	18.9	18.49 in Fichtner study

The estimated specific fixed O&M cost (18.9 EUR/kW/a) following this methodology is broadly aligned with the estimate in Table 15 of the Fichtner study (18.49 €/kW/a).

The extent to which the Fichtner estimates used in the above calculation (highlighted in bold text in the above table) is reasonable (or not) is discussed in the sections below.

[7] https://www.rolls-royce.com/media/press-releases-archive/yr-2012/120515-plant-in-belgium.aspx

3.3.2.1 **EPC cost**

Section 3.3.2.1 of the Fichtner study states that *"every year the Gas Turbine Handbook (GTW, 2019) publishes current turbine prices based on real machines sold…. The main technical components comprise a gas turbine, generator, associated mechanical and electrical auxiliaries, systems and an operational control system (GTW, 2019)."*

The gas turbine installed at the Angleur 4 facility are of the Trent 60 WLE type capable of dual fuel operation (63 MWe). The closest unit in the 2019 GT World Handbook is the SGT-A65 DLE (Trent), rated at 61.9 MWe at ISO conditions, and has a budget equipment supply price of 376 $/kW. Converting to Euros gives a budget price of 323 €/kW, which is the figure used in the table above.

The Fichtner study assumes the overall EPC price is 130% of the "equipment supply" price (adding 25% for construction and 5% for engineering). We consider this number to be on the low side:

- GTW 2019 states that the "equipment supply" cost is "*based on a standard bare bones single-fuel (gas only) packaged units*". The Fichtner study then does not make any allowance for the Angleur 4 units having dual fuel capability.
- GTW 2019 states that "*mechanical packages include lube oil and hydraulic fluid, sumps, pumps, controls and coolers*." The Fichtner study does not make any allowance for other equipment typically found on an OCGT plant including a dedicated fire water storage tank and associated fire water pumps, compressed air plant, liquid fuel storage tank (in case of dual fuel facilities), a water treatment plant (for water injection purposes in case of a dual fuel facility), a workshop and warehouse, a natural gas metering and regulating station, a gas compressor (if needed) etc.
- GTW 2019 states "*auxiliary transformers for conditioning power supply for plant motors are usually optional, as is the main power step up transformer*". The Fichtner study does not make any allowance for the cost of the generator step up transformer.
- GTW 2019 states that "*that the cost of engineering, construction services and other project costs can add from 60% to 100% and more of the cost of equipment alone. A practical rule of thumb is to double the equipment price for a rough estimate of the total installed cost.*" The Fichtner Study only adds 30%, far less than the 60% to 100% recommended in GTW 2019.
- The EPC cost breakdown for an OCGT plant given in Brattle 2018 shows that, excluding sales taxes, the overall EPC cost is around 180% of the total equipment costs ("gas turbine" plus "other equipment"). [Table 9 of Brattle 2018, CONE Area 3]
- Thermoflow Inc provide a suite of engineering tools that are well-established and recognised throughout the power generation industry. The EPC cost breakdown data in the table below has been derived using the Thermoflow GTPRO software (version 26.1 library) and associated PEACE module for a similar sized OCGT plant to Angleur 4. The overall

EPC cost is 173% of the cost of the "equipment supply" cost (referring to the line item named "Specialised Equipment").

Table 5 – EPC cost breakdown provided for OCGT plant by PEACE

Cost component	% of EPC cost
Specialized Equipment (i.e. GTG package)	58%
Other Equipment	1%
Civil	8%
Mechanical	7%
Electrical Assembly & Wiring	2%
Buildings & Structures	2%
Engineering & Plant Start-up	4%
Contractor's Soft & Miscellaneous Costs	17%
Total EPC Cost	100%

In line with the above, we recommend for the overall EPC cost to be set at 180% of the equipment supply cost, rather than the 130% used in Fichtner study.

3.3.2.2 Fixed Operating Cost

The fixed operating costs include "personnel costs, administrative costs, electricity and gas transmission charges".

We note that property taxes and land lease costs, which are eligible operating expenses in Brattle 2018 and Pöyry 2018, are excluded from the above definition and have not been considered in the Fichtner study or in the analysis below.

Section 3.3.2.1 of the Fichtner study states that the operating costs are "*usually presented as a percentage of the EPC contact price*". The percentage used is not explicitly stated in the Fichtner study, however by comparing the operating costs contained in Table 10 of the Fichtner study with the EPC costs contained in Table 6, we can infer that Fichtner have assumed operating costs at 3.5% of the EPC cost.

The Fichtner study states that "*total fixed O&M costs for the different technologies are given in several studies such as (IEA, 2010)*". The IEA, 2010 citation is described in the Fichtner study as "Gas-fired power, https://iea-etsap.org/E-TechDS/PDF/E02-gas_fired_power-GS-AD-gct.pdf: s.n.". We have reviewed the IEA, 2010 document, but could not find any clear justification for the 3.5% choice.

We have extracted the equivalent operating costs from the Pöyry 2018 report and calculated these as a percentage of the EPC cost. The results are shown in the table below and reflect the situation for a 200MWe OCGT plant construction in Ireland.

Table 6 – Operating Costs for 200MWe OCGT in Ireland

Parameter	Cost (€)	Remark
EPC cost	93,400,000	
Operating costs		
Trading and admin costs	740,362	assumed 0.8% of the EPC contract price
Personnel costs	780,000	assumed an O&M team comprising 10 full time employees and an average cost of €78k per employee
Electricity transmission charges	1,236,742	determined by tariffs published by the Irish transmission system operator
Gas capacity charges	-	Assumed zero for OCGT in Ireland
Total operating costs	2,757,104	
Operating cost as percentage of EPC cost	3.0%	

Source: Pöyry 2018

The operating costs as a percentage of the EPC cost is 3.0% based on the Pöyry 2018 report. AFRY notes however that the electricity transmission charge and gas transmission charges can be a significant component of the overall cost in the above table and these are country-specific. We understand that for a 200MW OCGT plant in Belgium, the electricity and gas transmission charges would be as follows:

- in terms of electricity transmission and connection charges, units pay a fixed connection charge (on average 1€/kW) and charges for injecting electricity to the grid, which is estimated at 98,704 €/year for a 200MWe plant operating for 800 hours per year (160,000 MWh per annum); and
- in terms of the gas transmission charges, we have assumed that short-term gas capacity products are available, and peaking units treat these as variable costs.

Replacing the above transmission charges in the table somewhat reduces the above operating cost as percentage of EPC cost (from 3% to 1.9%), reflecting the difference between grid charges in Ireland and Belgium.

In line with the above, we consider the Fichtner estimate to be on the high side.

3.3.2.3 Operating Insurance Cost

The insurance cost includes "O&M insurance for general liability, machine breakdown and interruption of operation of the power plant".

Section 3.3.2.2 of the Fichtner Study states that "*the annual costs for insurances are set to 0.5 % of the EPC contract price for all technologies based on Fichtner's experience and values from (Konstantin 2013) and (Pöyry 2018)*."

Pöyry 2018 assumes the insurance cost at 0.6% of the EPC cost. Brattle 2018 assumes the insurance cost at 0.6% of the total project investment cost (referred to as the overnight capital cost in Brattle 2018) which equates to around 0.8% of the EPC cost. Analysis 2020 assumes the insurance cost at 0.6% of the total project investment cost (referred to as the capital cost in Analysis 2020) which equates to around 0.8% of the EPC cost.

Based on the above AFRY considers Fichtner number (0.5%) to be on the low side and AFRY would recommend increasing this to 0.6% as per Pöyry 2018 (albeit still lower than Brattle 2018 and Anaysis 2020).

3.3.2.4 Fixed Maintenance Cost

The fixed maintenance cost includes "intra-year maintenance and a provision for major overhauls that do not necessarily take place on a yearly basis.

Section 3.3.2.2 of the Fichtner study states that "*based on Fichtner's expertise and values from literature (Konstantin, 2013), (Pöyry 2018) the fixed maintenance costs are estimated with 0.5 % of the EPC contract price*".

Pöyry 2018 assumed the fixed maintenance cost at 0.5% of the EPC contract price. However, this fixed maintenance cost only covered routine and preventative maintenance activities including consumables (filters, fuses, bulbs, gaskets, pump mechanical seals, pump / motor bearings, lubricating oil changes, etc). It did not cover the cost of planned maintenance on the gas turbines (i.e. major overhauls that do not necessarily take place on a yearly basis). Pöyry 2018 assumed that the cost of this planned maintenance (parts and labour) would be covered under a separate Long Term Service Agreement (LTSA) to be entered into between the plant owner and the LTSA contractor (who is also typically the gas turbine manufacturer).

Pöyry 2018, estimated the total annual LTSA costs for a 200MWe "frame" type gas turbine, having an operating regime of 150 starts and 500 operating hours per annum, at € 2 million per annum (on top of the 0.5% of the EPC cost allowance for fixed annual maintenance).

Brattle 2018 also follow the Pöyry 2018 approach. Brattle 2018 include "*minor maintenance and repairs*" at 0.27% of the EPC cost and includes a separate line item for the "LTSA" cost. With respect to the LTSA cost, Brattle 2018 provides the following explanation:

"Major maintenance is assumed to be completed through a long-term service agreement (LTSA) with the original equipment manufacturer that specifies when to complete the maintenance based on either fired-hours or starts. Each major maintenance cycle for a combustion turbine typically includes regular combustion inspections, periodic hot gas path inspections, and one major overhaul. [Section V(B)(1) of Brattle 2018]

In the report above, we included hours-based major maintenance costs as variable O&M costs. Since June 2015, long-term major maintenance and overhaul costs that are specified in Long-Term Service Agreements (LTSAs) have been excluded from being counted as variable O&M costs in the PJM cost guidelines for cost offers.103 We understand these guidelines are being discussed in a current initiative within the Market Implementation Committee. In case the guidelines remain unchanged, we provide a second set of O&M costs and CONE estimates below that include these costs as fixed O&M. [Appendix C of Brattle 2018]

Since major maintenance activities and costs are spaced irregularly over the long-term, the cost in a given year represents an annual accrual for future major maintenance. For hours-based major maintenance, the fixed O&M cost is calculated based on the estimated hours-based costs of major maintenance times the expected operation of the unit in a given year. For a CC, we assume it will operate at 75% capacity factor based on the capacity factors of actual units. For the CT, we assume it will start 240 times per year based on the results of PJM's Peak-Hour Dispatch simulation for estimating the E&AS revenue offset. Removing these costs from variable O&M will increase Net E&AS revenues and offset some (or all) of the increased CONE value in the calculation of Net CONE." [Appendix C of Brattle 2018]

Brattle 2018, estimated the total annual LTSA costs for a 321MWe "frame" type gas turbine, having an operating regime of 240 starts per annum, at USD 5.9 million (€ 5 million) per annum [Table 13 of Brattle 2018]. This LTSA cost was addition to an allowance of 0.27% of the EPC cost for fixed maintenance (referred to as "maintenance and minor repairs" in Brattle 2018).

The OCGT plants considered in Brattle 2018 and Pöyry 2018 were of the large industrial frame type. The maintenance schedule for this type of gas turbine typically involves combustion inspections, hot gas path inspections and major inspections. The intervals for each type of inspection are based on independent counts of either unit starts or unit operating hours. The exact interval varies from manufacturer to manufacturer however some typical figures are shown in the table below.

Table 7 – Typical maintenance intervals for frame type gas turbines

Planned maintenance action	Hours	Starts
Combustion inspection	8,000	450
Hot gas path inspection	24,000	900
Major inspection	48,000	2400

Source: Pöyry 2018

For an OCGT operating as a low merit peaking plant, it is typically the number of starts that are the determining factor for when scheduled maintenance is required to be carried out. The LTSA costs can therefore be presented as a cost per start. This has been done for the LTSA costs given in Pöyry 2018 and Brattle 2018 in the table below.

Table 8 – LTSA costs according to Pöyry 2018 and Brattle 2018

Reference source	Units	Pöyry 2018	Brattle 2018
GT type		SGT5-2000E	GE 7HA.02
Plant output	MW	198.6	320
LTSA levelized annual cost	MM € / year	2.0	5.0
starts per annum	starts / year	150	240
LTSA cost per start	€/start	13,333	21,015

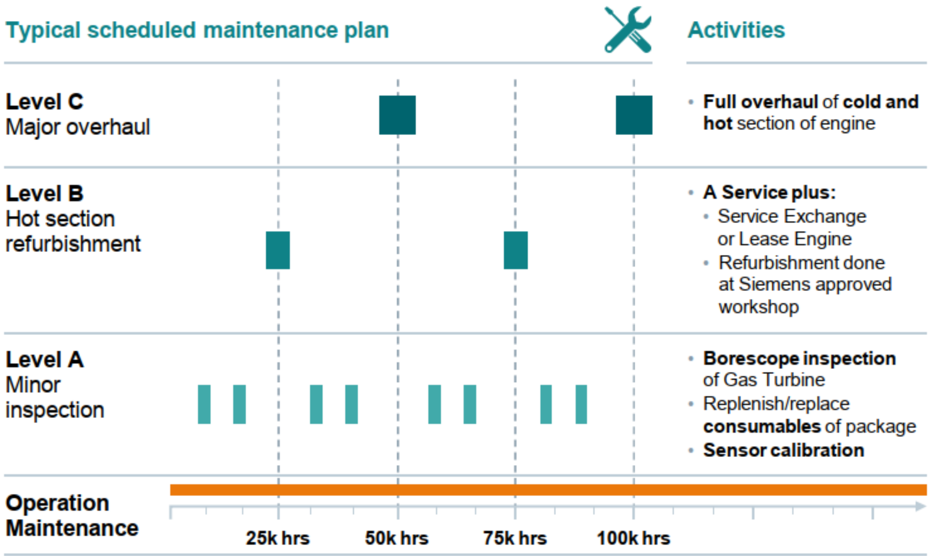
There is a difference in cost per start between Pöyry 2018 and Brattle 2018. However, this is explained by the differences in capacity (200MW versus 320 MW) and technology class (E class versus H class) of the gas turbines considered.

Pöyry 2018 and Brattle 2018 use different operating regime assumptions. For an OCGT plant we would recommend using the definition for a "utility peaking" application in Part 9 of ISO 3977: 1999 (Gas turbines — Procurement — Part 9: Reliability, availability, maintainability and safety). This operating regime considers up to 150 starts each year and up to 800 operating hours. The OCGT operating regime assumption is not stated in the Fichtner study.

Both Pöyry 2018 and Brattle 2018 consider Frame type gas turbines. However, the Angleur 4 and Ham units are of the aero-derivative type. There is a basic difference in the maintenance regimes between aero-derivative and frame type gas turbines. In particular, aero-derivatives are designed to start and stop regularly without 'penalty' and are usually maintained on an operating hours only basis.

The typical maintenance interval requirements for an aeroderivative gas turbine are presented in the Figure below.

Figure 1 – Typical maintenance intervals for aeroderivative



Source: Siemens [8]]

The Analysis 2020 report provides major maintenance (i.e. LTSA) cost data for both aeroderivative type and frame type gas turbines. These costs are summarised in the table below and have been converted from 2020 to 2019 price levels (assuming inflation rate of 2%) and from $ to €. The Analysis 2020 report clarifies that "*major maintenance costs for the Siemens SGT-A65 unit are estimated on dollar per gas turbine hourly operation ($/GT-hr) basis and are not affected by number of starts. Note that the $/GT-hr and $/start costs are not meant to be additive. The operational profile determines whether the annual maintenance costs will be based on hours or starts.*"

Table 9 – Major maintenance costs according to Analysis 2020

Gas turbine model	-	60 Hz Siemens SGT-A65	GE 7F.05	GE 7HA.02
Gas turbine type	-	Aero	Frame	Frame
Gas turbine rating	MW	53	207	327
Specific Major maintenance cost	€/GT-hour	160.2	295.1	505.9
Specific Major maintenance cost	€/start		8,010	22,427

8 https://assets.new.siemens.com/siemens/assets/public.1527864266.4de437a8864594a098cf00eb86366a7ab1ad1760.sgt-a45-sgt-750-gas-turbines.pdf

AFRY notes that the major maintenance cost for GE 7HA.02 from the table above (22,427 €/h) is in close alignment with the corresponding figure in Brattle 2018 which considers the same gas turbine model (21,015 €/start as shown in the table above).

The SGT-A65 (formerly known as the Industrial Trent 60) is the 60 Hz version of the gas turbines installed at Angleur 4. Scaling up this cost for the slightly larger 50 Hz version installed at Angleur 4 (assuming power increase is 6.3 MW as per product information on the Siemens website) increases the specific maintenance cost from 160.2 €/hour to 173.4 EUR/hour. Based on this specific maintenance cost, and assuming an operating regime of 800 hours per annum, the LTSA for one of the gas turbine units at Angleur 4 would be €140,000 per annum.

The analysis for all existing peaking units is based on 800h of operation per annum. This may be typical industry standard ,but it is on the upper end of the spectrum. Lower operating hours and fewer starts may then also mean a lower overall O&M cost.

3.3.2.5 **Recalculation of Specific Fixed O&M cost for Angleur 4 based on AFRY recommended numbers**

The table below presents the results of recalculating the specific fixed O&M cost for the gas turbine units at the Angleur 4 facility using the numbers recommended by AFRY.

Table 10 – Recalculation of specific fixed O&M cost for GT unit at Angleur 4 using AFRY recommended numbers

Parameter	Unit	Value	Remark
Plant	-	Angleur 4	
Gas turbine model		Trent 60	
Fuel type		gas/oil	
Rated output	MWe	63	
EPC cost			
Specific "Equipment supply" cost	€/kW	323	From GTW2019
Specific uplift for whole plant EPC cost	€/kW	258.688	80% of "equipment supply" cost
Specific EPC cost	€/kW	582	
Plant capacity	kW	63,000	
EPC cost	€	36,669,024	
Fixed O&M			
(a) Annual operating	€/a	696,711	1.9% of EPC cost
(b) Annual insurance	€/a	183,345	0.6% of EPC cost
(c) Annual fixed maintenance (excl major maintenance)		183,345	0.5% of EPC cost
(d) Specific major maintenance	€/hour	173	Derived from Analysis 2020 report
(e) run hours /annum	-	800	Upper end of range for "utility peaker";Part 9 of ISO 3977 : 1999
(f) annual major maintenance	€/a	138,749	(d) x (e)
(h) Total fixed O&M	€/a	1,202,150	(a)+(b)+(c)+(f)
Specific fixed O&M	€/kW/a	19.1	(h) divided by rated output
Specific fixed O&M cost (Fichtner study)		18.49	For comparison

3.3.3 Review of Fichtner estimates for the 18MW turbojet units

The table below presents the results of recalculating the specific fixed O&M cost for the 18MW turbojet units in Belgium using the numbers recommended by us.

Table 11 – Recalculation of specific fixed O&M cost for turbojet unit at Cierreux using AFRY recommended numbers

Parameter	Units	Value	Remark
Plant	-	Cierreux	Also Zelzate, Aalter, Zedelgem, Noordschote and Zeebrugge
Gas turbine model		Turbojet	
Fuel type		Kerosene	
Rated output	MWe	18	From GTW2019 for LM 2500
EPC cost			
Specific "Equipment supply" cost	€/kW	473	From GTW2019 for LM 2500
Specific uplift for whole plant EPC cost	€/kW	378	80% of "equipment supply" cost
Specific EPC cost	€/kW	851	
Plant capacity	kW	18,000	
EPC cost	€	15,325,200	
Fixed O&M			
(a)Annual operating costs	€/a	291,178	1.9% of EPC cost
(b) Annual operating insurance	€/a	91,951	0.6% of EPC cost
(c) Annual fixed maintenance (excl major maintenance)		76,626	0.5% of EPC cost
(d) specific major maintenance cost	€/hour	88.8	Derived from Analysis 2020 report and scaled to smaller GT size and fuel type
(e) run hours per annum	-	800	Upper end of range for "utility peaker" regime from Part 9 of ISO 3977 : 1999
(f) annual major maintenance cost	€/a	71,078	(d) x (e)
(h) Total fixed O&M cost	€/a	530,833	(a)+(b)+(c)+(f)
Specific fixed O&M cost	€/kW/a	29.49	(h) divided by rated output (in kW)
Specific fixed O&M cost from Fichtner study		33.8	For comparison

The “turbojet” units in Belgium were installed between 1963 and 1968. The model is unknown to us and we assume a Rolls Royce Avon turbojet or similar, which were commonly installed around this time. Given their age, there is no identical unit in GTW 2019. We have therefore derived an “equipment supply” cost from the cost curve given in GTW 2019. Based on this cost curve, an 18MW capacity turbine is estimated to have an equipment supply price of 550 USD/kW (2019 price level). Converting to Euro gives a budget price of 473 €/kW, which is the figure used in the table above.

The specific major maintenance cost (€/GT-hour) used in the table above is based on the figure determined in connection with the Angleur 4 units which has been scaled to take account of the difference in unit size. The cost has then been multiplied by a factor of 1.2 to reflect the fact the turbojet units burn kerosene rather than natural gas. The factor of 1.2 has been derived by comparing the variable O&M costs in Tables 3-5 and 3-6 of the Parson Brinckerhoff 2008 report.

3.3.4 Review of Fichtner estimates for the 32MW turbojet unit

The table below presents the results of recalculating the specific fixed O&M cost for the 32MW turbojet units installed at Beerse using the numbers recommended by us.

Table 12 – Recalculation of specific fixed O&M cost for turbojet unit at Beerse using AFRY recommended numbers

Parameter	Units	Value	Remark
Plant	-	Beerse	
Gas turbine model		Turbojet	
Fuel type		Kerosene	
Rated output	MWe	32	From GTW2019
EPC cost			
Specific “Equipment supply” cost	€/kW	366	From GTW2019
Specific uplift for whole plant EPC cost	€/kW	292	80% of “equipment supply” cost
Specific EPC cost	€kW	658	
Plant capacity	kW	32,000	
EPC cost	€	21,052,800	
Fixed O&M			
(a)Annual operating costs	€/a	400,004	1.9% of EPC cost
(b) Annual operating insurance	€/a	126,317	0.6% of EPC cost
(c) Annual fixed maintenance (excl major maintenance)		105,264	0.5% of EPC cost
(d) specific major maintenance cost	€/hour	133.4	Derived from Analysis 2020 report and scaled to smaller GT size and fuel type
(e) run hours per annum	-	800	Upper end of range for “utility peaker” regime from Part 9 of ISO 3977: 1999
(f) annual major maintenance cost	€/a	106,757	(d) x (e)
(h) Total fixed O&M cost	€/a	738,342	(a)+(b)+(c)+(f)
Specific fixed O&M cost	€/kW/a	23.1	(h) divided by rated output (in kW)
Specific fixed O&M cost from Fichtner Study		28.9	For comparison

The “turbojet” units in Belgium were installed between 1963 and 1968. Given its age, there is no identical unit in GTW 2019. AFRY has therefore derived an “equipment supply” cost from the cost curve given in GTW 2019. Based on this curve, a 32 MW capacity turbine is estimated to have an equipment supply price of 425 $/kW (2019 price level). Converting to € gives a budget price of 366 €/kW, which is the figure used in the table above.

The specific major maintenance cost (€/GT-hour) used in the table above is based on the figure determined in connection with the Angleur 4 units which has been scaled to take account of the difference in unit size. The cost has then been multiplied by a factor of 1.2 to reflect the fact the turboject units burn kerosene rather than natural gas. The factor of 1.2 has been derived by comparing the variable O&M costs in Tables 3-5 and 3-6 of the Parson Brinckerhoff 2008 report.

3.3.5 Review of Fichtner estimates for Angleur 3 units

The table below presents the results of recalculating the specific fixed O&M cost for the Angleur 3 gas turbine units using the numbers recommended by us.

Table 13 – Recalculation of specific fixed O&M cost for Angleur 3 gas turbines using AFRY recommended numbers

Parameter	Units	Value	Remark
Plant	-	Angleur 3	
Gas turbine model		Frame Type	Model is not known
Fuel type		Gas	
Rated output	MWe	25	
EPC cost			
Specific “Equipment supply” cost	€/kW	413	From GTW2019
Specific uplift for whole plant EPC cost	€/kW	330	80% of “equipment supply” cost
Specific EPC cost	€/kW	743	
Plant capacity	kW	25,000	
EPC cost	€	18,576,000	
Fixed O&M			
(a)Annual operating costs	€/a	352,944	1.9% of EPC cost
(b) Annual operating insurance	€/a	111,456	0.6% of EPC cost
(c) Annual fixed maintenance (excl major maintenance)		92,880	0.5% of EPC cost
(d) specific major maintenance cost	€/start	3,065.2	Derived from Pöyry 2018 report and scaled to smaller GT size
(e) starts per annum	starts/annum	150	Upper end of range for “utility peaker” regime from Part 9 of ISO 3977 : 1999
(f) annual major maintenance cost	€/a	459,775	(d) x (e)
(h) Total fixed O&M cost	€/a	1,017,055	(a)+(b)+(c)+(f)
Specific fixed O&M cost	€/kW/a	40.7	(h) divided by rated output (in kW)
Specific fixed O&M cost from Fichtner Study		25.4	For comparison

The Angleur 3 gas turbines first entered operation in 1978 as part of a combined cycle power plant. The units were converted to open cycle in

2013. The model is unknown but we have assumed an industrial frame type, such as the Brown Boveri GT13 series or similar, which had a capacity of around 35MW at that time.

Given their age, there is no identical unit in GTW 2019. We have therefore derived an "equipment supply" cost from the cost curve given in GTW 2019. Based on this cost curve, a 25MW capacity turbine is estimated to have an equipment supply price of 480 $/kW (2019 price level). Converting to Euro gives a budget price of 413 €/kW, which is the figure used in the table above.

The specific major maintenance cost (€/GT-hour) used in the table above is based on the figure shown for a SGT5-2000E frame type gas turbine, which has been scaled to take account of the difference in unit size.

The calculated specific fixed O&M cost (40.7 €/kW/a) is higher than the result contained in Table 15 of the Fichtner study (25.4 €/kW/a).

3.3.6 Conclusions

The table below presents the results of recalculating the specific fixed O&M cost for each of the OCGT units in Belgium. The Fichtner number is shown for comparison purposes.

Electricity transmission charges are incurred in line with amount of electricity injected to the grid. They can therefore be viewed as variable cost element, and we therefore also present the specific O&M cost excluding the electricity transmission charges.

Table 14 – Results of recalculating specific fixed O&M cost for all OCGT units

Unit	Capacity (MW)	Type	Commercial operation date	Specific fixed O&M cost (€/kW/a)		
				Fichtner	AFRY	AFRY (excl. grid charge)
Angleur 3 - TG31	25	Frame type	1978	25.40	40.68	40.19
Angleur 3 - TG32	25	Frame type	1978	25.40	40.68	40.19
Angleur 4 - TG41	63	Aero	2012	18.49	19.08	18.59
Angleur 4 - TG42	63	Aero	2012	18.49	19.08	18.59
Ham - HAM31	56	Aero	2006	19.38	19.08	18.59
Ham - HAM32	56	Aero	2006	19.38	19.08	18.59
Cierreux	18	Turbojet	1960's	33.83	29.49	29.00
Beerse	32	Turbojet	1960's	28.94	23.07	22.58
Zelzate	18	Turbojet	1960's	33.83	29.49	29.00
Aalter	18	Turbojet	1960's	33.83	29.49	29.00
Zedelgem	18	Turbojet	1960's	33.83	29.49	29.00
Noordschote	18	Turbojet	1960's	33.83	29.49	29.00
Zeebrugge	18	Turbojet	1960's	33.83	29.49	29.00

The EPC costs used in the calculation of fixed O&M costs have been derived from the price curves contained in GTW 2019. Based on our experience, costs provided by GTW 2019 are found to be on the conservative side when compared to prices subsequently obtained via a competitive bidding process. A 10 to 15% reduction would not be unusual. This is also supported even by GTW 2019, which attaches a plus or minus accuracy of 15% to the estimated budget prices.

3.4 Review of section 4.3 of the Fichtner study – CCGTs

3.4.1 Fichtner study estimate

In accordance with the agreed methodology for this peer review, the first step has been to extract the numbers from Section 4.3.1 of the Fichtner study. The numbers with have a bearing on the fixed O&M costs are presented in the table below.

Table 15 – Fichtner estimates for existing CCGTs

Unit name	Capacity (MW)	Config	GT model	Year of construction	Annual Fixed O&M costs (€/a)	Specific Annual Fixed O&M costs (€/kW/a)
T-Power	425	1x1	SGT5-4000F	2011	17,600,000	41.41
Seraing	485	2x1	SGT5-2000E	1994	19,500,000	40.21
Amercoeur	451	1x1	GE 9FB	2010	18,300,000	40.58
Marcinelle	405	1x1	SGT5-4000F	2011	16,900,000	41.73
Saint-Ghislain	350	1x1	GE 9FA	2000	15,100,000	43.14
Drogenbos	460	2x1	SGT5-2000E	1993	18,700,000	40.65
Knippergroen	315	1x1		2010	13,900,000	44.13
Ringvaart	357	1x1	GE 9FA	1998	15,400,000	43.14
Herdersbrug	480	2x1	SGT5-2000E	1998	19,300,000	40.21
Zandvliet	384	1x1	SGT5-4000F	2005	16,200,000	42.19
Inesco	138	2x1	SGT-800	2007	7,450,000	53.99

Source: Table 16 of Fichtner study

AFRY has the following observations on the above table:

- all the CCGT plants are based around large frame type industrial gas turbines;
- all the plants used F class gas turbine technology (Siemens SGT5-4000F and GE 9F) with the exception of Seraing, Drogenbos, Herdesbrug which are based on E class technology (GE 9E and Siemens SGT5-2000E) and Inesco which is based on Siemens SGT-800 gas turbines;
- the capacities quoted in the table above are understood to be at ISO conditions (15oC and 60% relative humidity);
- Zandvliet and Inesco are categorised in CCGT-CHP to reflect their ability to operate in CHP mode. The MW capacities in the above table relate to CCGT operation.

— the Inesco (INEOS Essent Cogeneration) plant is powered by two natural-gas-fired 43MW SGT-800 gas turbines.[9]

3.4.2 Review of Fichtner estimates for T-Power plant

Section 4.3.2 of the Fichtner study states "The numbers provided in Table 16 are estimated by Fichtner (Fichtner 2020) based on the data provided for the individual units, the methodology presented (i.a. in Section 4.2) and Fichtner's experience as a technical consultant)." Fichtner 2020 is described within the Fichtner study as "Internal data, calculations and interviews with experts. Stuttgart". This reference data has not been provided to AFRY for review.

In the absence of any information to the contrary, AFRY considers it reasonable to assume that Fichtner estimated the fixed O&M costs for the existing plants in Belgium in the same way that they estimated the fixed O&M costs for the gross CONE calculation.

The Table below contains an estimate of fixed O&M costs for the T-Power plant using the methodology used by Fichtner for the gross CONE calculation (as set out in Section 3.3.3 of the Fichtner study).

[9] https://www.powerengineeringint.com/coal-fired/equipment-coal-fired/flexible-cogeneration-for-chemicals-plant/

Table 16 – Fichtner's Gross CONE calculation methodology applied to the T-power plant

Parameter	Units	Value	Remark
Plant	-	T-Power	
Gas turbine model		SGT5-4000F	
Fuel type		Gas only	
Rated output	MWe	425	
EPC cost			
Specific EPC cost	€/kW	637	**From GTW2019 (price curve)**
Plant capacity	kW	425,000	
EPC cost	€	270,764,480	
Fixed O&M			
Operating costs	€	14,215,135	**5.25%**
Insurance	€	1,353,822	**0.50%**
Maintenance	€	2,030,734	**0.75%**
Total	€	17,599,691	
Specific fixed O&M cost	€/kW/a	41.41	
Fichtner specific fixed O&M cost	€/kW/a	41.41	For comparison

The calculated specific fixed O&M cost (41.41 €/kW/a) is in exact alignment to the result contained in Table 16 of the Fichtner study (41.41 €/kW/a).

The reasonableness of each of the Fichtner "numbers" used in the above calculation (high-lighted in red text in the above table) are discussed in the sections below.

3.4.2.1 **EPC cost**

As for the OCGT plant, GTW 2019 is once again used as the basis for deriving the EPC cost for the CCGT plant. Fichtner note that the approach is different however, as the prices quotes in GTW2019 are already for the full EPC "turnkey" scope (including major equipment supply, plant engineering and construction), rather than just being for "equipment supply" as is the case for the OCGT plants.

The specific EPC cost in the table above is derived from the 2019 combined cycle cost curve given in GTW 2019. Based on this cost curve, a 425MW capacity CCGT plant is estimated to have an specific EPC cost of 713 $/kW (2019 price level). Converting to Euro gives a specific EPC cost of 637 €/kW, which is the figure used in the table above.

AFRY has the following observations on the prices quoted in GTW2019:

- The prices are for plants designed for single fuel operation. We understand this is consistent with the design of the T-Power facility (and other CCGTs in Belgium) and thus no correction is required.
- The prices do not include high variable project specific costs such as transportation and delivery. EPC cost breakdown data derived using the Thermoflow GTPRO software and associated PEACE module for a similar sized CCGT plant to T-Power indicates the transportation and delivery costs would add approx. 3.5% of the overall EPC cost.
- The prices do not include the main step-up transformers for connecting the plant output to the utility substation. EPC cost breakdown data derived using the Thermoflow GTPRO software and associated PEACE module for a similar sized CCGT plant to T-Power indicates the main step up transformers would add approx. 1.9 % of the overall EPC cost.
- The prices exclude fuel gas booster compressors. We understand this is consistent with the design of the T-Power facility (and other CCGT's in Belgium) and thus no correction is required.
- The prices exclude project specific balance of plant equipment such as water treatment systems, waste water systems and cooling towers. EPC cost breakdown data derived using the Thermoflow GTPRO software and associated PEACE module for a similar sized CCGT plant to T-Power indicates this equipment would add approx. 6 % of the overall EPC cost.

The above observations would increase the GTW2019 price by 11.4%. Correcting the GTW2019 for the above mentioned additional scope increases the specific EPC cost from 637 €/kW to 709 €/kW. These specific costs are compared to the values contained in Brattle 2018 and Pöyry 2018 (after correction to be based on the same plant scope of supply) in the table below.

Table 17 – Comparison of CCGT EPC cost estimates from different sources

Source		From GTW 2019 price curve	GTW 2019 price curve (corrected)	Pöyry 2018 (corrected)	Brattle 2018 (corrected)
Plant type	-	CCGT	CCGT	CCGT	CCGT
Configuration	-	generic	generic	1x1	2x1
Gas turbine class	-	generic	generic	F class	H class
Gas turbine model	-	generic	generic	GE 9FB.05	GE 7HA.02
EPC cost	MM €			281.4	612
Plant capacity	MW	425	425	438.5	1138
Specific EPC cost	€/kW	637	710	642	538

Pöyry 2018 estimated the EPC cost for a 438.5 MW capacity CCGT at €284.1 million [2018 price level - Table 5 in Pöyry 2018]. This price considered a dual fuel plant with a fuel gas compressor. In order to be comparable with the Fichtner study, we have deducted €3.5 million to account for the fuel gas compressor and €4.8 million to account for the dual fuel equipment (noting the fuel oil storage tank foreseen in Pöyry 2018 was sufficient for 5 days storage). The resulting figure was then corrected to 2019 price level assuming inflation rate of 2%.

Brattle 2018 estimated the EPC cost for a 1138 MW capacity CCGT at $764 million [Table 10 in Brattle 2018, Cone Area 3, sum of owner furnished equipment and EPC cost excluding sales taxes]. This price considered a dual fuel plant fitted with selective catalytic reduction (SCR) to meet stringent emission limits for oxides of nitrogen (NOx). In order to be comparable with the Fichtner study, AFRY has deducted $50 million to account for the SCR [Page 19 of Brattle 2018] and $7.4 million to account for the dual fuel equipment (noting the cost of $16 million quoted in Brattle 2018 included a fuel oil inventory sufficient for 3 days operation of the plant). The resulting figure was then corrected to 2019 price level (from 2022 price levels) using the indexation factors quoted in Brattle 2018. Finally, the resulting cost was converted from $ to €.

We have the following observations on the above:

- the Fichtner EPC cost for a CCGT plant is based on the GTW 2019 cost without correction (i.e. 637 €/kW).
- the Brattle 2018 cost is in line with the GTW 2019 price curve considering the plant size (1138 MW). This supports the view that the GTW2019 prices can be used without correction; and
- the Fichtner number is in line with the Pöyry 2018 number (after correction). The Pöyry 2018 number was derived using the Thermoflow

software model rather than GTW2019 and this further supports the view that the GTW2019 prices can be used without correction.

- based on the above, we consider the Fichtner number, based on the price quoted in GTW 2019, to be reasonable.

3.4.2.2 **Fixed Operating Cost**

The fixed operating costs includes "*personnel costs, administrative costs, electricity and gas transmission charges*.

We note that property taxes and land lease costs, which are eligible operating expenses in Brattle 2018 and Pöyry 2018, are excluded from the above definition and have not been considered in the Fichtner Study or in the analysis below.

Section 3.3.2.1 of the Fichtner study states that the operating costs (covering) are "*usually presented as a percentage of the EPC contact price*". The percentage used is not explicitly stated in the Fichtner study, however by comparing the operating costs contained in Table 10 of the Fichtner study with the EPC costs contained in Table 6, it can be deduced that Fichtner have assumed operating costs at 5.25% of the EPC cost.

The Fichtner study states "Total fixed O&M costs for the different technologies are given in several studies such as (IEA, 2010)". The IEA, 2010 citation is described in the Fichtner study as "Gas-fired power, https://iea-etsap.org/E-TechDS/PDF/E02-gas_fired_power-GS-AD-gct.pdf: s.n.". AFRY has reviewed the IEA, 2010 document, but could not find any clear justification for the selected number of 5.25%.

We have extracted the corresponding operating costs from Pöyry 2018, which are presented in the table below. The costs relate to a 438 MWe CCGT plant constructed in Ireland.

Table 18 – Operating Costs for 438 MWe CCGT in Ireland

Parameter	Cost (€)	Remark
EPC cost	284,000,000	
Operating costs		
Trading and admin costs	2,132,936	assumed 0.8% of the EPC contract price
Personnel costs	3,166,000	assumed an O&M team comprising 38 full time employees and an average cost of €83k per employee
Electricity transmission charges	2,785,918	Based on published tariffs
Gas transportation charges	12,820,913	Based on published tariffs
Total operating costs	20,905,767	
Operating cost as percentage of EPC cost	7.4%	

Source: Pöyry 2018

The operating costs as a percentage of the EPC cost is 7.4% based on Pöyry 2018. We note, however, that the electricity transmission charge and gas transportation charges constitute a significant component of the overall cost in the above table and are highly country specific.

Within Belgium the charges depend on the plant operating regime, and are therefore variable to some extent.

The CCGT operating costs in Pöyry 2018 is based on an operating profile of 50 starts and 8000 hours per annum. The CCGT operating costs in Brattle 2018 is based on a capacity factor of 75%. Assuming the CCGT plants operate with a load factor of around 85%, this capacity factor implies an operating profile of at least 7,700 hours per annum. The Fichter study does not state the operating profile that has been assumed. AFRY has adopted the Pöyry 2018 operating assumptions for the purposes of this report.

In terms of electricity transmission charges, these are estimated at 2,164,085 €/year, calculated as shown in the table below. This calculation is based on the spreadsheet SimulateYourInvoice2020_V04 (1).xlsm (published by Elia), and based on the explanations in Workshop-14112019-Elia-tariffs-2020-2023v1-ADU (1).pdf (published by Elia) determined that only the Net Injected Energy would be applicable to tariffs for a CCGT plant (row 76 of the Data sheet in the spreadsheet).

Table 19 – Estimate of electricity transmission charges for a 438 MWe CCGT in Belgium

	Units	Value	Remark
Electrical output	MW	438.5	
Run hours	hours	8000	
Annual electrical generation	MWh	3,508,000	
Tariff	€/MWh	0.6169	
Connection cost fee	€/kW	0.5	
Connection cost	€	219,250	
Annual charge	€	2,383,335	

In terms of the gas transportation charges, these are estimated at €905,000/year, calculated as shown in the table below. This assumes capacity is booked on an annual (rather than short duration timeframe).

Table 20 – Estimate of gas transportation charges for a 438 MWe CCGT in Belgium

	Units	Value	Remark
Inputs			
Electrical output	MWe	438.5	
Net Efficiency	%	55.0%	
Thermal input	MWth	797.3	
Tariff			Net injected energy
Services	(€/MW)	1,048.0	Firm capacity, using (Domestic) Exit HP Service on the H-grid.
Odorisation	(€/MW)	87.2	
Annual Charge			
Total	€/year	905,064.0	

Using the above electricity transmission charges and gas transportation charges, the operating cost as percentage of EPC cost reduces from 7.4% to 3.0%.

Based on the above AFRY considers Fichtner number (5.25%) to be on the high side and we would recommend reducing to 3.0 % as per Pöyry 2018.

3.4.2.3 **Operating Insurance Cost**

The insurance cost includes "O&M insurance for general liability, machine breakdown and interruption of operation of the power plant".

Section 3.3.2.2 of the Fichtner study states that "the annual costs for insurances are set to 0.5 % of the EPC contract price for all technologies based on Fichtner's experience and values from (Konstantin 2013) and (Pöyry 2018)."

Pöyry 2018 assumes the insurance cost at 0.6% of the EPC cost. Brattle 2018 assumes the insurance cost at 0.6% of the total project investment cost (referred to as the overnight capital cost in Brattle 2018) which equates to around 0.8% of the EPC cost. Brattle 2018 assumes the insurance cost at 0.6% of the total project investment cost (referred to as the capital cost in Analysis 2020) which will once again equate to around 0.8% of the EPC cost.

Based on the above AFRY considers Fichtner number (0.5%) to be on the low side and AFRY would recommend increasing to 0.6% as per Pöyry 2018 (albeit still lower than Brattle 2018 and Anaysis 2020).

3.4.2.4 **Fixed Maintenance Cost**

The fixed maintenance cost includes "intra-year maintenance and a provision for major overhauls that do not necessarily take place on a yearly basis".

Section 3.3.2.2 of the Fichtner study states that "*based on Fichtner's expertise and values from literature (Konstantin, 2013), (Pöyry 2018) the fixed maintenance costs are estimated with 0.75 % of the EPC contract price*".

Pöyry 2018 assumed the fixed maintenance cost at 0.5% of the EPC contract price. However, this fixed maintenance cost only covered routine and preventative maintenance activities including consumables (filters, fuses, bulbs, gaskets, pump mechanical seals, pump / motor bearings, lubricating oil changes, etc). It did not cover the cost of planned maintenance on the gas turbines (i.e. major overhauls that do not necessarily take place on a yearly basis). Pöyry 2018 assumed that the cost of this planned maintenance (parts and labour) would be covered under a separate Long Term Service Agreement (LTSA) to be entered into between the plant owner and the LTSA contractor (who is also typically the gas turbine manufacturer).

Pöyry 2018, estimated the total annual LTSA costs for a 438 MWe CCGT plant, having an operating regime of 50 starts and 8000 operating hours per annum, at € 5.81 million per annum corrected to 2019 price level using assumed inflation rate of 2% (on top of the 0.5% of the EPC cost allowance for fixed annual maintenance).

Brattle 2018 also follow the Pöyry 2018 approach. Brattle 2018 include "minor maintenance and repairs" at 0.71% of the EPC cost [Table 32 of Brattle 2018] and includes a separate line item for the "LTSA" cost. With respect to the LTSA cost, Brattle 2018 provides the following explanation:

"Major maintenance is assumed to be completed through a long-term service agreement (LTSA) with the original equipment manufacturer that specifies when to complete the maintenance based on either fired-hours or starts. Each major maintenance cycle for a combustion turbine typically includes regular combustion inspections, periodic hot gas path inspections, and one major overhaul. [Section V(B)(1) of Brattle 2018]

In the report above, we included hours-based major maintenance costs as variable O&M costs. Since June 2015, long-term major maintenance and overhaul costs that are specified in Long-Term Service Agreements (LTSAs) have been excluded from being counted as variable O&M costs in the PJM cost guidelines for cost offers.103 We understand these guidelines are being discussed in a current initiative within the Market Implementation Committee. In case the guidelines remain unchanged, we provide a second set of O&M costs and CONE estimates below that include these costs as fixed O&M. [Appendix C of Brattle 2018]

Since major maintenance activities and costs are spaced irregularly over the long-term, the cost in a given year represents an annual accrual for future major maintenance. For hours-based major maintenance, the fixed O&M cost is calculated based on the estimated hours-based costs of major maintenance times the expected operation of the unit in a given year. For a CC, we assume it will operate at 75% capacity factor based on the capacity factors of actual units. For the CT, we assume it will start 240 times per year based on the results of PJM's Peak-Hour Dispatch simulation for estimating the E&AS revenue offset. Removing these costs from variable O&M will increase Net E&AS revenues and offset some (or all) of the increased CONE value in the calculation of Net CONE." [Appendix C of Brattle 2018]

Brattle 2018, estimated the total annual LTSA costs for a 1138 MWe CCGT operating with a 75% capacity factor, at € 9.3 million per annum [Table 32 of Brattle 2018 after correction to 2019 price level and to Euros]. This LTSA cost was addition to an allowance of 0.71% of the EPC cost for fixed maintenance (referred to as "maintenance and minor repairs" in Brattle 2018).

The CCGT plants considered in Brattle 2018 and Pöyry 2018 were of the large industrial frame type. The maintenance schedule for this type of gas turbine typically involves combustion inspections, hot gas path inspections and major inspections. The intervals for each type of inspection are based on independent counts of either unit starts or unit operating hours. The exact interval varies from manufacturer to manufacturer however some typical figures are shown in the table below.

Table 21 – Typical maintenance intervals for frame type gas turbines

Planned maintenance action	Hours	Starts
Combustion inspection	8,000	450
Hot gas path inspection	24,000	900
Major inspection	48,000	2400

Source: Pöyry 2018

For a CCGT operating in the utility-intermediate mode (up to 50 starts per annum and 6000 hours per annum) it will be the number of operating hours that are the determining factor for when scheduled maintenance is required to be carried out. The LTSA costs can therefore be presented as a cost per GT-hour. This has been done for the LTSA costs given in Pöyry 2018 and Brattle 2018 in the table below.

Table 22 – LTSA costs according to Pöyry 2018 and Brattle 2018

Reference source	Units	Pöyry 2018	Brattle 2018
Plant type		CCGT	CCGT
Configuration		1x1	2x1
Number of gas turbines		1	2
GT type		GE 9FB.05	GE 7HA.02
Technology class		F class	H class
Plant output	MW	438.5	1138
Levelised LTSA cost	MM €	5.81	9.3
Annual generation	hours	8000	7,729
Specific LTSA cost	€/GT- hour	726.8	602.9

The annual run hour figures for Brattle 2018 are based on the stated capacity factor of 75% for the combined cycle power plant and assuming the plant runs at 85% load whenever it is running (giving a "run hours" factor of 88%).[10]

There is a difference in specific cost (€-GT hour) between Pöyry 2018 and Brattle 2018. This is explained by the differences in capacity (200MW versus 320 MW) and technology class (F class versus H class) of the gas turbines considered.

[10] Capacity factor = run hours factor x load factor

Based on the above, we consider that 726.8 €-GT-hour is the appropriate cost to use for calculating LTSA costs for any existing CCGT plant in Belgium using F class (nominal 280MW) gas turbine technology, such as T-power plant. This cost can also be scaled for use with smaller (nominal 150MWe) E class gas turbines installed at Seraing, Drogenbos, Herdesbrug and Inesco and the even smaller (nominal 43 MWe) SGT-800 gas turbines installed at the Inesco plant. The results of this scaling are shown in the table below.

Table 23 – Specific LTSA costs by turbine class

		Gas turbine class		
Parameter	**Units**	**F class**	**E class**	**SGT-800**
Nominal gas turbine rating	MWe	280	150	43
LTSA costs (i.e. gas turbine scheduled maintenance costs)	€/GT-h	726.8	459.0	174.3

3.4.2.5 Recalculation of Specific Fixed O&M cost for T-Power based on AFRY recommended numbers

The table below presents the results of recalculating the specific fixed O&M cost for the T-Power facility using the numbers recommended by AFRY.

Table 24 – Recalculation of specific fixed O&M cost for T-Power using AFRY recommended numbers

Parameter	Units	Value	Remark
Plant	-	T Power	
Gas turbine model		SGT5-4000F	
Number of gas turbines		1	
Fuel type		gas only	
Rated output	MWe	425	
EPC cost			
EPC cost	€/kW	637	GTW2019
Plant capacity	kW	425,000	
EPC cost	€	270,764,480	
Fixed O&M			
(a)Annual operating costs	€	8,122,934	3.0% of EPC cost
(b) Annual operating insurance	€	1,624,587	0.6% of EPC cost
(c) Annual fixed maintenance (excl major maintenance)		2,030,734	0.75% of EPC cost
(d) specific major maintenance cost	€/GT-hour	726.8	Derived from Pöyry 2018 report and applicable to F class technology
(e) run hours per annum	-	8,000	
(f) annual major maintenance cost	€	5,814,000	(d) x (e)
(h) Total fixed O&M cost	€	17,592,255	(a)+(b)+(c)+(f)
Specific fixed O&M cost		41.4	(h) divided by rated output (in kW)
Specific fixed O&M cost from Fichtner Study		41.41	For comparison

The calculated specific fixed O&M cost (41.4 €/kW/a) is well aligned with the result contained in Table 16 of the Fichtner study (41.41 €/kW/a).

3.4.3 Sensitivity of annual major maintenance to running hours

Major maintenance schedules are typically linked to number of hours of operation. We have so far assumed that a CCGT assumes baseload operation. This is however not necessarily the case for existing CCGTs in Belgium, or indeed in Europe. The wider deployment of low variable cost renewable generation has challenged the traditional paradigm of baseload operation and CCGTs now tend to operate in a more mid-merit fashion.

We have therefore considered a sensitivity of lower operating hours (in a given year), and the corresponding impact on annual fixed costs. Lower operating hours means that the need for major maintenance is less frequent. Assuming 4000 hours of operation in a year, the specific O&M cost for T-Power would drop from 40.1 €/kW to 33.3 €/kW. With 1500 hours of operation (which is the case for some Belgian CCGTs) this would decrease even further to 29.0 €/kW.

3.4.4 Results of recalculation for all CCGT plants in Belgium

The table below presents the results of recalculating the specific fixed O&M cost for each of the CCGT units in Belgium. The Fichtner number is shown for comparison purposes.

Table 25 – Results of recalculating specific fixed O&M cost for all CCGT units

				Specific fixed O&M cost (€/kW/a)	
Unit	Capacity (MW)	Type	Commercial operation date	Fichtner	AFRY
T-Power	425	1x1	2011	41.41	41.39
Seraing	485	2x1	1994	40.21	42.10
Amercoeur	451	1x1	2010	40.58	40.26
Marcinelle	405	1x1	2011	41.73	42.36
Saint-Ghislain	350	1x1	2000	43.14	45.52
Drogenbos	460	2x1	1993	40.65	43.22
Knippergroen	315	1x1	2010	44.13	48.06
Ringvaart	357	1x1	1998	43.14	45.07
Herdersbrug	480	2x1	1998	40.21	42.31
Zandvliet	384	1x1	2005	42.19	43.47
Inesco	138	1x1	2007	53.99	56.46

The above estimates are on the basis of 'baseload' operation. Assuming more limited hours of operation (4000h) we would expect substantially lower costs, as shown in Table 26. In this table we also present the specific O&M cost with and without electricity transmission charges, which can be seen as variable (rather than annual fixed) charges.

Table 26 – Range of specific fixed O&M cost for all CCGT units

Unit	Capacity (MW)	Type	Commercial operation date	Specific fixed O&M cost (€/kW/a)				
				Fichtner	AFRY (8000h)	AFRY (4000h)	AFRY (8000h, no elec)	AFRY (4000h, no elec)
T-Power	425	1x1	2011	41.41	41.39	34.55	36.46	29.62
Seraing	485	2x1	1994	40.21	42.10	34.53	37.16	29.59
Amercoeur	451	1x1	2010	40.58	40.26	33.81	35.32	28.88
Marcinelle	405	1x1	2011	41.73	42.36	35.18	37.42	30.24
Saint-Ghislain	350	1x1	2000	43.14	45.52	37.21	40.59	32.28
Drogenbos	460	2x1	1993	40.65	43.22	35.24	38.28	30.30
Knippergroen	315	1x1	2010	44.13	48.06	38.83	43.12	33.89
Ringvaart	357	1x1	1998	43.14	45.07	36.93	40.13	31.99
Herdersbrug	480	2x1	1998	40.21	42.31	34.66	37.38	29.73
Zandvliet	384	1x1	2005	42.19	43.47	35.90	38.53	30.96
Inesco	138	1x1	2007	53.99	56.46	46.35	51.52	41.42

The gas turbine major overhaul costs used in the calculation of fixed O&M costs assume the plant owner will enter into a long term service agreement (LTSA) with the original equipment manufacturer. Whilst this is a reasonable assumption for a new build plant based on advanced gas turbine technology, we do recognise that the average age of the existing CCGTs in Belgium is over 16 years. By this time the original LTSA will have normally expired, as a typical LTSA term covers the first 100,000 equivalent operating hours. Once the original LTSA expires, a plant owner will be able to procure maintenance services competitively from a much wider range of third party maintenance service providers. In this way a plant owner can typically realise gas turbine maintenance cost savings of between 10 and 15% when compared to an LTSA.

The same considerations we have described for OCGTs when it comes to EPC costs also apply to CCGTs. The EPC costs used in the calculation of fixed O&M costs have been derived from the price curves contained in

GTW 2019. A competitive bidding process may result in a reduction to these quoted prices.

3.5 Overlap between fixed O&M and lifetime extension costs

We have been asked to opine as to whether there is any overlap between the major overhaul costs included as part of the Fixed O&M costs and the investments to augment the capacity or extend a unit's lifetime that are evaluated and quantified in Section 5.2 of the Fichter study.

Section 5.2.1 of the Fichtner Study provides a list of measures that augment the capacity of existing power plants or extend their lifetime. These are presented in the table below.

Table 27 – List of measures to augment capacity and extend life

Description	Augment capacity	Life time extension
Replace HP, IP and LP rotors of turbines		✓
Replace steam chest		✓
Improve/Renew Combustor	✓	✓
Replace generator	✓	✓
Replace transformer		✓
Re-tubing Condenser		✓
Repair/Replace exposed steelwork, roof and cladding		✓
Replace gas turbine	✓	✓
Replace steam turbine	✓	✓

Source: Fichtner study

We can confirm that the above types of measures are not included within the Fixed O&M Costs in the above sections of this of this report and that there is no overlap between the Fixed O&M costs and the investments to augment the capacity or extend a unit's lifetime that are evaluated and quantified in Section 5.2 of the Fichter study.

4 Fixed O&M costs for pumped storage

The estimation of operational expenditures for hydropower plants and in particular for pumped hydro plants are well known with respect to their different main cost components but may considerably differ between countries in Europe as the interpretations are dissimilar regarding of what shall be included as fixed cost and what forms part of the variable part. The latter one is linked to the annual operating hours and usage of water. In this chapter the fixed operation and maintenance cost for pumped storage plants are discussed and cost relationships expressed in €/kW are presented.

Fixed O&M cost comprises of the following three main cost components:

- staffing costs (Manpower), required for the direct operation and maintenance of the plant;
- third party and materials costs (e.g. external companies being hired for specific O&M services), which are required to maintain and operate the plant including civil structures and electro-mechanical equipment; and
- various O&M expenses which are required for the operation (e.g. administration, back office, dispatching & control centre, etc.) but which are not directly linked to the civil or mechanical parts of the plant.

Costs for major overhaul normally are not included in the fixed O&M cost and are calculated separately. However, and for completeness, general assumptions based on international experience are shown in section 4.1.2. Furthermore, referencing to IRENA11 database as well as World Energy Council12 operation and maintenance costs are mentioned in the rather wide range of 10 to 50 €/kW (in real 2020 money terms).

4.1 General assumptions

4.1.1 Cost due to maintenance of the installations without major overhauls

Annual Cost of Operation and Maintenance (without major overhauls) covers the following items:

- general maintenance of major E&M equipment, such as:

[11] RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES, IRENA 2012 & also on https://www.irena.org/
[12] World Energy Perspective - Cost of Energy Technologies, World Energy Council 2013

  - minor moving parts like guide vane cylinders, small bearing rings, packers but also painting, cooling oil, etc.;
  - consumables like carbon brushes, small cooling pumps, isolators, etc.;
  - HVAC – equipment;
  - switchyard components of minor priority and function;
- general maintenance of major H&M equipment, such as:
  - minor parts of gates;
  - annual maintenance of the penstock;
- general maintenance of the civil structures, including:
  - roads;
  - riverside & reservoir;
  - power house structure (roof, windows, heating);
  - dam and reservoir structures as well as monitoring facilities;
- general maintenance of transmission line & substation, as far as they belong to the plant operator:
  - towers and cables; and
  - switchgears.

Based on information from USBR (Estimation of Economic Parameters of U.S. Hydropower Resources[13]), where more than 380 hydropower plants in operation are assessed as well as in-house experience from AFRY, annual refurbishment of the plant can be calculated as function of capacity with:

- materials, parts and services for routine operation and maintenance in the range of 900 – 1200 €/MW;
- repair or minor repair of civil in the range of 1000 – 1300 €/MW;
- repair or minor repair of hydro-mechanical equipment, estimate at 750 – 1100 €/MW;
- repair or minor repair of E & M equipment with costs of ~2500 €/MW (Pelton) & ~27000 €/MW (Francis); and
- maintenance of transmission line in the order of 0.25% of TL-invest.

The origin of the E&M equipment manufacturer has a certain impact on the annual expenditures. The overall maintenance philosophy (predictive or reactive) can also influence the expected annual operation and maintenance costs.

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[13] Estimation of Economic Parameters of U.S. Hydropower Resources, Douglas et al. - Idaho National Engineering and Environmental Laboratory, June 2003

4.1.2 Annual Cost of Operation and Maintenance - major overhauls

These costs reflect the periodical maintenance of the E&M equipment as well as the control units. Within the first 10 to 20 years of operation no major overhaul shall be required and hence OPEX cost at the beginning of the lifetime of a PSP are normally lower than compared to older plants. Cost items to be included in major overhauls are as follows:

- major overhaul (exchange) of major E&M equipment, like:
  - turbine (runner, guide vanes, etc.), which is done in general after 20 to 50 years;
  - generator (windings, bearings, erection, etc.), which is done in general after 20 to 60 years;
  - substation components (switches, transformers, etc), which will be done in general after 25 – 35 years;
- major overhaul (exchange) of the H&M equipment, including:
  - gates (in general this is done after 40 years or more);
  - cranes (in general this is done after at least 25 years);
  - penstock (in general this is done after 40 years or more);
- major overhaul (exchange / reconstruction) of the civil structures, including:
  - spillway & intake (in general this is done after 80 years or more); and
  - steel constructions (in general this is done after 40 years and more).

4.2 Fixed OPEX cost assessment

Based on AFRY's internal database fixed annual OPEX cost for PSP and storage plants are in the range of 10 to 40 €/kW. As shown in Figure 2, this cost range is based on more than 20 different PSP plants in Germany, Austria and Switzerland with capacities from ~60 to ~1700 MW. Data from the Swiss and German Ministry for Energy (BFE and BMWI)[14] [15], which undertook a survey concerning the profitability of the swiss hydropower industry in 2018 as well as an assessment on how to achieve contribution margins for pumped storage schemes, are also included.

In the latter reference the fixed operation and maintenance cost are reported with 16 €/kW and 0.1 €/kWh stored energy. Furthermore, the

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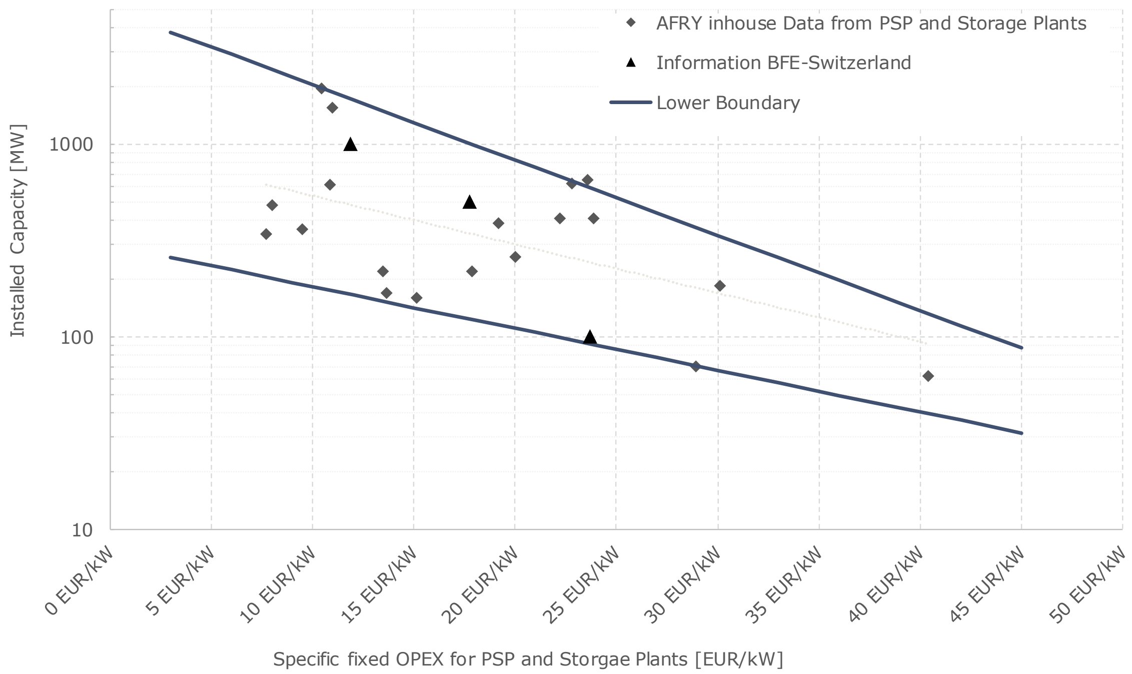
[14] Profitability of Swiss hydropower, BFE 2018 (https://pubdb.bfe.admin.ch/de/publication/download/9012)
[15] Potential to achieve contribution margins for pumped storage power plants in Switzerland, Austria and Germany, BFE 2014 (https://www.bmwi.de/Redaktion/DE/Downloads/S-T/trilaterale-studie-zu-pumpspeicherkraftwerken-deutschland-oesterreich-schweiz-gutachten.html)

storage scheme Linth-Limmern including the 1000 MW Linth-Limmern pump storage scheme, which recently became operational is included based on the detailed information available from the annual fiscal report[16]. Data from Swiss hydropower plants were adjusted in terms of manpower cost based on relationships stated on Eurostat[17] between Switzerland and Belgium. Cost for third parties and material is not seen to be affected by a notable distortion between Belgium and Switzerland.

Figure 2 – Specific OPEX cost for PSP as a function of installed capacity



As already mentioned, cost items for the fixed OPEX cost consist of:

- cost for Staffing (Manpower);
- cost for materials and 3rd parties; and
- various O&M expenses.

Figure 3 shows the distribution of these 3 cost items. Almost 50% of the annual fixed OPEX cost is linked to manpower costs whereas material and 3rd party costs represent only ~1/3 of the entire fixed annual OPEX cost.

Cost items related to the energy generation, such as:

- water usage or royalty fees;

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[16] Kraftwerke Linth-Limmern AG – Annual report 2018/19 (https://www.axpo.com/content/dam/axpo19/master/files-master/about-us/investor-relations/publications---dates/2005_Axpo_KLL_Gesch%C3%A4ftsbericht_18_19_DE.pdf)

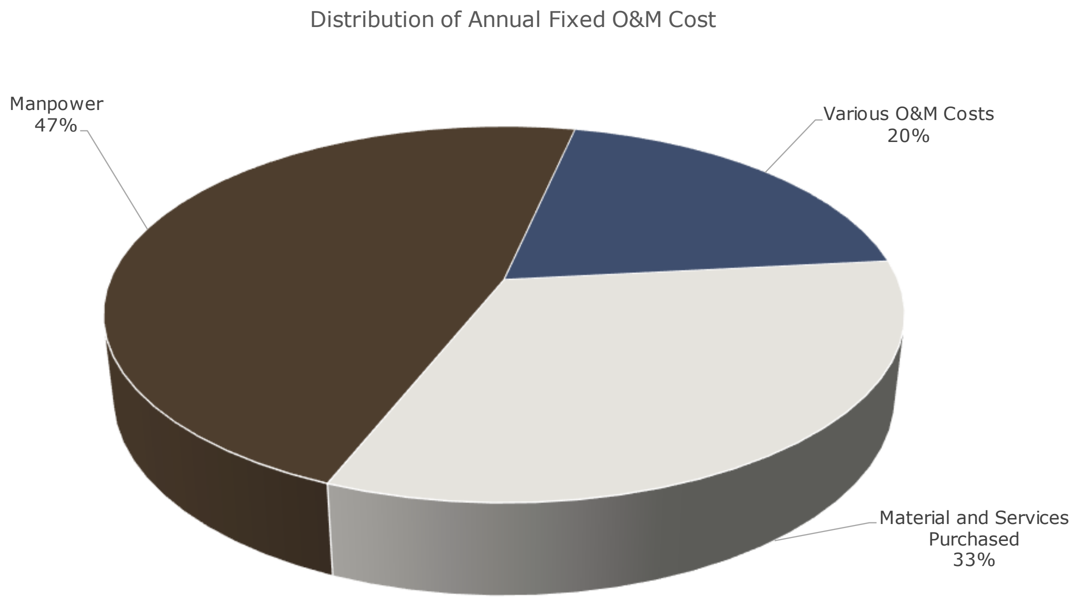
[17] https://ec.europa.eu/eurostat/databrowser/view/earn_ses_annual/default/table?lang=de

- grid usage fees;
- energy cost for pumping;
- taxes for purchase and delivery of energy.

are **excluded** from this assessment.

Costs for major overhauls are also excluded, as are costs linked to depreciation and financing. Depending on the magnitude of the overhaul and the age of the plant this cost can be easily in the range of 10 to 20 €/kW, which shall be added to the annual fixed OPEX cost.

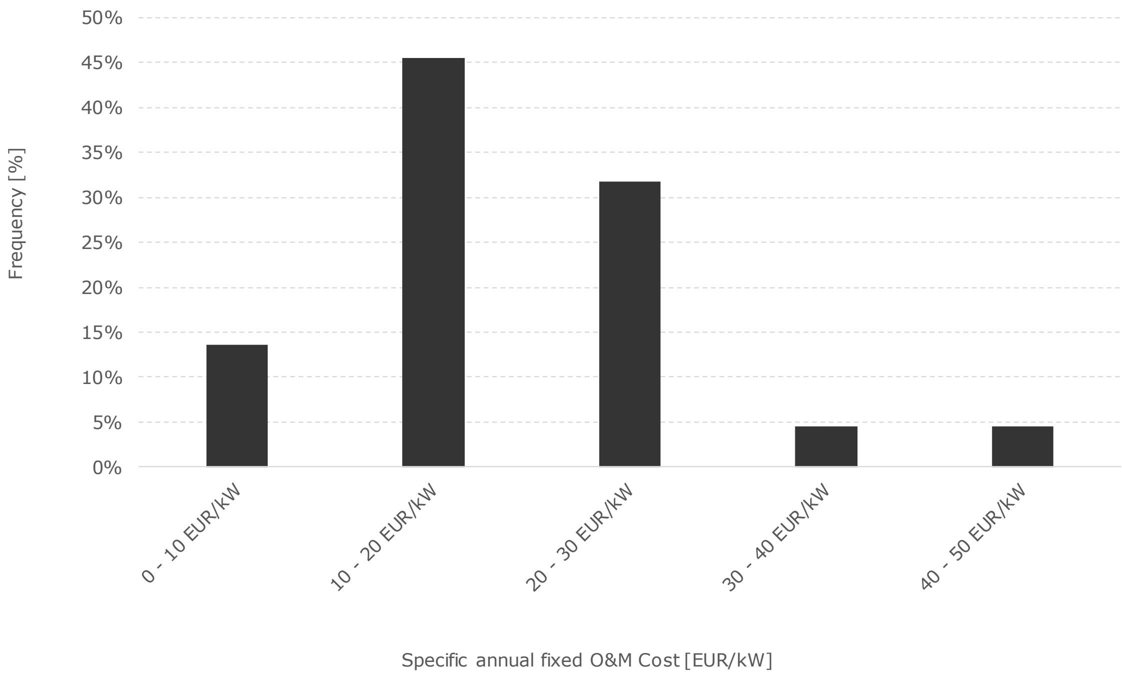
Figure 3 – Distribution of cost items for annual fixed OPEX cost



The majority of the annual OPEX cost of the PSP and storage plants are in the range of 10 to 30 €/kW. The average value is 18.6 €/kW which is also aligned with data presented in BFE 2014[18] (17 €/kW).

[18] Potential to achieve contribution margins for pumped storage power plants in Switzerland, Austria and Germany, BFE 2014 (https://www.bmwi.de/Redaktion/DE/Downloads/S-T/trilaterale-studie-zu-pumpspeicherkraftwerken-deutschland-oesterreich-schweiz-gutachten.html)

Figure 4 – Distribution of specific annual fixed OPEX cost



4.3 Conclusions

Based on the various data sources used in our analysis, there is significant variation in reported O&M costs for PSP plants, ranging from as from 10 €/kW to 50 €/kW. The lower end of the range is more representative of PSP plants integrated in a pool of hydropower plants allowing the utility to optimise resources – most notably manpower. On the other end of the spectrum, smaller PSP plants tend to have a higher O&M cost – a similar sized team is needed to operate the plant when compared to larger PSP plants.

Costs attached to major overhaul can have a strong impact on O&M costs. Maintenance may be done preventively or reactively which considerably impacts the cost side and in the latter case the availability of the plant.

Our review of different public data sources (from power utilities as well as authorities) combined with our inhouse knowledge suggests annual fixed OPEX for PSP in the range of 10 to 30 €/kW. As already discussed, there may, however, be a significant difference between small and large PSP plants. We recommend the use of an average cost of 19 €/kW for the purposes of defining a typical OPEX value for a pumped storage plant in Belgium. Larger facilities may however find themselves on the lower end of the spectrum.

This value excludes any royalty or water usage fees, major overhauls, and fees related to the plant operation in terms of grid usage, pumping energy or taxes in connection with the generation or purchase of energy.

Quality control

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ÅF and Pöyry have come together as AFRY. We don't care much about making history.

We care about making future.

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