Cost of Capacity for calibration of the Belgian CRM

-

List of technologies & FOM/VOM components and values

Final version

Project n°: ESID-23-022.2	**Contact**: Jens Baetens (jens.baetens@entras.be)	**Document n°**: ESID-23-022_d1

Rev.N°	Date	Description	Author	Reviewed by	Approved by
1.7	06/09/2023	Include CCS	Jens Baetens	Frank Alaerts	Approved by
1.8	07/09/2023	Correct FOM & VOM values	Jens Baetens	Frank Alaerts	
1.9	13/09/2023	Integrate more details	Jens Baetens	Frank Alaerts	
1.10	15/09/2023	Updated version	Jens Baetens	Frank Alaerts	
1.11	12/10/2023	Updated version	Jens Baetens	Frank Alaerts	
1.12	27/10/2023	Updated version	Jens Baetens	Frank Alaerts	
1.13	14/12/2023	Final version	Jens Baetens	Frank Alaerts	
2.1	19/6/2023	First version of update	Twan Bearda	Jens Baetens	
2.3	30/8/2024	Table update + clarifications	Twan Bearda	Frank Alaerts	

Disclaimer

The content of this document is intended for the exclusive use of Entras' client and other contractually agreed recipients. It may only be made available in whole or in part to third parties with the client's consent and on a non-reliance basis. Entras is not liable to third parties for the completeness and accuracy of the information provided therein.

Table of Contents

Abbreviations

ACER	Agency for the Cooperation of Energy Regulators
AFC	Alkaline Fuel Cell
AMT	Availability Monitoring Trigger
AUSC	Advanced Ultra-Supercritical Technology
BAT	Best Available Technology
BBL	Bond Beter Leefmilieu
BEE	Belgian Eco Energy
BESS	Battery Energy Storage System
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditures
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
CHP	Combined Heat and Power
CONE	Cost Of New Entry
CREG	Commission for Electricity and Gas Regulation
CRM	Capacity Remuneration Mechanism
CSP	Concentrated Solar Power
DC	Direct Current
DCS	Distributed Control System
DR	Demand Response
DSM	Demand Side Management
DSR	Demand Side Response
ECB	European Central Bank
EUA	EU Allowances (CO_2)
FC	Fuel Cell
FOM	Fixed Operation and Maintenance
GAPC	Global Auction Price Cap
GJ	Giga Joule
Gross CONE	Gross Cost Of New Entrant
GT	Gas Turbine
GW	Giga Watt
H_2	Hydrogen
HHV	Higher Heating Value
HVAC	Heating, Ventilation & Air Conditioning
IC	Internal Combustion
IPC	Intermediate Price Cap
ISO	International Organization for Standardization
ISVAG	Intercommunale Voor Slib- en Vuilverwijdering van Antwerpse Gemeenten
LFP	LiFePO4 – Lithium iron phosphate
LHV	Lower Heating Value
LTMA	Long Term Maintenance Agreement
MW	Mega Watt
Net CONE	Net Cost Of a New Entrant
O&M	Operations & Maintenance
OCGT	Open Cycle Gas Turbine

OECD	Organization for Economic Co-operation and Development
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij
PEM	Proton Exchange Membrane
PV	Photo Voltaic
RD	Royal Decree
SOFC	Solid Oxide Fuel Cell
ST	Steam Turbine
TRL	Technology Readiness Level
TTF	Title Transfer Facility
USA	United States of America
VLM	Vlaamse Landmaatschappij
VOM	Variable Operations and Maintenance
WACC	Weighted Average Cost of Capital

1 Introduction

1.1 Context and background

In order to ensure adequate means of electricity supply by 2025, the Belgian state has implemented a Capacity Remuneration Mechanism (CRM), the first auction of which took place in October 2021 for a first delivery period as of November 2025.

For the calibration process of the CRM auctions the cost of capacity is an important parameter. It helps to determine, among other parameters:

- The Intermediate Price Cap (IPC) applicable to capacities obtaining a capacity contract of 1 year;
- The Global Auction Price Cap (GAPC) of the demand curve via the determination of the Net Cost of a New Entrant (Net CONE).

In 2019, the CREG and Elia issued a first study to have input on the Gross CONE and IPC, which was performed by Fichtner [1]. Following the presentation of Fichtner's work in the Elia Working Group Adequacy, various market stakeholders explicitly requested a peer review to take place on the results presented by Fichtner. AFRY was retained as consultant to perform such review. It were the values as presented in the report by AFRY [2] which were used for the first two calibration processes of the CRM (auction October 2021 and October 2022). In 2022, AFRY updated the values from its 2020 report [3].

The results of the aforementioned studies have been used to determine a variety of parameters in the yearly calibration exercises of the CRM auction.

Mid 2023, Elia launched the request for a new study, on which Entras applied. The purpose is twofold: first and foremost, to fulfil the legal obligation to update the cost of capacity in the light of evolving market circumstances, and second to provide clarity on the different cost component parts of the calculation of the auction parameters.

1.1.1 CRM auction calibration elements

1.1.1.1 Gross CONE

The Belgian CRM comprises a centralised 'single buyer' auction to contract capacity to be available in a specified delivery year. In other words, a contracted capacity provider is obliged to be available in the energy market during the delivery year and is remunerated for that service as determined in the auction clearing. At the time of writing, there are two capacity auctions: 4 years and 1 year in advance of each delivery year. Whereas the supply curve of the auction is determined by bids made by market parties, the demand curve is administratively determined every year.

The demand curve is made up of two dimensions: capacity volume (in MW) and price (in €/kW/year). The volume dimension is calibrated on legally imposed reliability standards and is out of scope for this study. The price dimension is based on estimates of reasonable prices for additional new capacity on the Belgian grid. This relies on, amongst others, reasonable estimates of the cost of new capacity, which is part of the scope of this study.

These reasonable prices are based on an estimate of the Net CONE. Net CONE represents the revenues that the best new entrant technology would need to earn in the capacity market to compensate for "missing money" in the energy and balancing markets. Net CONE are defined on a technology level.

The calculation of the Gross CONE and Net CONE is performed as visualised in Figure 1. The initial capital costs (CAPEX) and the annual fixed operation and maintenance costs (FOM) are defined for each technology and are part of this study. Together with other parameters (not scope of this study) – the WACC, derating factor, construction time and expected lifetime – the Gross CONE for each technology is defined. Subtracting the net annual market revenues (not scope of this study) results in the Net CONE. For the calculation of these net annual market revenues, the variable operation and maintenance costs (VOM) are required, which are in the scope of this study.[1]

The Net CONE of the selected technology, representing the best new entrant, will be the central point on the Y-axis of the demand curve.

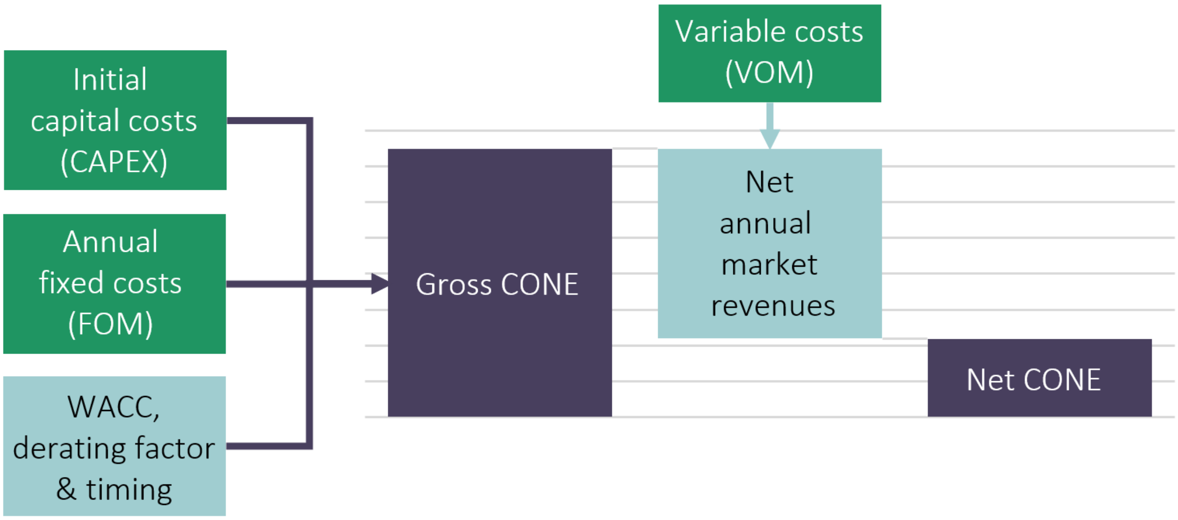

Figure 1 : Net CONE calculation principle. Parts in dark green are in scope of this study.
Annual market revenues include revenues from energy markets, ancillary services and heat (CHP).

1.1.1.2 Global Auction Price Cap

To be able to take into account uncertainties regarding the estimation of Net CONE, the bidding prices are allowed to go up to a predefined price cap (the Global Auction Price Cap). This is typically provided by taking a multiple of Net CONE reflecting this uncertainty (in previous auctions, a value of 1.5 was used). On the other hand, the auction must not allow unreasonably high bids. Therefore, reasonable order of magnitude estimates of the variations in Net CONE under different hypotheses are needed to determine this factor.

1.1.1.3 Intermediate Price Cap for existing capacity

The Primary Law for the Capacity Remuneration Mechanism, the Electricity Law, stipulates that it should be implemented at the lowest cost for society. For that purpose, a price cap for existing capacity is used to limit abuse of market power and avoid disproportionate remuneration for capacities requiring no or limited investment. Any capacity that can only apply for a contract for a delivery period of 1 year is subject to this price cap. To be allowed to contract for more than 1 year, an investment file has to be submitted to the CREG and specified investment threshold have to be reached to be able to apply for a 3, 8 or 15-year contract.

---

[1] Fuel costs, i.e., cost of natural gas and CO_2 are not included in the VOM. Market revenues to be considered are those out of the energy markets, ancillary services remunerations and revenues from heat (in case of CHP capability).

The existing capacity is, however, still entitled to bid in the auction allowing for a "fair and reasonable" remuneration. In order to assess this, information on the cost for existing capacity is needed. This cost includes Fixed Operation and Maintenance (FOM) costs, but also the provision for recurring investments (e.g. major overhaul) and an activation cost for technologies with a high variable cost.

1.1.1.4 Revenues on the energy market

The estimate of the revenues on the energy market is out-of-scope of this study. Those will be determined by Elia based on a Monte-Carlo simulation implementing a reference scenario selected by the Minister. However, the calculation of the infra-marginal rents requires variable cost parameters associated with technologies selected either in the framework of the Net CONE or of the IPC. Therefore, information on the Variable Operation and Maintenance (VOM) costs are also in the scope of this study. Among others, it is required to have a clear definition of which costs should be integrated in FOM or VOM costs to avoid double-counting.

1.2 Scope of the study

This study will provide Elia and the CREG with detailed information on the cost of capacity of electricity generating and storage technologies, which serves as input for, amongst other, the CRM calibration process. The horizon for this study considering relevant technologies is delivery period 2028-2029 and onwards.

In more detail, in this study we will:

A) Define a longlist of electricity generation and storage technologies as well as technologies with potential of reduction of offtake from the grid
    1) Shortlist this longlist for the use of Net CONE eligible technologies, based on relevant criteria
    2) Shortlist this longlist for the use of IPC eligible technologies, based on relevant criteria
B) Define a clear overview of the FOM and VOM costs
    1) Create an overview of FOM and VOM cost components, to be expressed in €/kW/year or €/MWh respectively
    2) Provide a value for each of the relevant defined cost components for technologies expected to enter the Belgian energy market, i.e., the technologies as defined under A1
    3) Provide a low – mid – high value for each of the relevant defined cost components for existing technologies in the Belgian energy market, i.e., the technologies as defined under A2
C) Define a clear overview of the total initial CAPEX costs
    1) Create an overview of the total initial CAPEX cost components for each technology as defined under A1
    2) Provide a value for each of the CAPEX cost components, for each technology as defined under A1

All prices in this report are expressed in €2023 (June), unless explicitly stated otherwise.

1.3 Structure of this report

The first deliverable (A) is the construction of a longlist of technologies and the subsequent shortlistings, once for technologies to be considered for the Net CONE (A1), and once for the technologies to be considered for the IPC (A2). Deliverable B1 is the creation of an overview of the FOM and VOM costs for these different technologies. In deliverables B2 and B3, FOM and VOM values are reported by technology type, both for new entrants and existing assets in the Belgian energy market.

The methodology and creation of a longlist of electricity generation technologies, storage and DSM is elaborated upon in §2.1, while the shortlisting methodology and the constructed lists are presented in §2.2 and §2.3. In §3.3 the FOM and VOM cost components are discussed, and in §3.5 an overview of the FOM and VOM values is presented.

2 Considered technologies

2.1 Identification of relevant technologies

As a starting point, a longlist of electricity generation, storage and DSR technologies is constructed. This longlist contains all today's commercially available technologies (TRL 9), as well as technologies which are expected to be commercially available in the near future. More concrete, the near future is interpreted as assets being operational by CRM delivery period 2028-2029. The lead and construction time of the assets is thus deducted from the delivery period 2028-2029 horizon, e.g., considering the construction time of 3 years for a certain technology requires the technology the be commercially available by 2025 the latest.

2.1.1 Methodology of definition and categorisation

An electricity generation technology is defined as a technical system which is able to generate electricity on a grid-scale level. A storage technology is defined as a technical system which has the ability to offtake electricity from the grid, store it in some form of energy, and again generate electricity from this stored energy and inject it into the grid. Demand Side Response technologies are defined as electricity consumers which can control their electricity consumption in time and/or magnitude based on certain signals.

Different methodologies can be used to define and categorise these technologies. The focus in this report is on the technical nature of the installation, rather than on the size, fuel-type or others.

To create the longlist, literature was consulted, as well as it was built upon previous reports by Fichtner [1] and AFRY [2], interviews with market parties and expertise of the Entras consultants. Market parties addressed are those in the Working Group Adequacy of Elia as well as additional contacts in the network of Entras. In total, a dozen market parties responded to the request for interview and supplied qualitative and/or quantitative information to Entras.

For certain technologies it is possible to define "*capabilities*". These are additional assets, installations or modifications to the technology which are possible but not considered as necessary to operate the main technology.

The rationale behind introducing this concept of *capabilities* or *add-ons* in this report results from the categorisation of the technologies based on their technical characteristics. Electricity generating, storing or DSR assets can be very complex in nature, with different combinations of technologies, fuels, etc. as well as ways of integrating them into larger processes. To allow a technology list to be composed, for the purpose of this study, standard technologies should be defined. The principle of *capability* is used as well in other relevant reports such as in [4].

The concept of Combined Heat and Power (CHP) generation is thus no longer considered as a separate technology but is a defined as a *capability*. This is fundamentally different to previous reports such as those from Fichtner [1]. This approach allows the electricity generating technology to be approached in a more standardised way in this report.

Also, discussion on the need for certain additional installations, e.g. Carbon Capture and Storage (CCS), might lead to the inclusion or exclusion of these costs for certain technologies. To objectively take these costs into account, they were categorised as *capability*, which might be relevant for a certain technology, e.g., CCS and CHP are capabilities relevant for a CCGT. The goal is to structure the costs of the capability in such a way that they (with certain ranges) can be added on top of the costs of a technology. It allows a more transparent view on the costs of technologies and the additional costs (and revenues[2]) of their additional capabilities.

The identified capabilities are:

- Combined Heat and Power (CHP)
- Carbon Capture and Storage (CCS)[3]
- Second fuel type (biogas, hydrogen, (bio)diesel, ammonia, syngas, industrial off-gas, etc.), additional to the primary type of fuel

---

[2] Additional revenues, such as a heat revenue for a CHP, are not in scope of this study.

[3] The values as reported for CCS will include the costs related to capture, transport and storage of the CO_2. For more details, see §3.4.4.9.

2.1.2 Technology longlist

Table 1: Longlist of technologies, including their primary fuel or energy and capabilities.

	Primary fuel or energy	Capabilities		
		CHP	CCS	2nd fuel type
1. Electricity generation technologies				
1.1. Thermal technologies				
1.1.1. Combined Cycle Gas Turbine (CCGT)	Natural gas	X	X	X
1.1.2. Open Cycle Gas Turbine (OCGT)	Natural gas	X	X	X
1.1.3. Combustion system & Steam Turbine (ST)				
1.1.3.1. Nuclear fission	Uranium			
1.1.3.2. Coal	Coal	X	X	
1.1.3.3. Waste	Waste	X	X	
1.1.3.4. Biomass	Biomass	X	X	
1.1.4. Internal Combustion Engines (IC engines)	Natural gas	X	X[4]	X
1.1.5. Turbojets	Light fuel			X
1.2. Renewable technologies				
1.2.1. Onshore wind turbines	Wind			
1.2.2. Offshore wind turbines	Wind			
1.2.3. Hydropower (run-of-river)	Potential			
1.2.4. Photo Voltaic (PV)	Sun			
1.3. Electrochemical technologies				
1.3.1. Fuel cell (FC)	Hydrogen	X[5]		
2. Storage technologies				
2.1. Pumped Hydro Storage	Electricity			
2.2. Battery Energy Storage Systems (BESS)	Electricity	X[6]		
2.3. Compressed Air Energy Storage (CAES)	Electricity	X[7]		
2.4. Flywheel	Electricity			
3. Demand Side Management (DSM) technology	Electricity			

---

[4] While theoretically possible, this is not common practice and therefore not included in this report.

[5] The conversion of hydrogen into electricity taking place in a fuel cell has a limited efficiency. During the conversion, energy is lost in the form of heat, which could be purposefully used. In that case, the fuel cell is considered to have a CHP capability.

[6] During the charging and discharging of a BESS, energy is lost as heat. This heat can be purposefully used. In that case, the BESS is considered to have a CHP capability. While a theoretical possibility, this capability is currently not common practice and therefore not included in this report.

[7] During the compressing of air, energy is lost in the form of heat, while during the expansion of the air, heat is required to increase the air temperature. If the heat during compression is purposefully used, e.g., it is stored and reused during air expansion, the CAES system is considered to have a CHP capability.

2.2 Shortlisting of technologies

2.2.1 Methodology

For the selection of technologies that can reasonably be expected to enter the Belgian energy market, i.e., **candidate technologies for determination of the Net-CONE**, a shortlisting is done based on the criteria as defined by ACER [5] and as stipulated by the Royal Decree (RD) in article 10, §4 [6]. The Royal Decree states that:

1) The reference for each technology should be a new entrant, which is not yet active on the electricity market and for which no existing infrastructure is available
2) The shortlist will be based on the existing technologies in the Belgian control area, or on technologies which can reasonably be expected to be available for the envisioned time frame
3) For technologies with the same magnitude of operating hours, technologies with significantly higher costs will be excluded from the shortlist
4) The technologies should meet the CO2 emission limits (see §2.2.1.1)

As communicated by ACER, a candidate technology shall refer to any new investment in any technology able to provide resource adequacy benefits, including but not limited to electricity generation capacity, storage facilities and DSR. To be classified as a reference technology, the following two cumulative criteria should be met:

1) The technology should be a standard technology, meaning that:
    a. Reliable and generic cost information is available for the defined cost components[8]
    b. The costs of building and operating units of the technology are reproducible between projects
    c. The development of the technology is not significantly bound by technical constrains[9]
2) The technology shall have potential for new entry, meaning that:
    a. Capacity representing this technology has been developed in the recent years, is in process of development or is planned for development for the considered timeframe
    b. Future development of this technology is allowed and is not significantly hampered by the Belgian and European regulatory framework, e.g., by CO_2 emission limits (see §2.2.1.1)

In fact, when the above criteria are met, the reference technology is expected to reflect a technology for which investment decisions are likely to be made by rational private investors in a considered geographical area, here Belgium.

---

[8] For a list of the cost components as defined by ACER, see article 13 in [5].

[9] Technologies with limited individual capacity which can be aggregated in homogeneous clusters shall be considered as standard if reliable data is available to characterise these clusters. Reliable data may consist of cluster capacity, cluster activation price or generation costs and economic and/or technical activation constraints representative of the cluster.

For the shortlist of technologies which can reasonably be expected to be present in the Belgian energy market, i.e., **the technology list for the calculation of the Intermediate Price Cap (IPC),** the following criteria are considered, hereafter referred to as the "IPC technology criteria":

1) Will there be operational installations of the technology in the market[10] during the considered time frame?
2) Can the technology reasonably be expected to contribute to the security of supply during the considered time frame?
3) Are the CO_2 emissions of the technology below the required threshold (see §2.2.1.1)?

As concluding criteria, a "fit-for-purpose" check is performed. It is analysed if the technology is to be expected to be used as the reference technology for either the Net-CONE or IPC calculation by taking into account the derating factor, i.e., its ability to contribute to the security of supply and adequacy. This allows a resource efficient way of working for the calculation of the FOM, VOM and CAPEX values for the shortlisted technologies. For example, the derating factor for PV will be very low, due to the very limited contribution to the security of supply. The resulting Net-CONE will therefore be significantly higher than other technologies and PV will not be considered as the reference technology. Similar reasonings can be made for other technologies as well.

In the sections 2.2.2 to 2.2.16, each technology on the longlist is discussed based on the above criteria and it is decided if this technology is withheld for the Net-CONE reference technology shortlist and/or the IPC technology shortlist. The evaluation is done based on publicly available information, expertise of Entras and information gathered during interviews with market parties. The resulting shortlists are to be found in sections 2.3.1 and 2.3.2 for the Net-CONE and IPC technologies respectively.

2.2.1.1 CO_2 emissions

Technologies operating on fossil fuels are bound to certain emission limits regarding CO_2, as set out by the European Parliament. The emission limits to be met are a specific emission below 550 g CO_2/kWh_e and an absolute emission limit of 350 kg CO_2 /kWe/year [7].

For new units entering the market, in the framework of the CRM, the specific emission limit of 550 g CO_2/kWh_e is applicable. It is this limit against which the technologies will be benchmarked in this report.

For existing units, also the specific emission limit of 550 g CO_2/kWh_e is in effect. But also an additional combination of emission limits can be applied in case the 550 g CO_2/kWh_e specific emission limit is not fulfilled. For existing units, commissioned before 04/07/2019, a specific emissions limit is set at 600 g CO_2/kWh_e if the annual emission threshold of 306 kg CO_2/kWe/year is not exceeded. This limits the number of operating hours of high CO_2 emitting technologies, but allows them to continue to operate in the market.

---

[10] With "in the market" we refer to the Belgian market.

As final note it should be clear that proposals for reduction trajectories regarding the emission limits for electricity generation are on the table on a Belgian Federal level. In one of the working documents specific emission limits of 527 to 435 g CO_2/kWh_e for the delivery years 2027 to 2031 are proposed (as according to trajectory nr. 2 [8]). As they are not yet officially in place, these limits are not taken into account in this report.

As the shortlisting is done in the frame of the reference technology for the Net-CONE, considered efficiencies of evaluated technologies will be those as applicable for newly built assets today and in the near future.

2.2.2 Combined Cycle Gas Turbine technology

A CCGT is a widespread and common technology to produce electricity and the construction of a CCGT plant is standardised. The CCGT technology consists of a gas turbine and a steam turbine as electricity generating assets. The heat of the hot flue gases coming out of the gas turbine is used to generate steam, which is converted to electricity in the steam turbine and subsequent generator. There are different OEMs who provide the CCGT technology, and several plants have been, are and will be built, also in Belgium. They will also be available in the market during delivery period 2028-2029 and beyond. This results in the availability of reliable and generic cost information, which is reproducible across projects. No technical constraints exist which hamper the development of a CCGT.

As primary fuel, fossil natural gas is being used in most of the existing CCGTs. Other fuel types are also possible such as hydrogen, diesel, or off gases from industrial processes. The use of carbon containing fuels such as natural gas result in the production of CO_2. Due to the high energy efficiency of the CCGT technology and the use of natural gas as typical fuel, the specific emissions for new installations are typically between 348 g CO_2/kWh_e and 404 g CO_2/kWh_e, which is well below the set limit of 550 g CO_2/kWh_e.

Meeting the Net-CONE criteria, the CCGT technology will thus be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Meeting the IPC technology criteria, the CCGT technology will be considered as a technology for the IPC calculation.

2.2.3 Open Cycle Gas Turbine technology

An OCGT is a widespread and common technology to produce electricity and the construction of an OCGT plant is standardised. In fact, a CCGT and an OCGT share the same gas turbine technology. The difference lies in the use of the heat of the hot flue gases; these are not valorised in the OCGT technology as they are vented directly to the atmosphere. Considering this similarity with CCGT technology, this means that reliable and generic cost information is available, which is reproducible between projects. Several OCGT plants are operational today in Belgium and elsewhere. It is expected that the Belgian OCGT plants will continue their operation during delivery period 2028-2029. Yet, no new OCGTs have been built over the past few years nor are there any projects publicly announced to be built in Belgium as of today. Yet, in other European countries, plants have been announced and/or built. For example, in Ireland new OCGT plants were recently announced to be built, of which one already obtained its environmental permit [9] [10]. In Germany, the Irsching 6 OCGT plant recently had its first firing and synchronisation to the grid [11].

Considering that OCGTs typically use natural gas as fuel, and that their efficiency is lower than that of the CCGT technology, the specific emissions of CO_2 are considerably higher. An AE94.3A turbine, as was installed at the Irsching 6 power plant, has a gross nominal power of 340 MWe and a gross efficiency of 40.3 % HHV [12]. This results in a specific emission of 498.8 g CO_2/kWh_e.

$$\frac{201\ \frac{g\ CO_2}{kWh_e}}{0.403} = 498.8\ \frac{g\ CO_2}{kWh_e}$$

The SGT5-9000HL turbine of Siemens, with a nominal power of 593 MWe has a gross efficiency of 43% HHV, being one of the highest of the gas turbines currently available on the market [13]. Operating this turbine with natural gas would results in a specific emission of 467.4 g CO_2/kWh_e. Turbines with a lower nominal power typically have a lower efficiency. Regarding the specific emission limit of 550 g CO_2/kWh_e and the fuel being natural gas, an efficiency as low as 36.5 % HHV is possible while still meeting the emission limit. For example, the Siemens SGT-700 turbine has a nominal power of 33 MWe and a gross efficiency of 37.2% HHV and thus meets the emission limit.

New OCGT power plants are thus considered to be possible regarding the specific emission limit of 550 g CO_2/kWh_e.

Existing OCGTs in Belgium have slightly lower efficiencies, resulting in higher specific emissions [1]. Yet, considering the specific emission limit of 600 g CO_2/kWh_e which applies in case if the annual emission threshold of 306 kg CO_2/kWe/year is not exceeded[11], it is assumed that the majority of the Belgian OCGTs meet these emission limit requirements [14].

Meeting the Net-CONE criteria, the OCGT technology will thus be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Meeting the IPC technology criteria, the OCGT technology will be considered as a technology for the IPC calculation.

2.2.4 Combustion systems and steam turbine technologies

This technology consists of a combustion system, where a fuel is used to produce heat and subsequently steam. This steam is expanded over a steam turbine, which is connected to a generator, which generates electricity. Depending on the primary fuel type being used, different technologies are considered.

2.2.4.1 Nuclear fission power plant technology

In a nuclear fission power plant, the heat source is the nuclear reactor in which the nuclear fission reaction takes place. The development and/or exploitation of new nuclear power plants in Belgium is not allowed by the Federal law[12].

It can be expected that nuclear power plants Doel 4 and Tihange 3 will be in the market during delivery period 2028-2029 [15]. Nevertheless, it can be expected that in the agreement between the Federal Government and the owner/operator Engie Electrabel the support under CRM is excluded.

Because of the Federal law on the nuclear exit, the nuclear fission technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

---

[11] These emission limits are valid for assets commissioned before the 4th of July 2019. As all existing OCGT installations are commissioned before this date, this criterion applies to all existing OCGT installations.

[12] Wet houdende de geleidelijke uitstap uit kernenergie voor industriële elektriciteitsproductie van 28/02/2003, Artikel 3 [84].

It is expected that existing nuclear power plants are excluded from receiving CRM support, therefore the nuclear fission technology will not be considered as a technology for the IPC calculation.

2.2.4.2 Coal-fired power plant technology

A coal-fired power plant operates with coal as primary energy source, of which anthracite bituminous, subbituminous and lignite are different grades. Coal is a fossil type of fuel, emitting CO_2 during the combustion. Depending on the type of operation of the coal-fired power plant (subcritical, supercritical or ultra-supercritical), the efficiency ranges from 34.4% to 43.3%, with the ultra-supercritical being the most efficient [16]. General Electric pioneers with a so called "Advanced ultra-supercritical" (AUSC) technology, where the net efficiency is increased up to 47.5% and goals are set to reach a 50% efficiency in the near future [17].

Despite the technological developments and increasing efficiency, the specific CO_2 emissions of such a coal-fired power plant are still significantly above the limit of 550 g CO_2/kWh_e. For example, the most efficient power plant operational today is the RDK8 in Germany with an efficiency of 47.5% and a specific CO2 emission of 740 g CO_2/kWh_e [18].

With the closure of the power plant in Langerlo in 2016, Belgium no longer has any operational coal-fired power plants.

Not meeting the specific emissions limit for CO_2, coal-fired power plant technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the IPC technology criteria, the coal-fired power plant technology will not be considered as a technology for the IPC calculation.

2.2.4.3 Waste incineration technology

Waste incineration with recuperation of energy is the main method of waste processing for residual waste in Belgium [19]. The recuperation of energy is done by purposefully using the produced heat from burning the waste, producing steam or hot water for further use. The steam can be converted to electricity in (a) steam turbine(s) with subsequent generator(s).

Belgium (with the region Flanders on top) has a good selective waste collection and recycling of municipal and industrial waste. Plastics, cardboard and biological waste are separately collected and treated, resulting in the residual waste fraction not being contaminated with those fractions.

The considered technology under this category is the burning of residual waste ("Restafval") with the recuperation of the energy by use of steam turbines and generators to produce electricity. The estimated emission factor for the incineration of residual waste is 489 kg CO_2/ton of waste, with an estimated avoided emission of 149 kg CO_2/ton of waste when the energy is recuperated, resulting in a net emission of 340 kg CO_2/ton of waste [19]. The average energy content of the processed waste is estimated at 10.45 GJ/ton of waste [20]. The net electrical efficiency of the most efficient operational waste plant in Belgium today is 30 % [20]. This results in a specific emission of 390.8 g CO_2/kWh_e, which is well below the set limit of 550 g CO_2/kWh_e.

$$\frac{340\ \frac{kg\ CO_2}{ton\ waste}}{10.45\ \frac{GJ}{ton\ waste} * 277.78\ \frac{kWh}{GJ} * 0.3} = 0.3908\ \frac{kg\ CO_2}{kWhe} = 390.8 \frac{g\ CO_2}{kWhe}$$

The technology of incinerating waste and recuperating energy can be considered as a mature and standardised technology. Therefore, reliable and generic cost information is available and they are reproducible across different projects.

The incineration of residual waste is considered as the Best Available Technology (BAT) for residual waste processing and has the priority over, for example, landfilling. Considering the availability of residual waste in Belgium, today and in the near future, it can be concluded that there is potential for this technology. There will be operational plants during delivery period 2028-2029 and beyond.

ISVAG, the intermunicipal collaboration for the processing of waste of 30 cities and municipalities in the neighbourhood of Antwerp, are planning a new waste incinerator. Despite the issues considering their permits, this shows that the waste incineration technology has potential for new entry. Yet, a limited amount of new capacity is considered to be possible, considering that the given amount of waste is a limiting factor. Therefore, under the fit-for-purpose criteria, the waste incineration technology is excluded as a Net-CONE technology.

While meeting the Net-CONE criteria, the waste incineration technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE due to not meeting the fit-for-purpose criteria as well as having significantly higher costs than other technologies with similar operating hours. Limited capacity is expected to enter due to the limited amount of waste available.

Meeting the IPC technology criteria, the waste incineration technology will be considered as a technology for the IPC calculation.

2.2.4.4 Biomass power plant technology

Under this technology the incineration of woody biomass is considered. This biomass can be heterogeneous in nature, ranging from uniform virgin wood pellets or chips to different grades post-consumer wood and woody waste from landscape maintenance and management.

Depending on the type of woody biomass considered, typically different scales of biomass power plants are considered. Large-scale power plants (several 10’s to 100’s of MW) tend to work on uniform wood pellets or chips, while smaller size power plants typically operate on post-consumer wood and wood waste from landscape management.

The use of biomass for the generation of electricity in large-scale power plants is contested by some parties and may be considered controversial. This is mainly because biomass (pellets, chips) needs to be imported from outside of Belgium, which has an unsustainable character. A report from the Bond Beter Leefmilieu (BBL) from 2015 discusses the, back then, planned large-scale biomass power plants in Belgium. Three biomass power plants were considered: the BEE power plant in the Port of Ghent (215 MW), the German Pellets power plant in Langerlo (reconversion of old coal-fired power plant, 500 MW) and a new biomass power plant in Wallonia (200 MW) [21].

Belgian Eco Energy (BEE) constructed and commissioned the new biomass power plant in the Port of Ghent in 2022 with a nominal electrical capacity of 20 MWe and a nominal heat capacity of 50 MW [22]. The size of the power plant has been downscaled from the initial foreseen 215 MW capacity. The reconversion of the Langerlo power plant was stopped due to issues with a heat exchanger, resulting in the loss on outlook on subsidies. In 2020 the plant demolition started.
The planned new biomass power plant in Wallonia was never constructed.

The coal-fired power plant Les Awirs, owned and operated by Engie Electrabel, was converted to a biomass power plant and restarted operation in 2015. With a nominal electrical power of 75 MWe it was the largest biomass power plant of Wallonia. In 2020 Engie Electrabel announced the closing of the power plant due to the ending of the subsidies (green power certificates) [23].

Small-scale biomass power plants (< 25 MWe) tend to operate based on woody biomass which is more locally sourced. Examples of existing installations in Belgium are the power plants of 2Valorise (9.6 MWe in Ham, 11.2 MWe in Amel [24]) and those of the cooperation of Aspiravi & Unilin (25 MWth A&S in Oostrozebeke, 19.9 MWth A&U in Wielsbeke [25] [26]). These power plants are also equipped with a CHP capability, allowing for the cogeneration of electricity and heat, increasing the overall efficiency.

Micro-scale electricity generation (kW-scale) from woody biomass is also possible, but here the focus mainly lies on the production of heat. The production of electricity is considered only in secondary order. This type of electricity generation is not further considered here.

In the report ordered by the Vlaamse Landmaatschap (VLM) on the economic potential of biomass waste from landscaping management, the conversion of woody biomass to energy is mentioned. Here the conclusion is that the main focus lies on the conversion to heat, but that CHP modus is also possible. Yet, several aspects hamper the development of such technology, of which the regional policy is one. It is also mentioned that the conversion of woody biomass to energy is seen as a low-value option in the cascade of biomass valorisation as depicted by OVAM, and that high-value applications such as bio-refinery will play a larger role in the near future [27].

Considering all the above arguments, it can be concluded that biomass power plant technology should not be withheld as a candidate technology for the Net-CONE. The cost information is not considered to be generic nor reproducible between projects. Due to the difference in type of biomass being burned, as well as in the size of power plants, these ACER criteria are not met. With the power plant of BEE, the criteria for today's development are met. Yet, the future development might be hampered by regional policies.

Not meeting the Net-CONE criteria of reliable and generic cost information, reproducibility of costs between projects, as well as doubts on future development of this technology, the biomass power plant technology will not be withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Meeting the IPC technology criteria, the biomass power plant technology will be considered as a technology for the IPC calculation.

2.2.5 Internal combustion engine technology

Internal Combustion (IC) engines generate electricity by a generator which is driven by a crank, which converts reciprocating motion to rotational motion. The reciprocating motion from the pistons is due to the burning of fuel in the cylinders, which causes expansion and therefore motion.

IC engines are a standard technology for electricity generation and are available in both small (few kW's) to large scale (few MW's) in size. They can be operated on an electricity-only basis, but are often also equipped with a CHP capability, increasing their overall efficiency. Indeed, due to the burning of fuel, heat is generated as well. In an electricity-only case, the heat is evacuated to the environment.

Different types of fuels can be used, with natural gas and diesel being the most common. Diesel fired IC engines are typically used as emergency generators to supply critical infrastructure with electricity in case of electricity grid interruptions. IC engines in the constellation of CHP and with natural gas as fuel are the more day-to-day typical use-case for electricity generation in Belgium. Also, the use of biogas, which is a mixture of CH_4 and CO_2, produced from fermentation of biological materials can be used as fuel. This has the advantage of valorising the produced biogas, without the need for purification to biomethane for natural gas grid injection. Other types of fuels, such as bio-fuels are possible as well. Several biogas IC engines are operational in Belgium and have also recently been constructed.

In this report, the use of natural gas as fuel will be considered the standard for the IC engines. Other fuel types are considered as a capability.

With electrical efficiencies between 38% and 44%, for IC engines with a nominal power of 100 kW and 2.5 MW respectively [28], and natural gas as fuel, the specific emissions are between 529 and 456 g CO_2/kWh_e, which is below the limit of 550 g CO_2/kWh_e. Note that smaller (< 100 kW) IC engines exist as well, which have a lower efficiency and will not always meet the specific emissions limit of 550 g CO_2/kWh_e or 600 g CO_2/kWh_e.

The IC engine technology is considered a standard technology for which reliable and generic cost information is available. No technical or legal restrictions hamper the development of this technology. A significant number of installations is present in the Belgian energy market today, and it is expected that they will be there during the delivery period of 2028-2029 as well. The development of new IC engine projects has been limited in the recent years. Yet, some projects materialised, being it mainly with CHP capability and with biogas or natural gas as fuel type.

Meeting the Net-CONE criteria, the IC engine technology will thus be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Meeting the IPC technology criteria, the IC engine technology will be considered as a technology for the IPC calculation.

2.2.6 Turbojet technology

Kerosene (light fuel) fuelled turbojets for electricity generation are an aeroderivative technology and are in fact engines from airplanes, converted for stationary usage and electricity production. Considering the low electrical efficiency (between 33.4 and 35% [1]) and the fact that a fuel is used with a high carbon content, the CO_2 emissions well exceed the limit of 550 g CO_2/kWh_e with a value of 714.3 g CO_2/kWh_e.

Today, several turbojets are available in the market in Belgium, and have been contracted under the first Y-4 CRM auction in 2021 with 1-year contracts. Yet, for future CRM participation, these units do not meet the specific emission limits of 550 g CO_2/kWh_e nor 600 g CO_2/kWh_e. Therefore, they will not be considered as technology under the IPC.

The CCS capability is considered to be not fit for the turbojet technology considering the very limited operating hours and the high capital intensiveness of CCS. Therefore, it cannot be used to lower the CO_2 emissions and does not alter the conclusion of exclusion of the technology.

$$\frac{3\ \frac{kg\ CO_2}{kg\ fuel}}{12\ \frac{kWh}{kg\ fuel} * 0.35} = 714.3 \frac{g\ CO_2}{kWhe}$$

Not meeting the specific emissions limit for CO_2, turbojet technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the specific emissions limit for CO_2, the turbojet technology will not be considered as a technology for the IPC calculation.

2.2.7 Onshore wind turbine technology

Onshore wind turbines are well developed in Belgium. The installed capacity in 2020 had grown to a size of 2408 MW [29]. Several projects are still under construction, development or are on the drawing table. Onshore wind turbines will be part of the energy market in Belgium during delivery period 2028-2029 and beyond. The onshore wind turbine technology can be considered as mature, despite the ongoing improvements and increase in single turbine sizes. Onshore wind turbines can thus be considered as a standard technology, of which reliable and generic cost information is available.

Technical and regulatory difficulties for the development of the onshore wind turbine technology do exist, due to the densely populated and fragmented geographical context of Belgium. Also, restrictions due to aviation and a long approval procedure are considered as barriers [30]. Nevertheless, these barriers are on the radar of the competent authorities and expected to be (partially) alleviated in the future [31].

Considering the defined Net-CONE criteria, onshore wind turbine technology is considered to be a candidate technology for the Net-CONE shortlist, i.e., it is considered a technology for which investment decisions are likely to be made by rational private investors. Nevertheless, this technology is excluded from the shortlist based on the fit-for-purpose criteria. Considering the limited contribution to the adequacy, expressed with a low derating factor of 6% to 10% in previous auctions [32] [33], the Gross CONE would be significantly higher than most other technologies [34]. This fit-for-purpose criteria is also applied for the IPC shortlisting.

Not meeting the fit-for-purpose criteria, the onshore wind turbine technology will not be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the fit-for-purpose criteria, the onshore wind turbine technology will not be considered as a technology for the IPC calculation.

2.2.8 Offshore wind turbine technology

Offshore wind turbine technology is well developed in Belgium. With the first offshore wind farm being operational in 2009, the total installed capacity has grown to 2262 MW by 2020 [29].

It was decided by the Federal government in 2021 to increase the capacity of offshore wind turbines to between 5.4 GW and 5.8 GW by 2030 [35].

The offshore wind turbine technology can be considered as mature, despite the ongoing improvements and increase in single turbine sizes.

It can thus be concluded that offshore wind turbine technology can be considered as a standard technology. Reliable and generic cost information is available and costs are reproducible between projects. No technical nor regulatory constrains hamper the development, in fact it is foreseen to facilitate the construction of offshore wind turbines even more so in the future than today. With projects being build, and plans are made for future projects, in Belgium and elsewhere, it is clear that this meets the ACER requirement of future development. Offshore wind turbines will play an important role in the Belgian energy landscape during delivery period 2028-2029 and beyond.

Considering the defined Net-CONE criteria, offshore wind turbine technology is considered to be a candidate technology for the Net-CONE shortlist, i.e., it is considered a technology for which investment decisions are likely to be made by rational private investors. Nevertheless, this technology is excluded from the shortlist based on the fit-for-purpose criteria. Considering the limited contribution to the adequacy, expressed with a low derating factor of 11% to 15% in previous auctions [32] [33], the Gross CONE would be significantly higher than most other technologies [34]. This fit-for-purpose criteria is also applied for the IPC shortlisting.

Not meeting the fit-for-purpose criteria, the offshore wind turbine technology will not be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the fit-for-purpose criteria, the offshore wind turbine technology will not be considered as a technology for the IPC calculation.

2.2.9 Hydropower (run-of-river) technology

The hydropower run-of-river installations as seen under this technology are considered as power plants where electricity is generated from the kinetic energy in the flow of water in rivers. The water flow of a river is diverted into pipes or tunnels, which run the water to the turbine, which is connected to a generator to produce electricity. None to very limited amount of water is stored, this in comparison to the hydroelectric dam technology.

This type of technology is very dependent on the geographical factors in a certain area and require a certain amounts of head and flow of water. Some installations are present in Belgium, with a total installed power of 125 MW [1]. It is expected that they will be part of the Belgian energy market during delivery period 2028-2029. Only very limited new volumes can be expected to enter the market, considering the Belgian geographical factors.

Under the fit-for-purpose criteria, the hydropower run-of-river technology is excluded from the IPC shortlist due to having very limited installed capacity.

Due to the development of the technology to be limited by technological constraints, namely the non-suitability of the Belgian geographical factors, and the fact that no projects are being constructed in Belgium, the hydropower run-of-river technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the fit-for-purpose criteria, the hydropower run-of-river technology will not be considered as a technology for the IPC calculation.

2.2.10 Photo Voltaic technology

Photo Voltaic (PV) installations are well developed in Belgium, with significant capacity on residential rooftops, on industrial rooftops, dedicated PV parks and developments in for example agrivoltaics [36] [37]. An estimated total capacity of 7.6 GWp of PV is installed in Belgium at the time of writing, with many projects currently being constructed and planned [38].

The PV technology is considered as mature, despite the ongoing improvements in terms of efficiency.

This results in the fact that reliable and generic cost information is available and that the costs of building and operating the PV installations is reproducible between projects. No technical constraints hamper the development of the PV technology. Also no regulatory issues are identified, in fact the ongoing development of PV installations is facilitated on all institutional levels. PV installations will play an important role in the Belgian energy landscape during delivery period 2028-2029 and beyond.

Considering the defined Net-CONE criteria, PV technology is considered to be a candidate technology for the Net-CONE shortlist, i.e., it is considered a technology for which investment decisions are likely to be made by rational private investors. Nevertheless, this technology is excluded from the shortlist based on the fit-for-purpose criteria. Considering the limited contribution to the adequacy, expressed with a low derating factor of 1% to 4% in previous auctions [32] [33], the Gross CONE would be significantly higher than most other technologies [34].

Not meeting the fit-for-purpose criteria, the Photo Voltaic technology will not be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the fit-for-purpose criteria, the Photo Voltaic technology will not be considered as a technology for the IPC calculation.

2.2.11 Fuel cell technology

The fuel cell technology, for the purpose of this report, is considered to be a hydrogen fuelled fuel cell. It is an electrochemical cell, converting the chemical energy of hydrogen and an oxidising agent, in this case air, into electricity through a pair or redox reactions. Different fuel cell technologies exist, such as PEM, Alkaline (AFC) or Solid Oxide (SOFC).

Existing grid scale fuel cell installations for the purpose of electricity generation, or for the combined generation of heat and electricity, are today mainly deployed in the USA and in South Korea, with only very limited installations in Europe, of which none in Belgium [39]. The installations in Europe typically use hydrogen as a fuel, which is a by-product from industrial processes. On other continents often a fossil fuel is converted to hydrogen, which is then used in the fuel cell [40]. Hydrogen-to-electricity efficiencies of up to 60% lhv are possible with PEM and AFC fuel cell technologies [41].

While the technology can be considered mature, no projects have been announced to be constructed in the near future in Belgium or Europe. Therefore, the fuel cell technology will not be withheld as candidate technology for the Net-CONE shortlist nor for the IPC shortlist.

Due to the fact that very limited projects have been, are being or will be constructed (of which non in Belgium) the fuel cell technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the IPC technology criteria, the fuel cell technology will not be considered as a technology for the IPC calculation.

2.2.12 Pumped hydro storage technology

The technology of storing energy by use of water, pumps and potential energy, and converting it back to electricity by letting it down a turbine is considered under the pumped hydro storage.

Pumped hydro storage is a well-known and mature technology, being used in Belgium and many other countries worldwide. In Belgium there are two existing installations: Coo (1080 MW, 5213 MWh) and La Platte Taille (144 MW, 700 MWh) [14]. Upgrades to both the installed power of the turbines as well as to the size of the water reservoir will result in a total installed capacity of 1251 MW/6300 MWh by the end of 2023 [14]. Note that these increased capacity sprouts from the upgrading of existing installations, rather than the development and construction of new installations. The existing installations, being recently upgraded, will be in the market during delivery period 2028-2029 and beyond.

Pumped hydro storage installations require specific geographical factors such as height differences and locations for basins to be developed. Considering the size of Belgium and its geographical landscape, it is clear that there are limitations towards the further development of pumped hydro storage installations. No new installations have been constructed in the recent years, nor have there been publicly announced plans for the development of new installations. This is also the main reason why this technology will not be considered as a candidate technology for determining the Net-CONE.

Due to the development of the technology to be limited by technological constraints, namely the non-suitability of the Belgian geographical factors, and the fact that no new installations have been built or plans for new installations are announced, the pumped hydro storage technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Meeting the IPC technology criteria, the pumped hydro storage technology will be considered as a technology for the IPC calculation.

2.2.13 Battery Energy Storage System technology

A Battery Energy Storage Systems (BESS) is the technology of storing electricity under the form of chemical energy, and releasing it back under the form of electricity. Many different types of battery technologies exist such as Lithium Ion (Li-Ion) batteries[13], lead acid batteries, flow batteries[14], high temperature batteries[15], zinc batteries, etc. Each of these technologies have different characteristics such as cycle life, roundtrip efficiencies and technology readiness level (TRL). Considered under the BESS technology, for the purpose of this report, are the stationary Li-Ion LFP batteries. This is the most mature, TRL9, technology with one of the highest roundtrip efficiencies. Several Li-Ion LFP BESS projects have been, are and will be built in the near future, in Belgium and abroad [42] [43]. Currently operational large scale BESS installations in Belgium have an estimated total capacity of 152 MW/406 MWh, being mainly 2-hour and 4-hour batteries. By delivery period 2028-2029 nearly 2 GW of additional BESS could be in the market [14]. Most recently constructed as well as announced BESS projects have a duration of 4 hours.

---

[13] Different sub technologies within the Li-Ion technology exist such as LFP, LCO, LMO, NMC, etc.

[14] Different sub technologies within the flow battery technology exist such as HBr, Vanadium, etc.

[15] Different sub technologies within the flow battery technology exist such as NaS and $NaNiCl_2$.

The Li-Ion LFP BESS technology can be seen as a mature technology for which generic and reliable initial CAPEX cost information is available, and which is reproducible across projects[16]. No significant legal or technical constraints hamper the development, in fact in Belgium a favourable legal climate is present for BESS technologies.

Some uncertainty regarding the operation and maintenance costs for the Li-Ion LFP BESS technology exist, considering that this technology is relatively new and only very few installations have been in service for a long time. Especially the degradation of the battery cells, which is amongst others depending on the way of using the battery (dispatching strategy[17]), is uncertain[18]. This creates a difficulty in assessing the FOM and VOM components as well as the values. Nevertheless, the technology will be available in the Belgian energy market and will be taken into account for the both the Net-CONE as well as the IPC calculation.

Meeting the Net-CONE criteria, the BESS technology will thus be considered as a candidate technology in the shortlist of technologies for determining the Net-CONE. A 4-hour battery is considered as the standard in this report.

Meeting the IPC technology criteria, the BESS technology will be considered as a technology for the IPC calculation.

2.2.14 Compressed Air Energy Storage technology

In Germany, salt caverns will be used to store compressed air on a large scale [44]. Due to limitations to Belgian geographical factors, no potential for CAES is seen in Belgium. Also today, no CAES installations are available in Belgium.

Due to the development of the technology to be limited by technological constraints, namely the non-suitability of the Belgian geographical factors, and the fact that very limited projects are being constructed (of which non in Belgium) the CAES technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

Not meeting the IPC technology criteria, the CAES technology will not be considered as a technology for the IPC calculation.

2.2.15 Flywheel technology

The flywheel technology is storing electrical energy under the form of kinetic energy in a large spinning mass. This technology is mainly used to provide fast responses to the grid for short durations, i.e., high power and low energy content. While the technology can be considered mature, only limited amount of installations have recently been built, of which one in the Netherlands (3 MW) and one in Ireland [45] [46].

Currently no installations are operational in Belgium, nor are there any projects announced.

Due to the fact that very limited projects have been, are being or will be constructed (of which non in Belgium) the flywheel technology is not withheld as a candidate technology in the shortlist of technologies for determining the Net-CONE.

---

[16] Since the CAPEX is expressed in €/MW, the costs are only considered generic and reproducible across projects in case of similar battery durations.

[17] A dispatch strategy is a set of rules by which the asset is controlled (for a BESS, charging and discharging), typically based on market signals.

[18] The dispatching strategy can also be depending on the installed battery duration, e.g., 1-hour batteries can be dispatched differently and on different markets than a 4-hour battery.

Not meeting the IPC technology criteria, the flywheel technology will not be considered as a technology for the IPC calculation.

2.2.16 Demand Side Management technology

Demand Side Management (DSM), Demand Side Response (DSR) or shortly Demand Response (DR) are terminology describing the flexibility of electricity consumers and the ability to adapt their consumption based on certain signals.

DSM can help to shave consumption peaks and in balancing the electricity grid, which are both useful in a system with a large share of renewables. In the first use case, the DSM will mostly take form as a shedable load, i.e., reduce consumption during specific moments by decreasing the power or shutting down of an asset. The second use case is a more granular one, where assets react to available electricity generation, and adapt their consumption either upwards or downwards to balance the overall system. Both use cases contribute to adequacy and security of supply and are therefore of interest in the light of the CRM. It is shown in the most recent Elia adequacy and flexibility study [14] that consumer flexibility is a key element for adequacy and has significant impact on future grid developments and conventional generation capacity needs.

DSM can be considered as a technology group with a very heterogeneous composition, which is significantly different to other technologies discussed in this report. Electricity consumers have different characteristics, abilities and costs depending on their sector (industrial, commercial, residential), way of reacting to signals (load shedding (peak shaving), load shifting,etc.), timings (reaction time, ramping time, maintaining time), and level of impact (no impact, comfort impact, process impact), etc. While several subgroups start to emerge, upon today no clear categorisation can be made. This makes it arduous to estimate a reliable FOM, VOM or CAPEX cost which is generic for this technology. It is expected that in the near future more clarity will be provided on this and that for certain DSM subcategories reliable and reproducible costs could be defined.

In several studies, assumptions are made on the required remuneration levels or consumer willingness needed to activate specific DSM categories and assets [47] [14] [48]. Values reported, if any, incorporate this willingness to activate or opportunity cost. Yet, no studies or values based on a bottom-up cost driven approach are found. This makes it arduous to reliably define FOM, VOM and CAPEX costs for the DSM technology, as is the scope of this report.

Considering the above arguments, it is decided to include the DSM technology on the Net-CONE and IPC shortlist, as it is expected to meet the set criteria in the near future, yet not to provide any values for the FOM, VOM or CAPEX today.

For the time being, we consider the Elia Adequacy and Flexibility study as the best available source of information.

2.3 Results of shortlisting

2.3.1 Resulting Net-CONE technology shortlist

The following technologies are withheld for the Net-CONE technologies shortlist:

- CCGT
- OCGT
- IC-engine
- BESS
- DSM

2.3.2 Resulting IPC technology shortlist

The following technologies are withheld for the IPC technologies shortlist:

- CCGT
- OCGT
- Combustion systems and steam turbine technologies – waste incineration
- Combustion systems and steam turbine technologies – biomass power plant
- IC-engine
- Pumped hydro storage
- BESS
- DSM

2.3.3 Overview of shortlisted technologies and exclusion arguments

Table 2: Overview of shortlisted technologies and exclusion arguments.

	Net-CONE	IPC
1. Electricity generation technologies		
1.1. Thermal technologies		
1.1.1. Combined Cycle Gas Turbine (CCGT)	√	√
1.1.2. Open Cycle Gas Turbine (OCGT)	√	√
1.1.3. Combustion system & Steam Turbine (ST)		
1.1.3.1. Nuclear fission	Nuclear exit	Expected to be excluded from CRM support
1.1.3.2. Coal	Not meeting the limit for CO_2	No existing operational installations
1.1.3.3. Waste	Not fit-for-purpose & limited new capacity	√
1.1.3.4. Biomass	Costs not reproducible & limited new capacity	√
1.1.4. Internal Combustion Engines (IC engines)	√	√
1.1.5. Turbojets	Not meeting the limit for CO_2	Not meeting the limit for CO_2
1.2. Renewable technologies		
1.2.1. Onshore wind turbines	Not fit-for-purpose	Not fit-for-purpose
1.2.2. Offshore wind turbines	Not fit-for-purpose	Not fit-for-purpose
1.2.3. Hydropower (run-of-river)	Limited new capacity	Not fit-for-purpose
1.2.4. Photo Voltaic (PV)	Not fit-for-purpose	Not fit-for-purpose
1.3. Electrochemical technologies		
1.3.1. Fuel cell (FC)	Limited new capacity	No existing operational installations
2. Storage technologies		
2.1. Pumped Hydro Storage	Limited new capacity	√
2.2. Battery Energy Storage Systems (BESS)	√	√
2.3. Compressed Air Energy Storage (CAES)	Limited new capacity	No existing operational installations
2.4. Flywheel	Limited new capacity	No existing operational installations
3. Demand Side Management (DSM) technology	√	√

3 FOM and VOM costs

3.1 Introduction & general methodology

This chapter will elaborate on the Fixed Operations and Maintenance (FOM) and Variable Operations and Maintenance (VOM) costs for each of the shortlisted technologies and capabilities.

In §3.2 the FOM and VOM cost definition is stated and explained, which is linked to the methodology as used in the Royal Decree [6].

In §3.3 a FOM and VOM cost model is presented. This model follows the cost structure of the Royal Decree and applies to each of the technologies as well as to new entrants and existing assets. The different studies consulted by Entras each have their own unique cost structure, and the Royal Decree aims to propose a general structure. Costs identified by either Entras or literature studies are as such mapped to the categories in the Royal Decree.

In §3.4 the methodology of defining values for the FOM and VOM is explained. The underlying assumptions are discussed. Where applicable, data points are converted, indexed, normalised and/or aggregated to result in a robust estimation of the FOM and VOM costs.

In §3.5 the FOM and VOM values are reported per technology. Values are reported separately for new entrants and existing assets in the Belgian energy market, as well as split based on the data source. A low, medium and high value is given, expressing a range in costs which are linked to varying cost components and parameters across data sources.

3.2 General definition of FOM and VOM costs

The Variable Operations and Maintenance (VOM) costs include all costs necessary to operate the asset throughout the duration of its economic lifetime, other than fuel costs and CO_2 costs, and are expressed as a cost per injected electricity in €/MWh.

The Fixed Operations and Maintenance (FOM) costs are defined as all the costs necessary to keep the electricity generating asset operational throughout the duration of its economic lifetime that are independent from the dispatch decision to produce electricity and are expressed in €/kW/year. The term “kW” as used in the unit of the FOM corresponds to the installed electric power generating capacity of the unit.

The FOM consists of actual annual costs and recurring capital expenditures, which do not necessarily occur each year. The latter costs are expressed in €/kW and typically comprise the major overhaul costs. The occurrence of these costs can depend on the number of running hours or starts of the asset. Their mapping on a yearly basis, i.e., to express them in €/kW/year, therefore requires assumptions on the operating regime of the asset. The operating regime assumptions as used in this report are transparently communicated in §3.4.3.

3.3 FOM and VOM cost structure

The following list provides the cost structure as defined in the Royal Decree [6]. The current report follows the same cost structure. Specific assumptions, interpretations and calculations pertaining to elements of this list are discussed in Section 3.4.2. FOM is covered by categories 2, 3 and 4. VOM is covered by category 5.

2. Direct annual fixed costs of the production site (€/MW/yr)
    a. General costs
        i. Insurance costs
        ii. Local taxes
        iii. Administrative costs related to the production site, excluding personnel costs
    b. Gas connection costs
        i. Costs for exit services at connection points
        ii. Costs of intraday flexibility, excluding balancing costs
    c. Electricity costs
        i. Estimated ‘stand-by’ costs for one year: electricity costs, costs of certificates for renewable generation or cogeneration, variable access costs
        ii. Fixed costs related to the electricity grid: connection costs and access costs
    d. Recurring/normal maintenance costs, excluding personnel costs
    e. Operational costs, excluding personnel costs
    f. Costs for bringing into compliance
        i. Health and safety
        ii. Cyber security
        iii. Environmental
        iv. Certification and audits
    g. Personnel costs related to the production site, excluding general annual fixed costs
3. General annual fixed costs comprising: general management, management control, financial services, human resources, information systems, general services and real estate, purchasing activities, legal services, strategy and regulatory/public affairs
4. The fixed personnel costs associated with the management of a portfolio of delivery points active on the day ahead energy market and the provision of support services. This includes the costs associated with dispatching, appointments to the transporter and verification of day ahead positions and transactions. Explicitly excluded are the costs of intraday trading and optimization, futures trading and portfolio optimization beyond the day-ahead horizon.
5. Variable costs related to the production site, other than the fuel costs and CO2 costs referred to in 6. and 7.
    a. Variable operational costs
    b. Variable normal maintenance costs
    c. Variable costs of the electricity grid related to electricity injection
    d. Variable costs related to the exit fee of the gas grid
    e. Reduction of stand-by costs during production
6. Fuel costs (€/MWh)
7. CO2 costs (€/tonne CO2)
8. Average start- and activation costs
    a. Fuel used for start (MWh/start)
    c. Start costs excluding fuel and excluding provision for minor/major maintenance (€/start)
    d. Provision for minor/major maintenance (€/start)

3.4 FOM and VOM costs calculation methodology

To define robust values for the FOM and VOM costs of different technologies, three main sources of data are used.

- First, a literature review is conducted, where relevant and recent studies are consulted. When the literature study is found relevant and sufficient data are available, the data are captured. The captured values are transformed to the Belgian situation. In case of missing data, literature values can be supplemented with values for the Belgian situation. An example of such a supplementing action is the addition of the municipal motive power tax. In case of country specific costs in the literature studies which do not apply to Belgium, and when these costs are clearly defined as such, these are not taken into account. The studies consulted and withheld are [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61] and [62]. Note that the previously conducted studies by Fichtner and AFRY are not used as a source of data. The main reason is that the values as reported by Fichtner and AFRY also refer to identical or similar literature studies, for which in this report updated versions are used. It should be noted that, on the basis of the literature review, a detailed cost breakdown is not possible. This is, firstly, because the specified costs are aggregated in higher level categories. Secondly, different publications generally use different cost structures. However, even at an aggregated level the literature values provide consistent support for the values from the sources discussed below.
- Secondly, the Entras FOM and VOM model for CCGT and OCGT technologies is used. This model is built bottom-up over the years and allows a detailed FOM and VOM costs estimation.
- A third source of data are market parties willing to share information on their existing or new to be built assets (asset owners, project developers) or information on the assets in their catalogue (OEMs). Interviews with market parties and subsequent communications resulted in several data points that were included in this study. Due to confidentiality, this data nor meta-data on the provided information can be disclosed directly. The data is checked, where needed transformed or supplemented, and aggregated. The aggregated data is communicated in this report.

In §3.4.1 general assumptions and calculation examples are given. In §3.4.2 we discuss assumptions relating to specific cost components. In §3.4.3 running regime, efficiency and energy price assumptions as used in this report are summarised. In §3.4.4 some more assumptions and details are given for each studied technology in detail. In §3.4.5 the Entras CCGT and OCGT model is discussed by means of an example.

3.4.1 General assumptions

- FOM and VOM values reported in a low, medium and high value include values of projects of different sizes and other elements. The following elements are integrated into the spread:
  1) Size of project
  2) Running regime cost effects (e.g. operating hours, see §3.4.3)
  3) Project specific costs (owner costs, connection costs for utilities, cooling principle, different approach of maintenance etc.)
- Where applicable, values from literature are transformed first in location (Belgium) and then in time (to June 2023). For the location transformation of costs other than labour costs, the annual average exchange rates are applied [63]. Labor costs, if the number of employees is specified, are calculated using published values for average labour costs in Belgium in the

appropriate sector [64]. If only labour costs are specified, a country-by-country comparison of labour costs is made using data of the national statistics agencies [65] [66] [67].

- Transformation in time is done using several indices, as deemed the most appropriate for the type of costs. To compensate for seasonality, the index of 2023Q2 is compared with the index of Q2 of the year of the publication. Specific indices for labour in the electricity supply sector [68], legal services [69], engineering services [70], manufacture of chemical products [71] and manufacture of electrical equipment and machinery [72] are used. For costs that cannot be related to a specific index, a general harmonised index of consumer prices is used [73].
- FOM and VOM costs of new entrants or existing installations are very similar in nature. While in principle, the same costs apply, the height of the costs can be different. The following points are to be taken into account:
    1) Existing installations usually have long term contracts, which were composed based upon the assumption of baseload operation and/or other assumptions. This has a significant influence on items like the LTMA contract. As the current operation regimes are different, old contracts result in different costs compared to contracts which are signed today. Those costs can be either lower or higher. The actual impact is difficult to calculate considering the heterogeneity in contracts.
    2) Existing installations of a certain technology typically have a lower efficiency than newly built installations. This is linked to technology improvements, degradation over lifetime and size of the installations. This results in a higher marginal cost, resulting in a lower number of operating hours. Costs which are dependent on operating hours, like the costs related to minor and major overhauls for OCGT and CCGT technologies, can thereby be significantly impacted.

  Note that the quantification of the above arguments is difficult considering the heterogeneity in both new and existing installations. To take this into account, a relative efficiency penalty of 10%[19] is considered for OCGT and CCGT technologies. For IC engine technology no efficiency penalty is applied as for this technology no significant efficiency improvements have been made over the past years. For BESS technology no efficiency penalty is applied as this technology is still relatively new and no difference in efficiency is assumed to exist between existing and new installations.
- The maintenance concept is based on a standard approach with preventive and predictive maintenance routines which are considered to be standard industry practices, the “keep the plant as new” principle. This entails that preventive maintenance is supposed to be carried out until the very end of the plant lifetime; this means that the maintenance schedule is carried out as if the plant will continue to be operational and to be kept as new. Under this principle, no postponements or neglecting of maintenance occurs[20].

---

[19] This means that the FOM and VOM values are increased with 10% for existing installations compared to new entrants.

[20] In practice, a plant owner can decide to follow other maintenance principles. As these are subject to owners strategy, these are not taken into account in this report.

3.4.2 Assumptions relating to cost components

In the following we discuss assumptions relating to the cost components as presented in section 3.3.

3.4.2.1 Direct annual fixed costs (cat. 2)

2a. The main constituent of local taxes is the motive power tax. In this report, we also include environmental taxes and property taxes.

Motive power tax is a municipal tax and is different across municipalities. The typical tax rates in €/kW are derived from a sample of current tax rates in various municipalities in Belgium. It is assumed that the generating capacity is exempted from motive power tax, which is usually the case. The motive power depends on technology and is assumed as a percentage of the generating capacity[21]:

1) CCGT: 5%
2) OCGT: 1%
3) ICE: 0% (de minimis)

2b. Firm gas transport service costs are based on rates as published by Fluxys for trading on ZTP, including the high pressure exit service at end user domestic points. These rates are typically expressed in €/MW HHV and need to be converted to €/MW electrical capacity (unit of the reported FOM). For this conversion, assumptions are used as defined in §3.4.3. Where needed, assumptions on a fixed gas price are made (see Table 5).

Gas balancing costs (also often referred to as gas logistics optimisation costs) are considered to be a part of the fuel cost and are therefore not estimated in this report.

2c. Fixed electricity costs include the fixed grid and supplier fees.

Stand-by electricity consumption is calculated based on the assumption that during moments of stand-by, the power consumption is 1% of the generation capacity (applicable for CCGT, OCGT, biomass and waste-to-energy). The FOM cost for stand-by consumption consists of grid fees and electricity costs for offtake during dispatch availability periods, assuming a fixed electricity price (see Table 5). For CCGT, biomass and waste technologies it is assumed that there is a 100% dispatch availability, i.e., that the power plant will always either generate electricity or be in a stand-by state, ready to be dispatched. For OCGT technology it is assumed that the power plant is either in a generating or stand-by state for 33% of the year, most of which would be during the winter period when demand and prices are high. During the remaining 67% of the time (summer period) the power plant is in a stand-still state, where it does not consume stand-by power. Based on historical data for 2023 this approximation is reasonable.

Further to the stand-by costs, the cost of renewable energy certificates or cogeneration certificates is not taken into account, considering the study horizon of 2028-2029 and the gradual phase-out of these certificates in the coming years.

2d. Fixed maintenance costs can be categorised under preventive maintenance during operation of the plant, and a maintenance provision for LTMA (minor/major overhauls). These costs also include the cost of 3rd party preventive maintenance and parts replacement, a contingency for unplanned maintenance and a provision for site maintenance. The cost of spare parts is included, limited to the consumables and normal wear parts. Strategic spare

---

[21] Entras assumption based on technical characteristics of the technologies.

parts, such as a back-up main transformer, are not included. This is considered as Capex and hence out of scope for the FOM/VOM costs. Costs linked to own personnel doing maintenance are classified under Human Resources (cat 2g).

2e. Fixed operational costs include spare parts storage (either on-site or linked to 3rd party storage), fixed costs related to waste disposal and fixed costs related to the maintenance of IT and communications infrastructure and DCS.

2f. The costs for bringing into compliance include, among other things: lock-out/tag-out, emergency plans, first aid measures, personal protective equipment and inspections.

2g. Personnel costs cover the cost of the staff required to operate the installation. It is assumed that the asset is operated as a stand-alone unit, i.e., no pool effects or synergy is considered. The personnel costs also include people rotation costs such as retiring and replacing people.

3.4.2.2 General annual fixed costs (cat. 3)

- In the Royal Decree [6], the general annual fixed costs are estimated as being 25% of the personnel costs (cat. 2g). In the current report we provide estimates based on the Entras model and literature data.
- We include land lease costs in the FOM. This means that land acquisition will not be included in the capex. The costs of land lease are calculated assuming typical rates in major Belgian areas (Antwerp, Brussels). They will be reported separately in §3.5. This allows to deduct them from the FOM in case future analysis wishes to include land costs as capex rather than FOM.
- The information systems comprise communication systems and DCS linked to the operations of the installation, as well as the IT infrastructure required to allow the installation to market its electricity on the markets. This includes dispatching, scheduling, finance and settlement.

3.4.2.3 Fixed costs related to portfolio management (cat. 4)

- These costs include the costs of a trading and energy management desk (limited to the day-ahead market, balancing and ancillary services) as well as the costs of 3rd party service providers. The costs linked to nomination and power exchange access are taken into account based on the rates of Epex Spot and REMIT fee. Energy management tasks are assumed to be executed by control room personnel, i.e. no specific personnel costs for portfolio management is considered.

3.4.2.4 Variable costs (cat. 5)

5a. Variable operational costs include chemicals & consumables (such as catalysts, various grades of water, lubricants, compressed air, etc.), HVAC control, sampling & analysis, water treatment (for technologies with a steam cycle and for the CHP capability) and by-products treatment (wastewater, ash, filters).

5b. Variable maintenance costs include preventive maintenance during operation of the plant, and a variable maintenance cost related to LTMA (minor/major overhauls).

5d. The variable part of the grid and supplier fees for fuels (e.g. commodity fee) are typically expressed in €/MWh HHV. These are converted to €/MWh electricity net injected (unit of the reported VOM). For this conversion, assumptions are used as defined in §3.4.3. Where needed, assumptions on a fixed gas price are made (see Table 5).

5e. The variable stand-by costs are negative and are interpreted as avoided costs in case of dispatch. Refer to the assumptions for cat. 2c in Section 3.4.2.1.

3.4.2.5 Fuel cost and CO2 cost (cat. 6, 7)

Fuel cost and CO2 cost, being parameters in the simulations by Elia, are explicitly out of the scope of the current study and will not be estimated.

3.4.2.6 Start- and activation costs (cat. 8)

Since start costs are not expressed in terms of FOM or VOM, they are reported separately in Section 3.5.4.

8a. The estimated fuel consumption for OCGT and CCGT is estimated from Entras internal data. The values are valid for starts from stand-by to 90% load and cover the range for hot, warm and cold starts. Other shortlisted technologies are assumed not to have any significant fuel consumption during start-up.

8.c The start costs for OCGT and CCGT, excluding provision for minor/major, are directly derived from the VOM (in €/MWh injected), the fuel consumption and the efficiency, neglecting any efficiency reduction during the start.

8d. Costs related to Long Term Maintenance Agreement (LTMA) for OCGT and CCGT technology are usually triggered by either a running hour limit or a starts-based limit. Information about starts based costs in the literature is scarce since the technology is often assumed to be operated at baseload. For this reason, LTMA costs are often included in FOM and VOM. Moreover, the distribution of LTMA costs over FOM, VOM and starts-based costs is often subject to negotiation between the plant owner and the OEM.

With these provisions in mind, we report in Section 3.5.4 the aggregated values for the starts-based LTMA costs which were found in the literature. The values were taken as-is after applying appropriate indexation, not considering the underlying assumptions of dispatch decisions. Costs which are linked to a lifetime extension of an installation are not considered.

3.4.3 Running regime, efficiency and energy price assumptions

The cost components for FOM and VOM are to be expressed in the correct units. To do so, an assumption is needed on the number of operating hours and/or number of starts of a power plant.

As the study horizon is 2028-2029, estimates for assets in the Belgian market in 2028 are considered. The operating hours for a CCGT and OCGT are estimated by Elia, with a P10, P50 and P90 value, in the Adequacy and Flexibility study [14]. Operating hours for IC Engines are estimated by Entras. Table 3 gives an overview on the operating hours for existing assets and new entrants, as used in this study. Based on [14] it is assumed that the running hours will continue to decrease after 2028.

Table 3: Assumptions on operating hours for different technologies.

		Existing assets	New entrant	Source
CCGT	Low	1900	4250	Elia [14]
	Medium	2800	5000	Elia [14]
	High	3500	5800	Elia [14]
OCGT	Low	50	120	Elia [14]
	Medium	100	400	Elia [14]
	High	200	750	Elia [14]
IC Engines	Low	950	950	Entras[22]
	Medium	1400	1400	Entras[22]
	High	1750	1750	Entras[22]

Table 4 gives an overview of the assumed lowest and highest electrical efficiency for each of the relevant technologies.

Table 4: Lowest and highest assumed electrical efficiencies of different technologies.

	Lowest efficiency [% LHV]	Highest efficiency [% LHV]	Source
CCGT	60[23]	63	2022 GTW Handbook [74]
OCGT	30	43	2022 GTW Handbook [74]
Waste	15	30	Entras[24]
Biomass	20	33	Entras[24]
IC Engines	38	49	Entras[25]

For certain FOM and VOM cost calculations it is necessary to assume a certain market price for fuel and electricity. Table 5 gives an overview of the used values in this study. The price of CO_2 is not used in the calculations but provided here for general information. The gas price is that as used by Elia in [14] for 2023. The electricity price is the off-peak price for June 2023, as communicated by the CREG. The off-peak price is being used, as this price is an input for the calculation of the stand-by electricity costs for CCGT, OCGT and IC engines.

---

[22] The operating hours for IC engines are based on the assumptions that no CHP capability is included and that their efficiencies vary with a range between 38% and 49%, as given in Table 4. No difference in operating hours is assumed between existing or new IC engines because their efficiencies do not significantly improve over time (this in contrast to CCGT and OCGT technologies where larger turbines with higher efficiencies are developed).

[23] Based on a 475 MW plant (SCC5-4000F), as smaller plants are not considered to be relevant.

[24] Estimated efficiencies based on technical data from different installations, with varying oven construction, thermal power, size of steam turbine and CHP capability.

[25] Estimated efficiencies based on technical data from different OEMs.

Table 5: Energy price assumption as used in this study.

	Value assumption	Source
Gas TTF [€/MWh hhv]	49.9	Elia [14]
CO2 EUA [€/t CO]	94.9	Elia [14]
Electricity [€/MWhe]	91.2[26]	CREG [75]

---

[26] Belpex off-peak D+1 value for June 2023.

3.4.4 Technology related assumptions and information

3.4.4.1 CCGT

The consulted literature, where values are obtained to calculate the FOM and VOM costs for the CCGT technology in this report, are [49], [53], [54], [55], [61] and [62]. The size of the CCGT installations as referred to in these literature studies range from 418 MW to 1083 MW. In total, eight different CCGT installations from literature are used in this report.

The values as found in literature are assumed to be for new installations, as indeed the literature is recent in nature and describes recent power plants. Therefore, the values are used for the new entrants (Net-CONE) values and adapted for existing (IPC) installations as mentioned in §3.4.1.

3.4.4.2 OCGT

The consulted literature, where values are obtained to calculate the FOM and VOM costs for the OCGT technology in this report, are [49], [53], [54], [55], [56] and [62]. The size of the OCGT installations as referred to in these literature studies range from 93 MW to 329 MW. In total, twelve different OCGT installations from literature are analysed.

The values as found in literature are assumed to be for new installations, as indeed the literature is recent in nature and describes recent power plants. Therefore, the values are used for the new entrants (Net-CONE) values and adapted for existing (IPC) installations as mentioned in §3.4.1.

3.4.4.3 Waste

A literature review on the FOM and VOM costs of waste incineration technology yielded no robust and reliable values. The values found in literature, for installations outside of Belgium, are considered not to be representative nor able to be converted to the Belgian situation.

The FOM and VOM values for waste incineration technology, as presented in §3.5, have been calculated based on the costs of CCGT technology and scaled based on the difference in efficiency. For this efficiency scaling, an efficiency range for the CCGT technology of 42% to 63% is used, for the waste technology a range of 15% to 30% is used.

3.4.4.4 Biomass

Biomass power plant technology is, as discussed in §2.2.4.4, subject to very heterogenous installations which hampers the collection of reliable and generic cost information. A literature review confirms this statement. It is therefore decided that the values as found in literature are not representative for Belgium nor is there a robust way of converting them to the Belgian situation.

The FOM and VOM values for biomass technology, as presented in §3.5, have been calculated based on the costs of CCGT technology and scaled based on the difference in efficiency. For this efficiency scaling, an efficiency range for the CCGT technology of 42% to 63% is used, for the biomass technology a range of 20% to 33% is used.

3.4.4.5 IC engines

The consulted literature, where values are obtained to calculate the FOM and VOM costs for the IC engine technology in this report, are [53], [54], [59] and [62]. The size of the IC engine power plants as referred to in these literature studies, and as used in this report, range from 7 kW to 200 MW, whereas the bigger plants consist of multiple engines. In total, nine different IC engine power plants from literature are analysed. Note that VEKA [59] reports fixed costs averaged over running hours and capacity (unit: €/MWh). These were converted to FOM costs to be consistent with the current approach. Further, the costs reported by VEKA concern seven different IC engines with a size between 7 kW and 7 MW. These are considerably smaller than those mentioned by [53] and [54], with plant sizes of 21 MW up to 200 MW. This is taken into account in the calculation of the low, medium and high FOM and VOM costs by consolidating the VEKA values separately, so as not to bias the results due to the higher number of small IC engines in the dataset.

3.4.4.6 Pumped Hydro Storage

The consulted literature, where values are obtained to calculate the FOM and VOM costs for the Pumped Hydro Storage technology in this report, are [50], [52] and [53]. The size of the PHS installations as referred to in these literature studies range from 100 MW to 2000 MW, with a storage duration between 16 and 100 hours. In total, three different PHS installations from literature are analysed. No market data nor in-house Entras model data is available to complement the data from literature. The resulting FOM and VOM costs can be found in §3.5.

3.4.4.7 BESS

The consulted literature, where values are obtained to calculate the FOM and VOM costs for the BESS technology in this report, are [49], [50], [51], [52], [53] and [55]. The size of the BESS installations as referred to in these literature studies range from 1 MW to 200 MW. In total, six different BESS installations from literature are analysed. The values for the BESS as calculated and given in this report are all for 4-hour duration Li-Ion LFP batteries. Market party data is present for new entrant (Net-CONE) values. No in-house Entras model is available for BESS technology.

The following assumptions are considered, applicable to the reported values in this report:

- In literature sometimes a fixed or variable cost is taken into account for the BESS, so to compensate for the degradation of the BESS over its lifetime. This can result in significantly higher FOM and VOM values. In this report, no BESS capacity addition to compensate for degradation is considered. Degradation affects the capacity of the BESS and should therefore not be considered in the FOM. The degradation of the BESS is very depending on the usage, hence the dispatching strategy. An upgrade of the BESS capacity is considered as a lifetime extension and therefore not taken into account in the FOM.
- Another practice described in literature and seen in projects is the oversizing of battery capacity. For example, if a degradation of 15% is expected over a 10-year lifetime of the BESS, the battery capacity is sized so that the battery, at the 10th year, has a 4-hour battery duration. This impacts the capex of the project, yet it is assumed that this does not significantly impact the FOM or VOM of the BESS. The literature value of the FOM and VOM is therefore used without corrections.
- Some literature sees additional warranty costs, and take this into account as FOM. Other sources report that, especially for Li-Ion LFP technology, no additional warranty contract is needed, and this is covered in the EPC (initial capex). In this report, the latter approach is used.
- It is assumed that a BESS is operated without personnel on-site. Rather a 3rd party battery monitoring and optimisation cost is included.
- In most literature, VOM costs are considered negligible.
- Considering the scope limitation to 4-hour duration BESS only, no significant cost difference is expected between existing BESS and new entrant BESS projects.
- The 4-hour BESS size is assumed to be ‘net’, this means that the actual technical capacity of the BESS is slightly larger, compensating for the minimum state of charge to be kept, so not to damage the BESS.

3.4.4.8 Capabilities – CHP

- Depending on the technology characteristics, the CHP capability has a limited to strong impact on FOM and VOM. However, no standard CHP capability exists. Every project has specific characteristics, like the amount of heat delivered, the fluidum (hot water, steam at various pressures) and the technology.
- Furthermore, CHP technology is in most cases driven by the heat demand. This means that the plant is possibly subject to a ‘must-run’ regime due to the need for heat production. This reflects in the cost structure, which is thus project specific.
- The impact assessment of CHP capability leads to the following conclusions:
    1) For technologies where the heat delivery does not impact the electricity production, the additional VOM and FOM costs due to the CHP capability are rather limited. This is the case for ICE technology. Additional FOM costs are linked to the preventive maintenance of the heat circuits (pumps, I&C etc); additional VOM costs are limited, as there is no impact on the electricity production. The value of heat could also be considered, which will in turn lead to lower costs[27]. For OCGT, the electricity production is also not impacted, but a high-pressure heat recovery steam generator with possibly auxiliary firing capability will lead to considerable additional O&M costs.

---

[27] The value of heat, or the “heat revenues” are not in scope of this report.

   2) For technologies where the heat delivery strongly impacts the electricity production, a huge impact on the VOM and FOM costs can be expected. This is the case for CCGT, biomass and waste to energy, as the heat is generally extracted from the water-steam cycle of the steam turbine. Any use of heat will immediately lead to a lower electricity production efficiency and a lower electrical power level. Therefore, this will lead in turn to a change in VOM and FOM costs relative to the change in efficiency, plus an additional O&M cost related to the heat supply system. The value of the heat could also be considered, which will lead to lower costs[27].

- Considering the above arguments, the following assumptions are made when calculating the FOM and VOM costs for the CHP capability:
   1) Revenues from heat are not included, in line with the earlier made assumptions in this report.
   2) Costs related to alternative heat sources are not included, i.e., the cost of a back-up boiler.
   3) The heat production part of the CHP is assumed to consist of one or more closed primary circulation loops, which provide heat via heat exchangers to one or more secondary loops.
   4) All costs associated with the combined heat and power production up to the primary circulation loops are attributed to the electricity when calculating the FOM and VOM costs.
   5) All costs associated with the secondary heat loops are not included in the FOM and VOM costs.
   6) Impact on costs from ‘must run’ conditions related to the heat demand are not included.
   7) The CHP plant is assumed to run for 6000 hours per year. This assumption is based on an average of different projects were Entras was involved as well as on the values as reported by VEKA in [59].
- The CHP capability for biomass and waste technologies is assumed to be already integrated into the spread of values as reported. The reason is that these technologies are typically equipped with the CHP capability and only a marginal number of installations are not. Consequently, the costs as found in literature and other sources for biomass and waste technologies are assumed to already include these costs.

3.4.4.9 Capabilities – Carbon Capture and Storage

This capability comprises the technology of capturing the CO_2 emissions of a carbon-fuelled technology, such as OCGT and CCGT with natural gas, at the stack. The following assumptions are made:

- A capture rate of 90% is assumed, i.e., 90% of the total emitted CO_2 is captured, processed, transported and stored.
- The CCS capability is only considered for CCGT and OCGT technology. The cost per tonne CO_2 captured of a CCS installation, both the initial capex as well as the FOM and VOM costs, decreases with the volume of the to be captured and processed CO_2, hence with the size of the power plant. In [76] it is shown that the (current) limit of assumed cost efficiency capturing is around 250 to 300 ton CO_2/hour. As the typical size of an IC engine, biomass or waste power plant is well below this limit, the CCS capability is not considered for these technologies.

- The reported costs include the FOM and VOM costs of the CCS installation itself, as well as the costs for the transport and the storage of the CO_2.
    1) Costs directly linked to the operation of the CCS installation itself such as the increase in personnel costs, insurance and property taxes, maintenance, consumables and waste disposal.
    2) Cost linked to the required electricity and heat to operate the CCS installation. This required heat and electricity reduces both the electrical efficiency as well as the nominal power of the power plant. To take this into account, the FOM and VOM costs of a non-CCS equipped installation are scaled with the difference in efficiency and nominal power.
    3) CO_2 transport costs can vary significantly depending on the nature of the transport (pipeline or ship), the length of the transport (between location of the power plant and the storage facility) and the to be transported volume. Considering the Belgian situation, it is assumed that the transport will be done partly by pipeline (via a CO_2 backbone to a harbour) and partly by ship (from the harbour to the storage location). As storage location it is assumed that North Sea depleted natural gas or oil fields will be used. The total length of transport is therefore considered to be around 250 km. The cost for transport and storage as assumed in this report are given in Table 6.
- The negative cost, linked to the avoidance of the cost of EU ETS allowances, is not considered.
- It is assumed that the CCS capability has no impact on the operating hours of the CCGT or OCGT technologies, i.e., the operating hours as presented in Table 3 remain valid.
- It should be mentioned that such CCS installations are not yet existing today and that all above assumptions are based on literature. Therefore the values as reported should be considered as indicative and a current best estimation. In the future, these values can be complemented or adapted based on costs of operational CCS installations.

Table 6: Assumptions on the CO_2 storage and transport cost for the CCS capability. Based on [77], [78] and [79].

	Low	Medium	High
CCS storage cost [€/ton CO_2]	16.00	18.00	20.00
CCS transport cost [€/ton CO_2]	15.00	20.00	25.00

3.4.4.10 Capabilities – second fuel type for CCGT and OCGT

- For CCGT and OCGT, the second fuel type is considered to be hydrogen. It is assumed that up to 30 vol% H_2 will be possible (with the other 70 vol% being natural gas) within the envisioned timeframe of this study (2028-2029). Higher percentages of H_2 will be only commercially available afterwards. Therefore, the 30% H_2/70%NG mixture will be the standard for CCGT/OCGT in this report [80] [81].
- With the assumed NG/H_2 mixture, the turbine loses 0.3% (percent point) of the efficiency and around 3% of nominal power. The FOM are considered to increase with 15% and the VOM costs increase with 0.6% for an average CCGT and 0.8% for an average OCGT [80] [81][28].

---

[28] The cost of the hydrogen is not included here, as in line with the main assumption made that fuel costs are not included in this study. Impact on the position of the asset in the merit order, and thus the resulting amount of running hours, is not included here. A same amount of running hours is assumed, whether the asset has or has not the second fuel type capability.

- It is assumed that the second fuel type capability for CCGT and OCGT has no impact on the operating hours of the CCGT or OCGT technologies, i.e., the operating hours as presented in Table 3 remain valid.

3.4.4.11 Capabilities – second fuel type for IC Engines

- For IC engines, the second fuel type is considered to be biogas. The costs as reported assume a full switch from natural gas to biogas.
- With biogas as fuel type, the IC Engine loses around 0.5% of the efficiency and around 5% of nominal power [82]. As result, the FOM costs are increased with 5% and the VOM costs are increased with 1.2%.
- It is assumed that the second fuel type capability for IC engines has no impact on the operating hours of the IC engine technology, i.e., the operating hours as presented in Table 3 remain valid.

3.4.5 Details on the in-house Entras CCGT and OCGT cost model

As discussed in §3.4, the Entras model is constructed in-house with a bottom-up approach and has been updated with relevant data over the years. It takes into account individually modelled cost components and the impact of size and running hours on these cost components.

For illustrative purposes, a specific CCGT installation is simulated and the result is shown in this paragraph. The values of the Entras model for a specific plant design, the Siemens SCC5-9000 HL single shaft are given in Table 7.

Table 7: FOM and VOM costs for a SCC5-9000HL single shaft plant, according to the cost structure of a model developed by Entras.

Cost category	FOM [€/kW/yr]	VOM [€/MWh]
Total costs	30.20	1.70
General	6.56	0.13
Compliance	0.15	0.04
Fuel	6.61	0.00
Electricity	5.87	-0.67
Maintenance	4.12	1.24
Operations	1.02	0.88
Trading and Energy Management	0.04	0.08
Human resources	5.87	0.00

The model is based on an assessment of all single costs that make up the total plant budget. This exercise has been started in 2016, since then Entras has carried out many studies regarding power plants, especially for CCGT plants. The studies involved the development of operation and maintenance programs, drafting business plans for CCGT, etc. Over time, Entras collected the budget information and brought the information together in a model. The sources include literature information, quotations from various parties, salary information for the Belgian market, data from manufacturers and operators, etc. The model was parametrised to allow use in in-house developed dispatching software, which is capable of simulating any detail of power plant operations.

Table 7 includes the output of the model. The FOM and VOM values were calculated based on different runs of the model, taking into account different yearly operating hours. The category *electricity* mainly represents the stand-by costs. The methodology on the implemented stand-by costs is discussed in more detail in §3.4.1.

In §4.1 a list of items as used in the cost structure of the Entras model is included.

3.5 FOM and VOM costs - results

3.5.1 Aggregation and consolidation methodology

For the different literature studies, the used methodology is as follows:

For each of the plants as discussed in a literature study (this can be one single installation, or can be multiple different configurations) a low, medium and high value is defined for the FOM and VOM. Several studies give a certain range or low, medium and high values for certain costs, which make it straightforward to use this range in our calculations. Other studies might only provide a single value for an installation, which is then used as value for both the low, medium and high value in our calculations. A range might also be introduced by certain specific costs which are added, due to the fact that these were not included in the literature study. Typical costs which are added to some literature values are insurance costs, several taxes, land lease costs, grid fees, stand-by consumption and energy trading fees.

The different installations, for which values are retrieved from literature sources, are then aggregated per technology. This is done by calculating the P25, P50 and P75 values of the complete dataset of low, medium and high values. For example, for the OCGT technology, values for 11 individual installations are found in literature. Each of these are defined by a low, medium and high value (both for FOM and VOM), resulting in 33 datapoints (each, for FOM and VOM). The aggregated literature values are then defined by calculating the P25, P50 and P75 values over these 33 datapoints. This results in a low, medium and high literature value for the OCGT technology for the FOM and VOM costs.

All the literature data is considered to be for new entrants, as indeed the literature sources consulted typically act on new installations.

For the data coming from the market parties, the following methodology is applied:

Similar to the methodology that was used for the literature studies, a low, medium and high value is defined for each of the installations where data was obtained. In case only a single value was communicated for a certain installation, this value was used as both the low, medium and high value. Each market party providing information is weighted equally per technology. This allows a robust value to be calculated, preventing a single market party from exercising influence on the result by providing information on more installations than other market parties.

Subsequently, the aggregation of the market parties data is done in a similar manner as with the literature data. A P25, P50 and P75 value is defined for each of the technologies.

The market data obtained for CCGT and IC engine technologies all deal with existing installations and are therefore taken into account as values for the IPC (existing) values. The market data obtained for BESS technology is for new installations, which is why it is taken into account for the new entrant (Net-CONE) values.

For the Entras model a single value for the FOM and VOM is defined for a specific CCGT or OCGT. In this case, no spread (low, medium and high value) is defined but rather a single value for the FOM and VOM is defined.

To define a single range per technology for the FOM and VOM costs, the three data sources are combined. Each of these data sources is weighted equally. For example, in case for a certain technology all three data sources are available, the consolidated data is defined by taking the average of the low, medium and high value respectively. For the Entras model data, the single value is used for both the low, medium and high value.

3.5.2 Tabulated results

Table 8: FOM values for Net-CONE technologies (new entrants) and their capabilities. Value of capability is to be added on top of the value of the technology.

FOM costs for New Entrant (Net-CONE) in €/kW/year										
	Literature			Entras Model	Market Parties			Consolidated		
	Low	Medium	High		Low	Medium	High	Low	Medium	High
CCGT	31.99	34.76	37.10	30.20	N/A	N/A	N/A	31.10	32.48	33.65
CHP								5.60	5.85	6.06
CCS								23.53	28.37	29.19
Second fuel								4.66	4.87	5.05
OCGT	20.52	24.14	29.41	32.20	N/A	N/A	N/A	26.36	28.17	30.80
CHP								6.06	6.48	7.08
CCS								23.02	27.84	28.81
Second fuel								3.95	4.23	4.63
IC engine	32.48	44.68	72.89	N/A	N/A	N/A	N/A	32.48	44.68	72.89
CHP								0.65	0.89	1.46
Second fuel								1.62	2.23	3.64
BESS	14.34	19.96	23.76	N/A	29.69	30.49	31.29	22.01	25.23	27.52
DSM[29]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

---

[29] For DSM technology, no values were calculated, see §2.2.16 for the rationale. Reference can be made to the Elia Adequacy and Flexibility study [14].

Table 9: VOM values for Net-CONE technologies (new entrants) and their capabilities. Value of capability is to be added on top of the value of the technology.

VOM costs for New Entrant (Net-CONE) in €/MWh										
	Literature			Entras Model	Market Parties			Consolidated		
	Low	Medium	High		Low	Medium	High	Low	Medium	High
CCGT	1.53	2.12	2.40	1.70	N/A	N/A	N/A	1.62	1.91	2.05
CHP								0.53	0.63	0.68
CCS								13.26	13.70	15.86
Second fuel								0.01	0.01	0.01
OCGT	1.82	2.67	3.28	1.34	N/A	N/A	N/A	1.58	2.00	2.31
CHP								0.36	0.46	0.53
CCS								13.25	13.71	15.90
Second fuel								0.01	0.01	0.01
IC engine	0.56	0.76	2.58	N/A	N/A	N/A	N/A	0.56	0.76	2.58
CHP								0.01	0.02	0.05
Second fuel								0.01	0.01	0.03
BESS	0.07	0.23	0.40	N/A	0.00	0.00	0.00	0.04	0.11	0.20
DSM[30]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

---

[30] For DSM technology, no values were calculated, see §2.2.16 for the rationale. Reference can be made to the Elia Adequacy and Flexibility study [14].

Table 10: FOM values for IPC technologies (existing assets) and their capabilities. Value of capability is to be added on top of the value of the technology.

FOM costs for Existing (IPC) in €/kW/year										
	Literature			Entras Model	Market Parties			Consolidated		
	Low	Medium	High		Low	Medium	High	Low	Medium	High
CCGT	35.55	38.62	41.22	36.10	30.15	32.29	41.50	33.93	35.67	39.61
CHP								6.11	6.42	7.13
CCS								23.84	28.77	30.00
Second fuel								5.09	5.35	5.94
OCGT	22.80	26.83	32.67	N/A	N/A	N/A	N/A	22.80	26.83	32.67
CHP								5.24	6.17	7.51
CCS								22.63	27.68	29.06
Second fuel								3.42	4.02	4.90
Waste								64.13	72.58	99.81
Biomass								58.30	61.83	74.86
IC engine	32.48	44.68	72.89	N/A	66.00	72.50	81.25	49.24	58.59	77.07
CHP								0.98	1.17	1.54
Second fuel								2.46	2.93	3.85
Pumped hydro storage	17.57	29.94	31.92	N/A	N/A	N/A	N/A	17.57	29.94	31.92
BESS	14.34	19.96	23.76	N/A	N/A	N/A	N/A	14.34	19.96	23.76
DSM[31]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

---

[31] For DSM technology, no values were calculated, see §2.2.16 for the rationale. Reference can be made to the Elia Adequacy and Flexibility study [14].

Table 11: VOM values for IPC technologies (existing assets) and their capabilities. Value of capability is to be added on top of the value of the technology.

VOM costs for Existing (IPC) in €/MWh										
	Literature			Entras Model	Market Parties			Consolidated		
	Low	Medium	High		Low	Medium	High	Low	Medium	High
CCGT	1.70	2.37	2.97	1.08	0.00	0.22	2.34	0.93	1.22	2.13
CHP								0.31	0.40	0.70
CCS								13.18	13.62	15.87
Second fuel								0.01	0.01	0.02
OCGT	2.02	2.96	3.64	N/A	N/A	N/A	N/A	2.02	2.96	3.64
CHP								0.47	0.68	0.84
CCS								13.30	13.83	16.08
Second fuel								0.02	0.02	0.03
Waste								1.75	2.49	5.37
Biomass								1.59	2.12	4.02
IC engine	0.62	0.84	2.87	N/A	0.00	0.00	1.19	0.31	0.42	2.03
CHP								0.01	0.01	0.04
Second fuel								0.00	0.01	0.02
Pumped hydro storage	0.07	0.07	0.69	N/A	N/A	N/A	N/A	0.07	0.07	0.69
BESS	0.07	0.23	0.40	N/A	N/A	N/A	N/A	0.07	0.23	0.40
DSM[32]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

---

[32] For DSM technology, no values were calculated, see §2.2.16 for the rationale. Reference can be made to the Elia Adequacy and Flexibility study [14].

3.5.3 Land lease costs

The costs for the land are integrated into the FOM costs. These costs are calculated based on the required amount of land for a specific technology, as given by the literature study, and converted to m²/MW. Together with the land lease rate, as given in Table 12, the land lease cost can be calculated in €/kW/year.

Table 12: Land lease rates as used in the study.

	Low	Medium	High
Land lease rate [€/m²/year]	5.00	10.00	15.00

3.5.4 Start costs

The methodology used for determining the starts-based costs was described in Section 3.4.2.6. The results are given in Table 13.

Table 13. Start costs and fuel consumption for OCGT and CCGT.

	OCGT			CCGT		
	L	M	H	L	M	H
8a. Fuel consumption during start [MWh HHV]	0.29	0.29	0.29	0.29	0.95	1.24
8c. Maintenance cost – starts based [€/start/MW]	0.20	0.29	0.39	0.49	1.16	1.57
8d. LTMA cost – starts based [€/start/MW]	45.39	74.68	80.75	NA	53.06	NA

4 Attachments

4.1 Attachment 1 – cost structure breakdown

The list below represents an extract of the cost breakdown of the Entras model for CCGT.

General

- Management fee
- Rent
  - Premises
- Insurance
- Liabilities
- Permits
- Finance and taxes
- Consulting
- Audits
- Community representation
- Purchasing
- Other

Compliance

- Health & Safety
- Environment
  - Emissions
  - Liquid waste
  - Waste disposal
  - Cooling water intake
  - Cooling water discharge
  - Oil separators
  - Measurement campaign
  - Legal inspections
- Quality
- Legal requirements

Fuel

- Gas fee

Electricity

- Grid access fee
- Stand-still consumption

Maintenance

- Regular
  - Powertrain
    - Vibrational analysis
    - Gas turbine
    - Steam turbine
    - Oil cleaning online
    - Generator
    - Preventive inspections
  - HRSG
  - Fuel handling
    - Gas yard
    - Gas analysis

  - Chromatograph
- Instrumentation & Control
  - Preventive maintenance
  - Control system
  - Emission monitoring system
- Electrical
  - Legal inspections
  - Electrical motors
  - Switchgear
  - Transformers
  - Generator brushes
  - Generator breaker
  - Lights
  - Cathodic protection
  - Batteries / UPS
  - Trace heating
  - Variable speed drives
  - Predictive maintenance
  - Actuators
  - Electrical protections
  - Assistance
  - Capacity test
- Mechanical
  - Static equipment
    - Control Valves
    - Safety Valves
    - Piping
    - Steam condensor
    - Air condensor
    - Air filter replacement
    - SCR package replacement
    - Oil filter replacement
    - Steam traps
  - Rotating equipment
    - Pumps
    - Fans
    - Compressors
    - Oil sampling BOP
    - Emergency generators
  - Aux.&preheat boilers
  - Greasing
  - Oil change
  - Taprogge maintenance
  - Vibration monitoring rotating
  - Leak sealing
- Facility management
  - Fire fighting system
  - Industrial cleaning

      - Gardening
      - Painting
      - Pest control
      - Insulation
      - Scaffolding
      - HVAC
      - Building maintenance
    - Civil construction
  - Unplanned maintenance
  - Planned overhaul
    - ST+CV+ESV
    - HRSG
    - GEN
    - LTMA
      - Minor Overhaul
      - Major Overhaul
      - Program Management
    - Burners
    - Infrastructure
    - Crane rent
    - Project team
    - Supervision
    - Technical assistance
  - Tools & equipment
    - General tools
    - Workshop
    - Vehicles
    - Crane hire
    - Overheadcranes
    - Lifting equipment
    - Calibration
    - Inspection equipment
  - Engineering
    - O&M expertise
    - Plant modifications
    - Project management
- Operations
  - Daily operations
  - Chemistry
    - Analysis
    - Products
    - SCR products
  - Oil & Grease
  - Oil sampling
  - GT washing and anti-freeze
  - Fuel emergency generator
  - Water treatment plant
  - Waste water treatment

- Maintenance Management System
- Performance monitoring
- Data management
  - Archive system
- Infrastructure
  - Servers
  - Computers
  - Other devices
- Communication
- Services
  - Demineralised water
  - Condensate
  - Waste water treatment
  - City water
  - Site security
- Stores
  - Deliveries & receipts
  - Spare parts
  - Chemical products
  - Oil&grease storage
  - External storage
  - Spare part pooling
  - Stock audit
  - Transport to/from site

Trading and Energy Management

- Trading and Energy Management desk
- 3rd party service provider - fixed
- 3rd party service provider - variable
- Ancillary services

Human resources

- Personnel
  - Organogram
  - Recruitment
  - Administration
- Training

5 References

[1] Fichtner, “Cost of Capacity for Calibration of the Belgian Capacity Remuneration Mechanism (CRM),” April 2020. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/%20public-consultations/2020/20200505_fichtner-report-cost-of-capacity-crm_en.pdf.

[2] AFRY, “Peer Review of "Cost of Capacity for Calibration of Belgian CRM" Study,” October 2020. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/users-group/crm-implementation/documents/20201214_afry_peer-review-of-annual-fixed-costs-for-belgian-crm_en.pdf.

[3] AFRY, “Update of Peer Review of "Cost of Capacity for Calibration of Belgian CRM",” October 2022. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/public-consultations/2022/20221028_afry_update-of-the-peer-review-of-cost-of-capacity-for-calibration-of-belgian-crm.pdf.

[4] S. A. Newell, J. M. Hagerty, J. P. Pfeifenberger, B. Zhou, E. Shorin and P. Fitz, “PJM Cost of New Entry - Combustion Turbines and Combined-Cycle Plants,” June 2022. [Online]. Available: https://www.pjm.com/~/media/committees-groups/committees/mic/20180425-special/20180425-pjm-2018-cost-of-new-entry-study.ashx.

[5] ACER, “Methodology for calculating the value of lost load, the cost of new entry and the reliability standard,” October 2020. [Online]. Available: https://acer.europa.eu/Decisions_annex/ACER%20Decision%2023-2020%20on%20VOLL%20CONE%20RS%20-%20Annex%20I.pdf.

[6] Royal Decree, “Koninklijk besluit tot vaststelling van de paramaters waarmee het volume aan te kopen capaciteit wordt bepaald, inclusief hun berekeningsmethode, en van de andere parameters die nodig zijn voor de organisatie van de veilingen, alsook de methode en voorwaa,” April 2021. [Online]. Available: http://www.ejustice.just.fgov.be/eli/besluit/2021/04/28/2021041351/justel.

[7] European Parliament and the council of the European Union, “Regulation (EU) 2019/943 of the European Parliament and of the council of 5 June 2019 on the internal market for electricity,” June 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=EN.

[8] Federal Public Service Economy, “Raadpleging van de Algemene Directie Energie van de FOD Economie over het voorstel voor een geleidelijk reductietraject, vanaf 2023, van de CO2-emissielimieten die moeten worden gerespecteerd in het kader van het Belgische CRM,” June 2022. [Online]. Available: https://economie.fgov.be/sites/default/files/Files/Energy/Raadpleging-reductietraject-CO2-emissielimieten-vanaf-2023.pdf.

[9] J. Manning, “€150 million gas-fired power station proposed for Fingal,” 7 December 2021. [Online]. Available: https://www.independent.ie/regionals/dublin/fingal/150-million-gas-fired-power-station-proposed-for-fingal/41122825.html.

[10] Vitol, “Vitol's VPI enters joint venture with Lumcloon Energy to build reserve gas power plant in Ireland,” July 2022. [Online]. Available: https://www.vitol.com/vitols-vpi-enters-joint-venture-with-

lumcloon-energy-to-build-reserve-gas-power-plant-in-ireland/.

[11] Ansaldo Energy, “Ansaldo Energia News: successful ignition of its first gas turbine in Germany,” May 2023. [Online]. Available: https://www.ansaldoenergia.com/about-us/media-center/power-generation-news-insights/detail-news/ansaldo-energia-news-successful-ignition-of-its-first-gas-turbine-in-germany.

[12] “AE94.3A - The proven value,” Ansaldo Energia, [Online]. Available: https://www.ansaldoenergia.com/offering/equipment/turbomachinery/heavy-duty-gas-turbine/ae943a. [Accessed 07 July 2023].

[13] Siemens Energy, “Technical data for the SGT5-9000HL,” [Online]. Available: https://www.siemens-energy.com/global/en/offerings/power-generation/gas-turbines/sgt5-9000hl.html. [Accessed 07 July 2023].

[14] Elia, “Adequacy and Flexibility Study for Belgium 2024 - 2034,” June 2023. [Online]. Available: https://issuu.com/eliagroup/docs/adequacy_flexibility_study_for_belgium_2024-203.

[15] W. Winckelmans, “Akkoord over verlenging kernreactoren Doel 4 en Tihange 3: Engie betaalt 15 miljard voor berging nucleair afval,” 2023 June 29. [Online]. Available: https://www.standaard.be/cnt/dmf20230629_92241964. [Accessed 10 July 2023].

[16] Global Energy Monitor Wiki, “Coal power technologies,” April 2021. [Online]. Available: https://www.gem.wiki/Coal_power_technologies. [Accessed 24 6 June].

[17] General Electric, “Ultra-supercritical and advanced supercritical technology,” July 2023. [Online]. Available: https://www.ge.com/steam-power/coal-power-plant/usc-ausc.

[18] Powermag, “The World-Class Coal Power Efficiency of Rheinhafen-Dampfkraftwerk Block 8,” August 2019. [Online]. Available: https://www.powermag.com/the-world-class-coal-power-efficiency-of-rheinhafen-dampfkraftwerk-block-8/.

[19] Deloitte, Denuo, “Klimaatstudie voor de afvalverwerking- en recyclagesector in België,” June 2023. [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/be/Documents/consulting/denuo_climate-study_june-2023_nl.pdf.

[20] S. Nusselder, G. Bergsma, D. Jaspers, E. R. Lindgreen and M. B. (. Delft), “Verwerkingsscenario's Vlaams huishoudelijk afval en gelijkaardig bedrijfsafval 2020-2030,” December 2019. [Online]. Available: https://ce.nl/wp-content/uploads/2021/03/CE_Delft_OVAM_2P04_Verwerkingsscearios_Vlaams_Huishoudelijk_Afval.pdf.

[21] Bond Beter Leefmilieu, “Grenzen aan biomassa in België,” December 2015. [Online]. Available: https://www.bondbeterleefmilieu.be/sites/default/files/files/biomassa_rapport_dec_2015.pdf.

[22] Belgian Eco Energy, “BEE is building its own power plant in Ghent: the Bio Energy Base,” BEE, 19 January 2020. [Online]. Available: https://www.bee.eu/en/news/-the-bio-energy-base-ghent. [Accessed 07 July 2023].

[2 T. Steel, “Electrabel sluit grootste biomassacentrale van Wallonië,” 28 August 2020. [Online].

3] Available: https://www.tijd.be/ondernemen/milieu-energie/electrabel-sluit-grootste-biomassacentrale-van-wallonie/10247962.html. [Accessed 07 July 2023].

[24] 2Valorise, “About - Missie - 2Valorise Amel - 2Valorise Ham,” [Online]. Available: https://www.2valorise.be/about.html. [Accessed 07 July 2023].

[25] Aspiravi, “Centrale voor niet-recycleerbaar houtafval A&U Energie,” 11 September 2020. [Online]. Available: https://www.aspiravi.com/projects/au-energie/. [Accessed 24 June 2024].

[26] Aspiravi, “Centrale voor niet-recyleerbaar houtafval A&S Energie,” [Online]. Available: https://www.aspiravi.com/projects/as-energie/. [Accessed 24 June 2024].

[27] IDEA Consult, “Economisch potentieel van biomassaresten uit landschapsbeheer,” March 2022. [Online]. Available: https://www.vlaanderen.be/publicaties/economisch-potentieel-van-biomassaresten-uit-landschapsbeheer-eindrapport.

[28] Cogen Vlaanderen, “Cogeneration Feasibility Tool,” Cogen Vlaanderen, April 2023.

[29] Wikipedia, “Wind power in Belgium,” [Online]. Available: https://en.wikipedia.org/wiki/Wind_power_in_Belgium. [Accessed 07 July 2023].

[30] D. Adriaen, “Regering wil meer windmolens, maar moet eerst hinderpalen slopen,” 17 March 2022. [Online]. Available: https://www.tijd.be/ondernemen/milieu-energie/regering-wil-meer-windmolens-maar-moet-eerst-hinderpalen-slopen/10374427.html. [Accessed 07 July 2023].

[31] D. Bleus, “Vlaanderen vermindert bureaucratie rond vergunningen,” 18 February 2023. [Online]. Available: https://www.tijd.be/politiek-economie/belgie/vlaanderen/vlaanderen-vermindert-bureaucratie-rond-vergunningen/10367794. [Accessed 07 July 2023].

[32] Elia, “Over de reductiefactoren,” [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/electricity-market-and-system/adequacy/crm/2023/230405_elia_crm3-quick-nl-fiche-7.pdf. [Accessed 7 July 2023].

[33] FPS Economy, “Capaciteitsremuneratiemechanisme Veiling 10/2021 - reductiefactoren,” October 2021. [Online]. Available: https://economie.fgov.be/sites/default/files/Files/Energy/CRM-bijlage-reductiefactoren-veiling-10-2021.pdf.

[34] FPS Economy, “NOTA - Bepaling van de kost van een nieuwe toegang (CONE),” 2021. [Online]. Available: https://economie.fgov.be/sites/default/files/Files/Energy/CRM-Nota-bepaling-kost-nieuwe-toegang-CONE.pdf.

[35] FPS Economy, “Belgian offshore wind energy,” [Online]. Available: https://economie.fgov.be/en/themes/energy/belgian-offshore-wind-energy. [Accessed 07 July 2023].

[36] PV-Vlaanderen, “Sectorfederatie voor fotovoltaische zonne-energie,” [Online]. Available: https://www.pv-vlaanderen.be/. [Accessed 07 July 2023].

[3 A. Mehta, “With agrivoltaics 'we don''t have to choose between solar power and producing food'',” Reuters, 20 March 2023. [Online]. Available: https://www.reuters.com/business/sustainable-

7] business/with-agrivoltaics-we-dont-have-choose-between-solar-power-producing-food-2023-03-20/. [Accessed 07 July 2023].

[38] Elia, “Solar Power Generation,” [Online]. Available: https://www.elia.be/en/grid-data/power-generation/solar-pv-power-generation-data. [Accessed 07 July 2023].

[39] E. Weidner, R. Ortiz Cebolla and J. Davies, “Global deployment of large capacity stationary fuel cells,” 2019. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/d5b49b34-6a28-11e9-9f05-01aa75ed71a1/language-en#.

[40] A. Larson, “World's largest fuel cell plant opens in South Korea,” February 2014. [Online]. Available: https://www.powermag.com/worlds-largest-fuel-cell-plant-opens-in-south-korea/.

[41] U.S. Departement of Energy, “Fuel Cell Technology Office - Fact Sheet,” November 2015. [Online]. Available: https://www.energy.gov/eere/fuelcells/articles/fuel-cells-fact-sheet.

[42] Pascal Sertyn, “Batterijparken groeien als kool in België,” May 2023. [Online]. Available: https://www.standaard.be/cnt/dmf20230505_96477224. [Accessed 7 July 2023].

[43] M. Maisch, “Europe's big battery fleet to surge to 95 GW by 2050, says research firm,” April 2023. [Online]. Available: https://www.pv-magazine.com/2023/04/24/europes-big-battery-fleet-to-surge-to-95-gw-by-2050-says-research-firm/. [Accessed 7 July 2023].

[44] T. Steel, “Zoutgrotten Solvay krijgen tweede leven als enorme persluchtbatterij,” 14 June 2023. [Online]. Available: https://www.tijd.be/ondernemen/milieu-energie/zoutgrotten-solvay-krijgen-tweede-leven-als-enorme-persluchtbatterij/10474583.html. [Accessed 07 July 2023].

[45] A. Colthorpe, “Flywheel-lithium battery hybrid energy storage system joining Dutch grid services markets,” September 2020. [Online]. Available: https://www.energy-storage.news/flywheel-lithium-battery-hybrid-energy-storage-system-joining-dutch-grid-services-markets/.

[46] en:former, “Mammoth flywheel for Ireland's grid stability,” July 2022. [Online]. Available: https://www.en-former.com/en/mammoth-flywheel-for-irelands-grid-stability/. [Accessed 07 July 2023].

[47] ADEME, E-CUBE Strategy Consultants, “L'effacement de consommation electrique en France,” September 2017. [Online]. Available: https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/1772-effacement-de-consommation-electrique-en-france.html.

[48] National Renewable Energy Laboratory, “Preparing distribution utilities for the future - unlocking demand-side management potential,” July 2021. [Online]. Available: https://www.nrel.gov/docs/fy21osti/79375.pdf.

[49] Brattle, “PJM CONE 2026/2027 Report,” 21 April 2022. [Online]. Available: https://www.pjm.com/-/media/library/reports-notices/special-reports/2022/20220422-brattle-final-cone-report.ashx.

[50] Pacific Northwest National Laboratory, “2022 Grid Energy Storage Technology Cost and Performance Assessment,” August 2022. [Online]. Available: https://www.pnnl.gov/sites/default/files/media/file/ESGC%20Cost%20Performance%20Report%202022%20PNNL-33283.pdf.

[51] Platte River Power Authority, “Battery Energy Storage Technology Assessment,” November 2017. [Online]. Available: https://www.prpa.org/wp-content/uploads/2017/10/HDR-Battery-Energy-Storage-Assessment.pdf.

[52] K. Mongird, V. Viswanathan, P. Balducci, J. Alam, V. Fotedar, V. Koritarov and B. Hadjerioua, “An Evaluation of Energy Storage Cost and Performance Characteristics,” 28 June 2020. [Online]. Available: https://www.mdpi.com/1996-1073/13/13/3307.

[53] U.S. Energy Information Administration, “Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies,” February 2020. [Online]. Available: https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf.

[54] Ramboll, “Best New Entrant Study 2022,” 18 October 2022. [Online]. Available: https://www.semcommittee.com/files/semcommittee/media-files/SEM-22-076a%20BNE-Net%20CONE%20Report.pdf.

[55] Potomac Economics, “2022 State of the Market Report for the New York ISO Markets,” May 2023. [Online]. Available: https://www.potomaceconomics.com/wp-content/uploads/2023/05/NYISO-2022-SOM-Full-Report__5-16-2023-final.pdf.

[56] GHD Advisory, “Power station and associated costs,” 8 December 2022. [Online]. Available: https://www.erawa.com.au/cproot/23060/2/-BRCP.2023---Power-Station-and-Associated-Costs-Report---GHD-Advisory---Dec-2022.PDF.

[57] The Brattle Group, “AESO Cost of New Entry Analysis,” 4 September 2018. [Online]. Available: https://www.aeso.ca/assets/Uploads/CONE-Study-2018-09-04.pdf.

[58] VEKA, “Rapport 2022 Deel 1: Rapport OT/Bf voor projecten met een startdatum vanaf 1 januari 2023,” 2022. [Online]. Available: https://assets.vlaanderen.be/image/upload/v1662990249/2022_deel1_qjlkrl.pdf.

[59] VEKA, “Rapporten van 2012 tot 2022 - Deel 1: Berekening OT en Bf voor nieuwe projecten,” 2021. [Online]. Available: https://assets.vlaanderen.be/raw/upload/v1672844413/2012-2022_PublicatiesDeel1_n12p9n.zip.

[60] Cogen Vlaanderen, “Cogeneration Feasibility Tool,” April 2023. [Online]. Available: https://www.cogenvlaanderen.be/.

[61] National Energy Technology Laboratory, “Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity,” 14 October 2022. [Online]. Available: https://www.osti.gov/biblio/1893822.

[62] Department for Energy Security & Net Zero, “Electricity Generation Costs 2023,” 2023. [Online]. Available: https://www.gov.uk/government/publications/electricity-generation-costs-2023.

[63] “Euro/ECU exchange rates - annual data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/ERT_BIL_EUR_A__custom_7212820/default/table?lang=en.

[6 “Labour cost, wages and salaries, direct remuneration (excluding apprentices) by NACE Rev. 2 activity,” [Online]. Available:

4] https://ec.europa.eu/eurostat/databrowser/view/LC_NCOST_R2__custom_7186677/default/table?lang=en.

[65] “Labour Account Australia, Annual Balanced: Subdivision, Division and Total All Industries,” [Online]. Available: https://tinyurl.com/Labour-Account-Australia.

[66] “Total compensation per job, by NAICS industry,” [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048905.

[67] “Total compensation cost per hour worked for private industry workers in utilities industries,” [Online]. Available: https://download.bls.gov/pub/time.series/cm/cm.data.1.AllData.

[68] Eurostat, “Labour cost index by NACE Rev. 2 activity - nominal value, quarterly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/LC_LCI_R2_Q__custom_7266289/default/table?lang=en.

[69] Eurostat, “Service producer prices - quarterly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/STS_SEPP_Q__custom_7266402/default/table?lang=en.

[70] Eurostat, “Service producer prices - quarterly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/STS_SEPP_Q__custom_7269232/default/table?lang=en.

[71] Eurostat, “Producer prices in industry, total - quarterly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/STS_INPP_Q__custom_7290795/default/table?lang=en.

[72] Eurostat, “Producer prices in industry, non domestic market - quartly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/STS_INPPND_Q__custom_7224489/default/table?lang=en.

[73] Eurostat, “HICP - monthly data,” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/PRC_HICP_MIDX__custom_7266116/default/table?lang=en.

[74] Gas Turbine World, “2022 GTW Handbook, Volume 37,” [Online]. Available: https://gasturbineworld.com/shop/annual-handbook/2022-gtw-handbook-volume-37/.

[75] CREG, “Maandelijkse boordtabel elektriciteit en aardgas - Juli 2023,” July 2023. [Online]. Available: https://www.creg.be/sites/default/files/assets/Prices/Dashboard/boordtabel202307.pdf.

[76] U.S. Environmental Protection Agency, “Greenhouse Gas Mitigation Measures - Carbon Capture and Storage for Combustion Turbines,” 23 May 2023. [Online]. Available: https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20GHG%20Mitigation%20Measures%20for%20Combustion%20Turbines.pdf.

[77] De Vlaams Minister van Justitie en Handhaving, Omgeving, Energie en Toerisme, “Ontwerp conceptnota: "Visie op CCUS: koolstof afvang, hergebruik en opslag",” 2021. [Online]. Available: https://assets.vlaanderen.be/image/upload/v1659014412/Conceptnota_-_visie_op_CCUS_-

_koolstof_opvang_hergebruik_en_opslag_2021_wcj9ao.pdf.

[78] Global CCS Institute, “Technology readiness and costs of CCS,” March 2021. [Online]. Available: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf.

[79] Zero Emisions Platform, “ZEP Report - The cost of subsurface storage of CO2,” December 2019. [Online]. Available: https://zeroemissionsplatform.eu/wp-content/uploads/Cost-of-storage.pdf.

[80] ETN Global, “Hydrogen Deployment in Centralised Power Generation - A techno-economic case study,” 5 April 2022. [Online]. Available: https://etn.global/wp-content/uploads/2022/06/H2-deployment-in-centralised-power-generation-techno-economic-study-April2022.pdf.

[81] S. Mulder, “Ready for the Energy Transition: Hydrogen Considerations for Combined Cycle Power Plants,” PowerMag, 19 October 2021. [Online]. Available: https://www.powermag.com/ready-for-the-energy-transition-hydrogen-considerations-for-combined-cycle-power-plants/.

[82] Jenbacher, “Jenbacher Type 4, An efficient milestone,” 2023. [Online]. Available: https://www.jenbacher.com/en/gas-engines/type-4.

[83] Federal Public Service Economy, “Publieke raadplegingen in het kader van het CRM,” [Online]. Available: https://economie.fgov.be/nl/themas/energie/bevoorradingszekerheid/elektriciteit/capaciteitsmechanismen/capaciteitsremuneratiemechanis/publieke-raadplegingen-het. [Accessed 07 July 2023].

[84] Belgium, “Wet houdende de geleidelijke uitstap uit kernenergie voor industriële elektriciteitsproductie,” February 2003. [Online]. Available: https://etaamb.openjustice.be/nl/wet-van-31-januari-2003_n2003011096.html.