Final Report

Study to Establish an Estonian Reliability Standard

31 March 2020

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CONTEXT AND OBJECTIVES OF THE STUDY

EU Regulation 2019/943, a part of the Clean Energy Package, requires Member States to develop **reliability standards** indicating the necessary level of security of supply of the national electricity system following the methodologies that are being developed by ENTSO-E. This includes:

- A methodology for the estimation of Value of Lost Load (Article 11 and Article 23.6);
- The methodology for the assessment of the cost of new entry (CONE) for generators or demand response (Article 23.6); and
- The reliability standards based on Loss of Load Expectation (LOLE) and Expected Energy not Served (EENS) (Article 25).

A dedicated “Adequacy Methodologies” task force within ENTSO-E has prepared drafts of these methodologies and these are now in the process of being reviewed by ACER. The methodologies are expected to be finalised in early 2020.

Elering seeks to establish the Estonian reliability standard for Estonia based on adequacy assessment consistent with the methodologies being developed under EU Regulation 2019-943. Compass Lexecon was mandated as a result of a competitive procurement process (reference No 215657).

Our mission is the following:

- Develop a proposal for the Estonian reliability standard consistent with the EU Regulation
- Draft a report providing thorough justification of the proposed reliability standard
- Run a quantitative analysis of the expected cost to society resulting from deviations from the proposed optimal reliability standard

DEFINITIONS

- **RS - Reliability Standard**
  - A measure of the necessary level of security of supply.
- **EENS (MWh/year) – Expected Energy Not Served**
  - The annual demand that is not served from market-based resources, e.g. due to the demand exceeding the available generating capacity and the electricity that can be imported in a market node.
- **LOLE (hours/year) – Loss of Load Expectation**
  - The expected number of hours per year during which the demand cannot be covered by market-based resources, i.e. the demand exceeds the available generating capacity and the electricity that can be imported in the market node and a positive ENS is observed.
- **VOLL (EUR/MWh) – Value of Loss of Load**
  - An estimation of the maximum electricity price that customers are willing to pay to avoid an outage.
- **CONE (EUR/MW) – Cost of New Entry**
  - The total annual net revenue per unit of de-rated capacity (net of variable operating costs) that a new generation resource or demand-side response would need to receive over its economic life in order to recover its capital investment and fixed costs.

Most definitions from: https://consultations.entsoe.eu/entso-e-general/proposal-for-voll-cone-and-reliability-standard-me/supporting_documents/191205_Methodology%20for%20VoLL%20CONE%20and%20reliability%20standard_public%20consultation.pdf
VOLL: Regulation (EU) 2019/943

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ECONOMIC APPROACH SUGGESTS USING A LOLE TARGET AS A RELIABILITY STANDARD

According to the EU Regulation 2019/943 **Article 25** Member States shall have a reliability standard in place when applying capacity mechanisms. The reliability standard shall transparently indicate the necessary level of security of supply. The reliability standard shall be calculated using at least the value of lost load (VOLL) and the cost of new entry (CONE) and be expressed as:

- Expected energy not served (EENS), and
- Loss of load expectation (LOLE).

The formula below defines the **Main Reliability Standard** in terms of optimal level of security of supply (LOLE) expressed as a ratio between CONE and VOLL. The optimal levels of CONE and VOLL are determined by the point at which the **incremental** cost of additional capacity insuring customers against load curtailments (CONE) is equal to the **incremental** cost of load curtailments to customers (incremental volume of Expected Energy Not Served expressed as LOLE, valued at VOLL). This is shown in Figure 1.

In sum, the social benefit is maximized in the point where the marginal cost of capacity is equal to the marginal benefit.

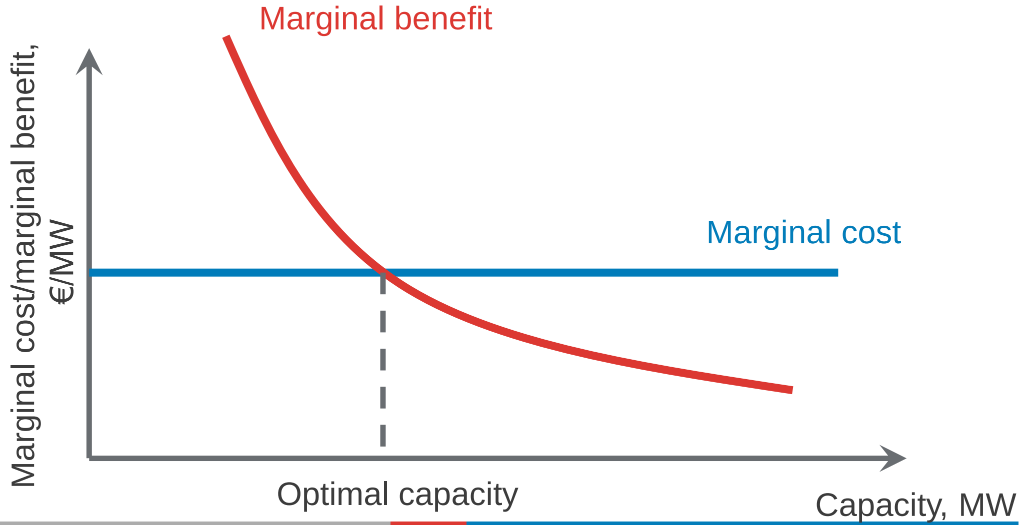
- **Marginal cost** of capacity is mainly determined by the fixed cost of a MW capacity of peaking units – CONE.
- **Marginal benefit** is characterised by the value of the outage avoided by MW of additional capacity – VOLL*LOLE.

In any point other than the one defined by the formula above, social welfare would be reduced:

- If adequacy assessment shows a LOLE value above target, it would imply that customers bear the cost of unserved energy that is higher than the cost of additional capacity.
- If adequacy assessment shows a LOLE value below target, it would imply that the customers bear the cost of additional capacity than is higher than the costs of unserved energy.

$$LOLE_{target}\ (\text{in hour}) = \frac{CONE\ (in\ local\ currency)/MWh}{VOLL\ (in\ local\ currency)/MWh}$$

Figure 1: Economic equilibrium determining the Reliability Standard



ECONOMIC APPROACH FOR RELIABILITY STANDARD IS BASED ON INCREMENTAL EENS (LOLE) AND NOT ON THE TOTAL EENS

An economic approach to set the optimal reliability standard can be expressed as a the **Loss of Load Expectation (LOLE)**, in hours per year, and be derived from the value of **Cost of New Entry (CONE)** and **Value of Lost Load (VOLL)** only**.** The reliability standard is therefore a trade-off between CONE and VOLL.

Optimality condition of a social welfare maximizing problem is met when the marginal cost, expressed as CONE, is equal to the marginal benefit, expressed as incremental change in expected energy not served (EENS) valued at VOLL.

For a given load duration curve it can be shown that the incremental change in expected energy not served (EENS) can be associated with an equivalent number of hours of lost load (LOLE). This is expressed in the equation below and shown in Figure 2.

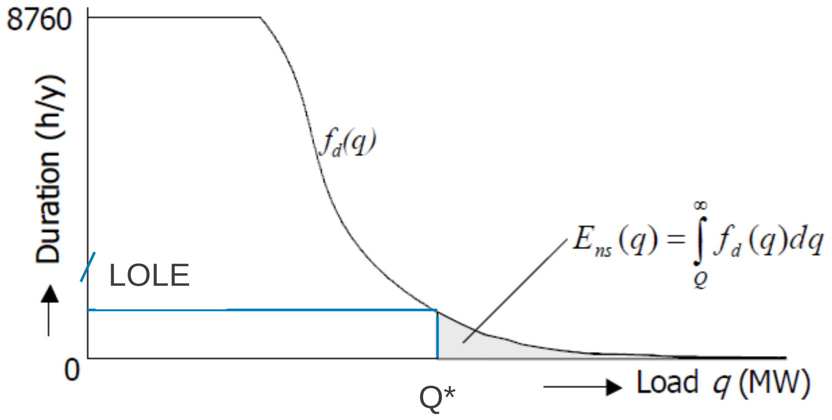
$$\frac{dEENS(Q^{*})}{dQ} = \mathrm{LOLE}$$

Substituting the above term into the original optimality condition leads to the following optimal relationship:

$$CONE = LOLE \; * VOLL$$

The last equation describes the relationship between the reliability standard (LOLE), the value of lost load (VOLL), and the cost of new entry (CONE) under which social welfare is maximized.

Figure 2: Load duration curve showing LOLE associated with incremental EENS



THERE IS NO ECONOMICALLY JUSTIFIED LEVEL OF EENS TO BE USED AS RELIABILITY STANDARD

According to the EU Regulation 2019/943 Article 25 (3), the Reliability Standard shall be expressed as ‘expected energy not served’ (EENS) and ‘loss of load expectation’ (LOLE).

In contrast to LOLE, reliability standard based on EENS has no economic justification, because economically optimal reliability standard should rely on the incremental EENS (i.e. the LOLE) and not the total EENS.

Reliability standards based on EENS are used in **Australia** and **Alberta**. In Australia, a reliability standard of 0.002% of EENS (USE, unserved energy) was set in NEM since 1998. In Alberta, the reliability standard is 800MWh of EENS, which corresponds to 0.0014% in 2008 when it was introduced.

Arguments used in favor of EENS are the following:

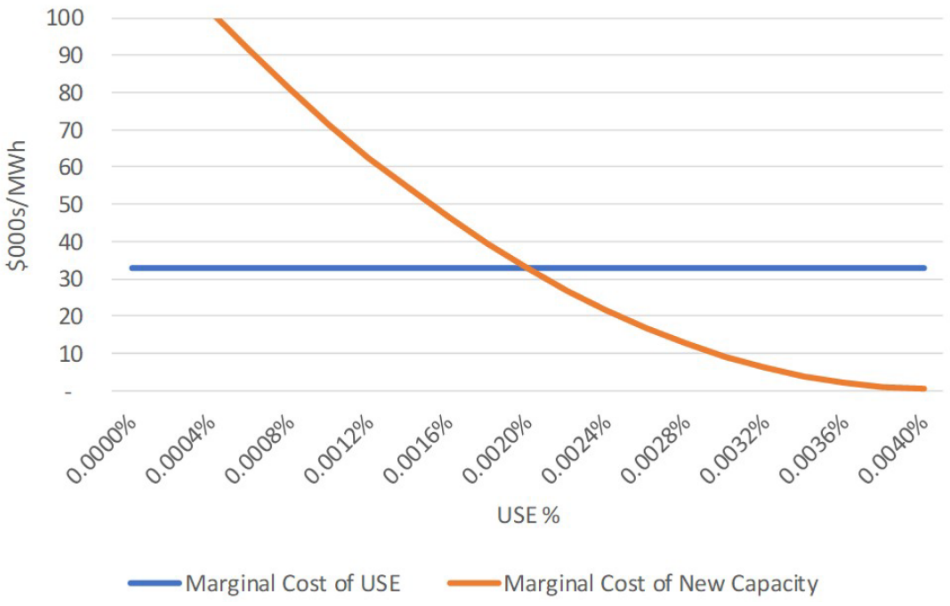
- Unlike LOLE, EENS is a target in terms of volume of energy lost, while the volume of energy lost during X hours of LOLE may vary depending on system conditions, such as variation of demand, RES production, and forced outages of transmission and generation capacity.
- This argument overlooks the fact that optimal reliability target should rely on the marginal EENS and not the total EENS.

One can still define an optimal level of ENS by the following relationship:

$$VOLL = -\frac{CONE}{\frac{dEENS(EENS)}{dQ}}$$

However, this would require estimating the relationship of how LOLE depends on ENS.

Figure 3: In Australia EENS level of reliability is set by the intersection of marginal cost of unserved energy (USE) and marginal cost of new capacity (CONE)



Source: AEMO 2018, “The NEM Reliability Framework”

RELIABILITY STANDARDS BASED ON LOLE OR EENS OFTEN USED TOGETHER WITH SUPPLEMENTARY REQUIREMENTS

Table 1 below summarises the reliability standards currently used in Europe, the US, Canada and Australia. LOLE is the most widely used Reliability Standard, although, EENS is used in Australia and Alberta. Table 1 below also highlights that along with the main Reliability Standard, a secondary requirement is often used to provide additional security.

Table 1: International reliability standards based on LOLE and EENS with supplementary requirements

Metric	Main requirement	Supplementary requirement	Jurisdiction
EENS	0.002%	Reserve margin	NEM, Australia
	800MWh – 0.0014%		Alberta, Canada
LOLE	1 in 10 or 2.4 hours		NYISO, PJM, ISO-NE, US
	1 in 10 or 2.4 hours	13.75% reserve margin	ERCOT, US
	3 hours	1 in 10 year winter peak	GB
	3 hours		France, Poland
	3 hours	<20h LOLE 95% of the time in Belgium	Belgium
	4 hours		Netherlands
	8 hours		Ireland
	8 hours	LSI (Load Supply Index)* > 1 in 95% of the time	Portugal

*ratio between the total available power and the hourly peak electricity demand.

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THE VOLL CORRESPONDS TO THE DAMAGE ARISING FROM THE NON-SUPPLY OF ENERGY

The Value of Lost Load (VOLL)

- VOLL measures the monetary damage (in €) arising from the non-supply of a given amount of energy (in MWh for instance) due to a power outage, which can be caused by a wide range of technical factors, from lack of generation capacity to networks outages, either on the transmission or on the distribution grid.
- These costs can be significant: power outages are highly prejudicial in modern societies as they imply the interruption of productive processes for industrials and businesses or the reduction of leisure activities.
- VOLL only concerns the inelastic demand, therefore price-responsive consumers considered as demand-side response (DSR) in the resource adequacy assessment should be excluded from VOLL estimates.

Several types of cost need to be considered

- Private costs and costs for the rest of the society
- Monetary and non-monetary costs
- Direct and indirect costs

Note that net costs need to be considered, in the sense that any savings (for instance on electricity bills due to outage) should be subtracted from total costs. Benefits from outages are likely to be negligible compared to costs.

Regulatory Agencies (RA) calculate a single estimate of VOLL representing the most likely cost of an adequacy outage. RA specify which categories and sub-categories (among domestic, tertiary, industry and transport) are likely to suffer from an adequacy outage and the **weight** of each of these categories in the total EENS (ENTSO-E Proposal, 2019).

THERE IS NOT A UNIQUE VOLL: IT VARIES DEPENDING ON INTERRUPTION'S CHARACTERISTICS

Consequences and costs of supply interruptions differ from one to another, e.g. a power interruption does not have the same consequences and costs if it occurs, e.g. during the night and for 5 minutes or during peak hours for several hours.

As a result, there is not a unique VOLL which can be applied for all types of outages. The VOLL should be fine-tuned to precisely consider interruption characteristics and then the real costs caused by an outage.

Main interruption characteristics, or VOLL parameters, are:

- **Customer type** (households, industrials, tertiary sector, …): the implications and associated costs of service interruptions are different across customers. Hence, VOLL varies by consumer group. VOLL for adequacy reasons may exclude certain industrial customers and critical infrastructure (e.g. hospitals).
- **Duration of interruption**: the cost of the interruption (per unit of energy interrupted) can also vary depending on the duration of the interruption. Certain types of damage, such as the loss of computer files, occur instantaneously. Others, such as the loss of working hours and the spoilage of food, are proportional to the length of the interruption and may only occur after a certain delay. In case of adequacy issues, outages can take from one to several hours, but if rolling blackouts are performed by the TSO, outage duration for each customer can be limited.
- **Time of interruption**: VOLL values differ depending on the hours of the year when the interruption occurs. For example, an electricity interruption at night might imply lower costs for the service sector compared to an interruption during business hours. Adequacy issues are more likely to occur during peak hours, which vary from country to country
- **Pre-notification of power interruption**: Planned interruptions tend to have a lower VOLL compared to unplanned interruptions, as the customer can take measures in advance to mitigate the costs. Pre-notification of several hours is usually possible for adequacy outages.

AS MARKETS CANNOT REVEAL VOLL, INDIRECT METHODOLOGIES NEED TO BE APPLIED TO ESTIMATE IT

Due to very limited price elasticity in demand (particularly for households and small business in the short term), electricity customers rarely reveal in the market their willingness to pay for electricity: VOLL cannot be directly inferred from market data and indirect methodologies should be implemented instead to assess it.

In particular, four methodologies are mentioned in the literature, each presenting pros and cons:

- **Revealed preferences** – this methodology relies on analysis of actual expenditures incurred by customers to ensure reliable generation, it has a very limited applicability (in particular for households) **and is almost never used**
- **Case study** – this methodology measures the actual value of loss load that occurred during actual interruptions in the past, it **is rarely used** on its own to estimate VOLL in Europe given the rarity of black-outs
- **Stated choice** – this methodology relies on preferences stated by customers through surveys, it allows obtaining precise and fine-tuned results and thus **provides the most accurate result**
- **Macroeconomic** – this methodology measures the direct cost of the outage relying on macroeconomic indicators (electricity supply rates and consumption, GDP, wage rate), it can be easily implemented but it **ignores some of the outage costs.**

The European methodology for VOLL (ENTSO-E Proposal, 2019) suggests conducting surveys for the **domestic** (private households) and **tertiary sectors** (SME and public sector).

For the **industrial sector**, the European methodology considers using the macro-economic approach to estimate the **production cost** component of VOLL which also considers a pre-notification factor discount and a sector-specific proportion of gross value added reliant on electricity supply. Another but smaller component of the industrial VOLL are also **other costs** (such as restart costs, damage costs, capacity utilization, …), which can be assessed through survey, depending on RA’s decision.

The **transport sector** (trains, electric public transportation in cities, …) uses the same approach as the industrial sector (lost production and other costs) but adds value of lost time component using an estimation of number of passengers at each hour and hourly value of time.

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CONE IS THE INVESTMENT COST OF THE CHEAPEST CAPACITY

Cost of New Entry (CONE) definition

Cost of New Entry (CONE) is the total annual net revenue per unit of de-rated capacity (net of variable operating costs) that a new generation resource or demand-side response would need to receive over its economic life in order to recover its capital investment and fixed costs.

CONE represents the investment cost of a **cheapest capacity** annualised over the plant lifetime. It reflects technology, location, and costs that a **competitive developer** of new generation facilities will be able to achieve at generic sites, i.e. not unique sites with unusual characteristics. CONE estimate shall be updated at least every five years or earlier, if significant changes occur.

CONE used for setting the CRM parameters or the Reliability Standard

Most existing examples calculate CONE for setting the **parameters of a CRM**, e.g. the demand curve, and the price and bid caps. **Net CONE** is calculated in this case, which is a CONE net of the wholesale and ancillary market revenues. Net CONE is an estimate of the missing money of a new entrant in energy-only market.

In other cases, such as GB, CONE is used to set the **Reliability Standard**. **Gross CONE** is used in this case and includes the revenues from ancillary and wholesale markets.

Cost of New Entry (CONE) calculation steps

a. Review and select potential candidate technologies that can be considered as Reference Technologies;

b. Define the detailed technical characteristics of the candidate Reference Technologies;

c. Develop a bottom-up estimate of Capital Costs and Annual Fixed Costs for each candidate reference technology;

d. Determine an appropriate Cost of Capital for each candidate Reference Technology;

e. Compute the Equivalent Annualized Costs (EAC) of each candidate Reference Technology and determine the final Cost of New Entry.

SETTING CONE LEVEL REQUIRES CHOOSING REFERENCE TECHNOLOGY AND THE CORRESPONDING PARAMETERS

Setting CONE level requires to choose the Reference Technology

The selected reference technologies should be **1. merchant**, **2. standard,** and based on **3. potential new entry.**

1. CONE needs to represent merchant technologies which do not receive a legal State Aid. Subsidised technologies, such as RES technologies benefitting from support schemes should be excluded. An exception are technologies receiving State Aid for adequacy objective, i.e. Capacity Mechanism.
2. Reliable and standard cost information should be available to support an accurate cost estimate. The cost of building and operating the technology should not vary significantly between projects, and the technology development should not be strongly bound by technical constraints. CCGT, OCGT, engines or batteries can be considered homogenous and suitable for the choice of reference technology.
3. Reference technologies should be representative of possible capacity additions based on recent past, current or near-future developments, with no inherent constraints to future developments of these resources.

The above criteria have to be evaluated on a **country-specific** basis using **up-to-date** knowledge from industry experts, competent authorities and stakeholders, external consultants or literature.

The typical choice of the reference technology is an **OCGT** plant. This is because OCGT’s lower capital costs play an important role for a peaking plant with low number of operating hours. Nonetheless, more efferent but higher cost CCGT plant can also be considered.

Setting CONE requires a number of technical and cost parameters of the Reference Technology

- The investment and fixed operating and maintenance costs
- The weighted average cost of capital (WACC)
- The economic lifetime
- The de-rated capacity

CONE CALCULATION CAN BE PERFORMED IN 5 STEPS

5 steps for calculating the CONE

1. Review and select potential candidate technologies that can be assessed as Reference Technologies (e.g. OCGT, CCGT, DSR…)
   - Merchant and standard technologies which shall be representative of possible capacity additions in the coming years
2. Define the detailed technical characteristics of each candidate Reference Technology
   - Technical specifications shall be determined based on the most likely choices that developers will make
3. Develop a bottom-up Capital and Annual Fixed Costs estimates for each candidate Reference Technology
   - Capital Costs (CC) shall include all costs incurred during the construction period, until the capacity resource is available
   - Annual Fixed Costs (AFC) refer to costs incurred each year once the capacity resource starts operating and which do not depend on the generated volume
4. Determine an appropriate WACC for each candidate Reference Technology
   - The minimum rate of return required by fund providers (shareholders and/or creditors) to finance investment in the Reference Technology in the Member State
5. Compute the Equivalent Annualized Costs (EAC) of each candidate Reference Technology and determine the CONE as the lowest EAC among the candidate Reference Technologies

The formula below represents the equivalent annualized costs (EAC) equal to the annualized capital and annual fixed costs of a de-rated capacity (K_d) of a candidate Reference Technology:

$$EAC = \frac{\left[\sum_{i=1}^{X} \frac{CC(i)}{(1+WACC)^{i}} + \sum_{i=X+1}^{X+Y} \frac{AFC(i)}{(1+WACC)^{i}}\right] \cdot \frac{WACC \cdot (1+WACC)^{X+Y}}{(1+WACC)^{Y}-1}}{K_d}$$

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CEPA STUDY SUGGESTS A VOLL OF 3.07€/KWH FOR ESTONIA, BUT THIS IS LIKELY AN UNDERESTIMATION

CEPA study realised for ACER in 2018(1) using a macro-economic approach provides VOLL estimates by sub-categories of industrial customers, for services customers and for residential customers.

Matching this with Eurostat data of electricity consumption results in a weighted average VOLL for Estonia of 3.07 €/kWh. However, we consider that VOLL estimation from ACER needs to be corrected because it uses a macro-economic approach that disregards a number of outage costs.

Table 2: Final electricity consumption by sector and the respective VOLL estimates

Category	VOLL, €/kWh CEPA	Consumption 2018, GWh Eurostat
Basic Metals	2.14	6
Chemical and Petrochemical	0.67	116
Non-metallic Minerals	0.7	194
Food and Tobacco	1	290
Textile and Leather	1.42	61
Paper, pulp and print	0.28	482
Transport equipment	1.48	82
Machinery	2.41	320
Wood and wood products	1.03	539
Construction	10.96	71
Transport	16.1	43
Agriculture, Forestry and Fishing	1.84	165
Domestic	5.18	1860
Services	2.86	2933
Total	3.07	

(1) ACER (2018) "Study on the estimation of the value of lost load of electricity supply in Europe"

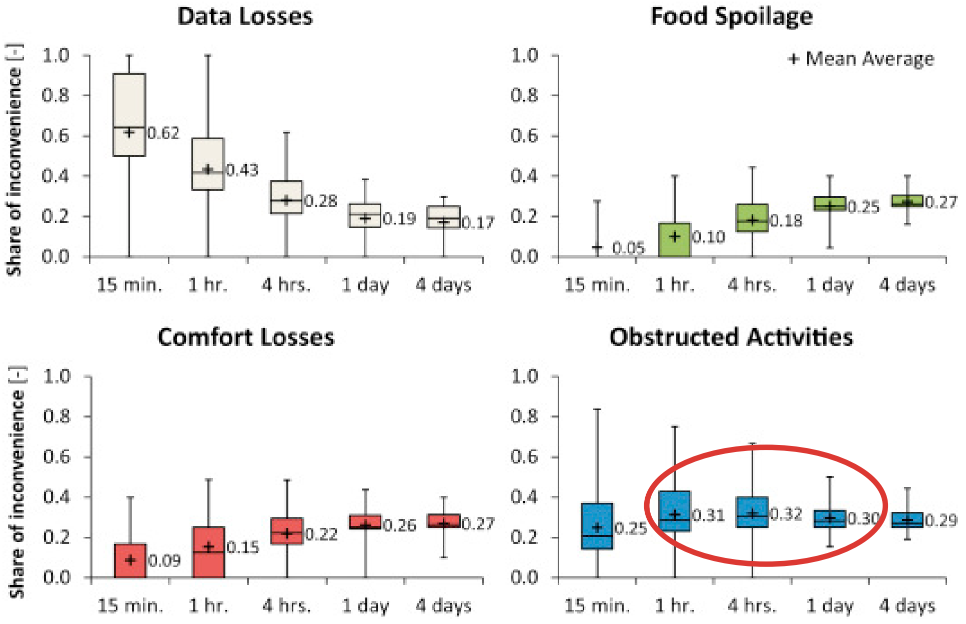
ADJUSTMENT OF THE VOLL VALUE RESULTING FROM MACRO APPROACHES

ACER’s approach is based on **two macro-economic indicators** depending on the type of customers: 1. Value of leisure for domestic customers, and 2. Value of production for non-domestic customers. However, both indicators are potentially ignoring significant part of the outage costs.

For the **domestic customers,** Figure 4 shows the percentage shares of inconvenience caused by power interruptions. However, the value of leisure time (obstructed activities) represents approximately **30-32%** of the domestic outage costs.

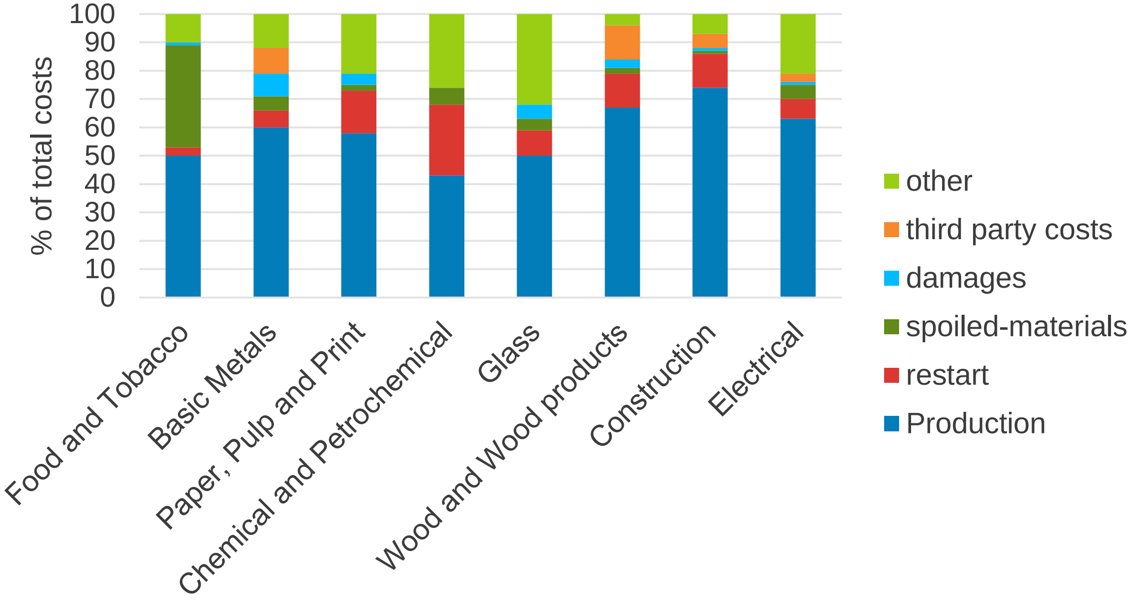
For the non-domestic **industrial sector**, Figure 5 displays the percentage shares of different cost types caused by power outage across industries. The figure highlights that the value of production represents approximately **43-74%** of total outage costs depending on industry.

Figure 4: Percentage shares of outage costs across different loss types and durations for domestic customers



Source: Praktijno (2014) “Stated preferences based estimation of power interruption costs in private households: An example from Germany”

Figure 5: Percentage shares of different outage-related costs across industries



Source: Küfeoğlu, 2015 Economic Impacts of Electric Power Outages and Evaluation of Customer Interruption Costs

VOLL FOR ESTONIA COULD BE ASSESSED IN A RANGE OF 6.5-8.5€/kWh AFTER CORRECTING FOR MISSING COST ELEMENTS

As a starting point, we consider the VOLL of 3.07€/kWh obtained from the ACER's macro-economic study.

We then adjust the VOLL for the outage costs non-accounted for by the macro-economic studies. As mentioned previously:

- VOLL for domestic agents (households) only covers between 30% and 32% of all outage costs
- VOLL for non-domestic agents (industry and services) covers between 43% and 74% of all outage costs

We therefore estimate an adjusted VOLL for Estonia using each sector's weights (% share of total electricity consumption) and the range of correction factors for each sector based on academic literature.

Table 3 summarizes the correction factors and the corrected VOLL for Estonia, which should range between **6.5 - 8.5 €/kWh.**

Table 3: Adjusted VOLL for Estonia

Range	**Outage costs included in the macro-economic VOLL estimation**			**Adjusted VOLL (€/kWh)**
	Households (26%)	**Services (41%)**	**Industry (33%)**	
Low	30%	43%	43%	6.5
Mid	31%	59%	59%	7.3
High	32%	74%	74%	8.5

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DERIVING CONE REQUIRES DEFINING REFERENCE TECHNOLOGY

Selection criteria for reference technology, a reminder

The candidate reference technology has to be **merchant**, **standard**, and based on **potential new entry.**

Top reference technology options for a peaking plant

- **Option 1: OCGT Dual,** natural gas as primary fuel with distillate fuel oil as secondary fuel
- **Option 2: OCGT Distillate,** fuel oil as primary fuel
- **Option 3: Reciprocating Engine** natural gas as primary fuel with distillate fuel oil as secondary fuel**;** Kiisa reference plant: Dual fuel, 250MW, 27 medium-speed 9.7MW engines, (area of ≈8 hectares)

Other technological considerations

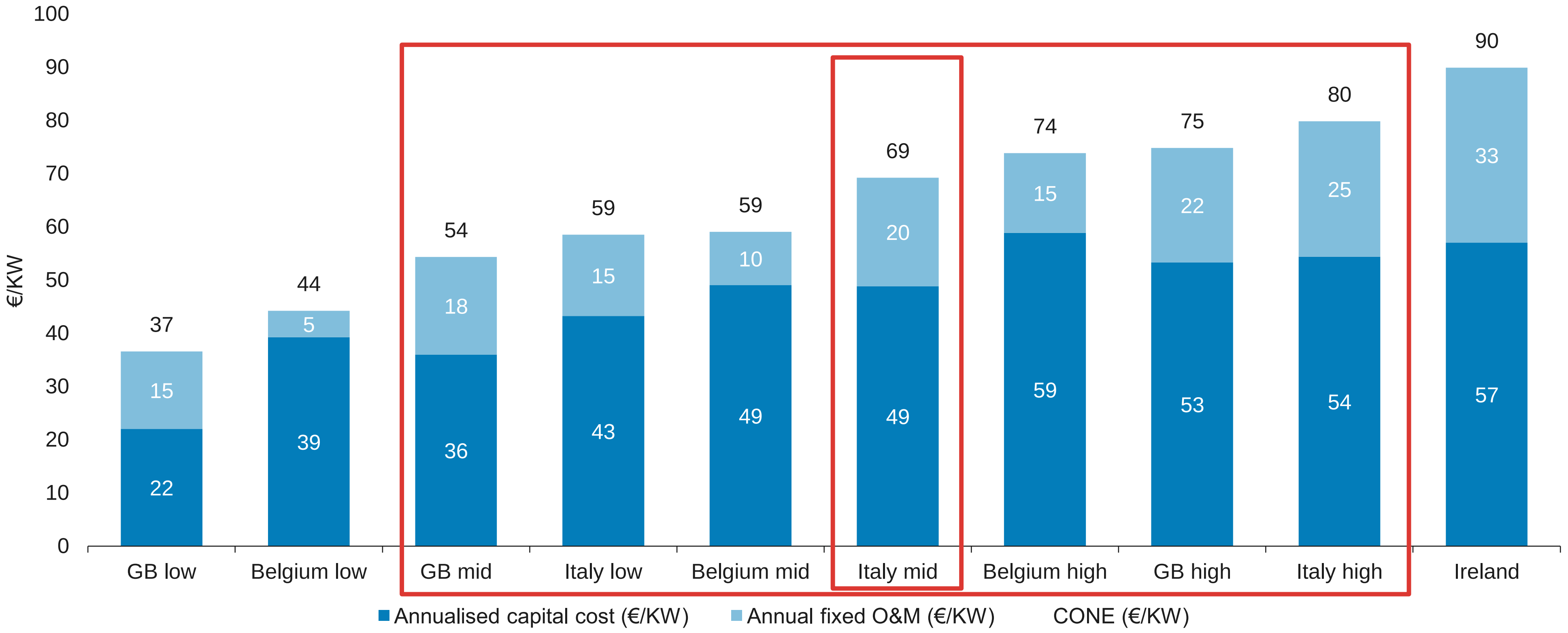
- **CCGT** dual fuel option
- **CHP** plants are mainly biomass-fueled and already subsidized in Estonia.
- **Batteries** (Cf. UK CM capacity additions) are also candidates, but current costs still high and business models (revenue sources) uncertain.
- **DSR** should currently be excluded because of difficulties to identify a standard demand-side resource.
- **Oil shale** fired power plants, such as Auvere plant, recognized environmentally unfit for future.

MOST EU BENCHMARKS FOR CONE BASED ON OCGT LIE BETWEEN 54 €/kW AND 80 €/kW

In the figure below we benchmarked CONE based on OCGT plants in a number of Member States. The mid scenarios typically represent the best estimate while the high and low scenarios provide a sensitivity to the underlying parameters, such as WACC and economic lifetime of a plant.

The results show that majority of the European benchmarks for CONE based on the OCGT technology lie in the range of **54-80 €/kW** with a central value of **69 €/kW.**

Figure 6: European benchmarks for OCGT CONE, € 2019

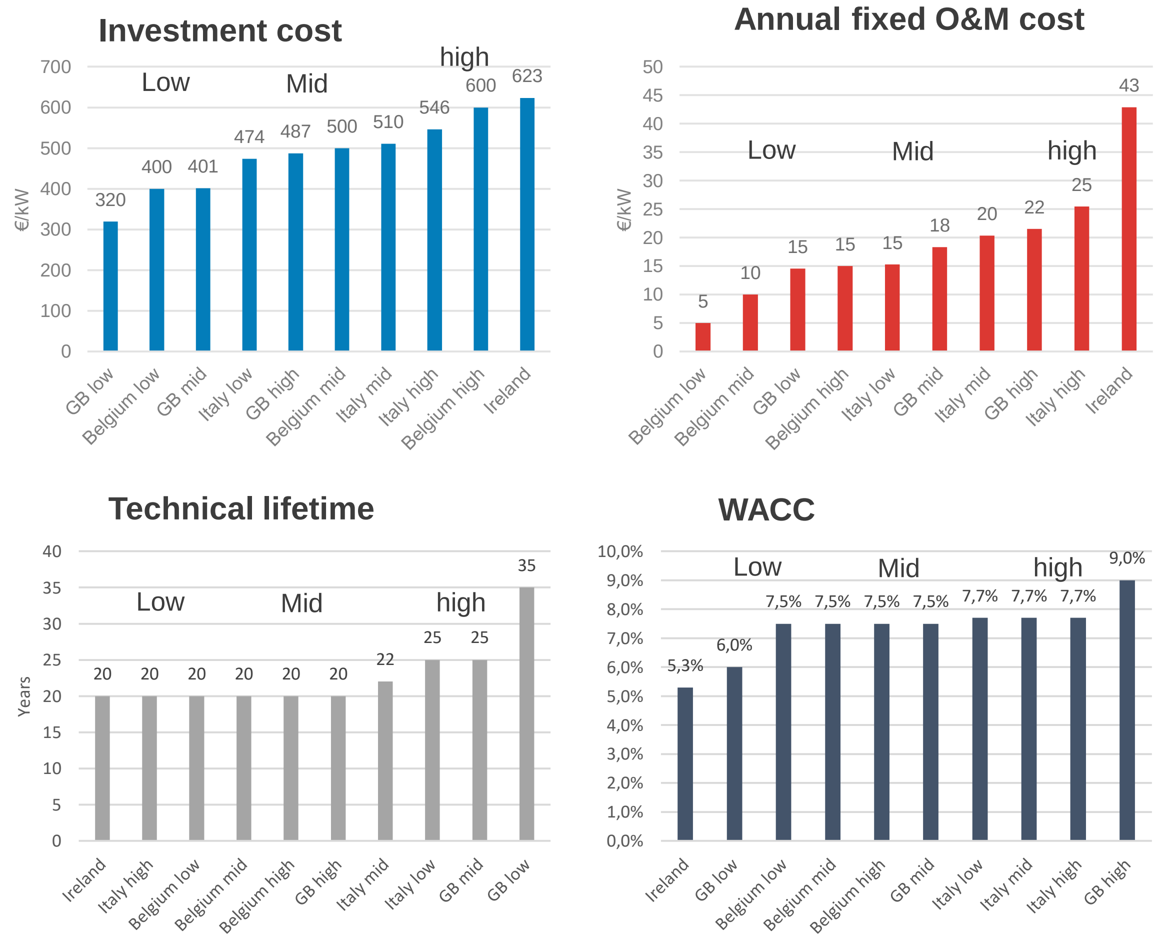


Source: FTI-CL

Notes: The figure shows de-rated CONE in real 2019 euros

RANGE OF THE EUROPEAN CONE PARAMETERS BASED ON OCGT TECHNOLOGY

Figure 7: European CONE parameter ranges



The range of CONE is explained by a range of parameter values.

The **investment costs** range between 400-600 €/kW, **annual fixed O&M** range between 15-22 €/kW, the **technical lifetime** between 18-22 years, and **WACC** from 5-7%.

The parameter ranges are driven by the **local characteristics** in a given Member State.

Some examples of the **drivers** of the parameter differences are the cost of labour, land, insurance, infrastructure connection and distribution charges, and key timings, such as pre-development and construction periods.

Source: FTI-CL
Notes: The figure shows European CONE parameters, euro values in real 2019 euros

RANGE OF THE EUROPEAN CONE BASED ON OCGT TECHNOLOGY

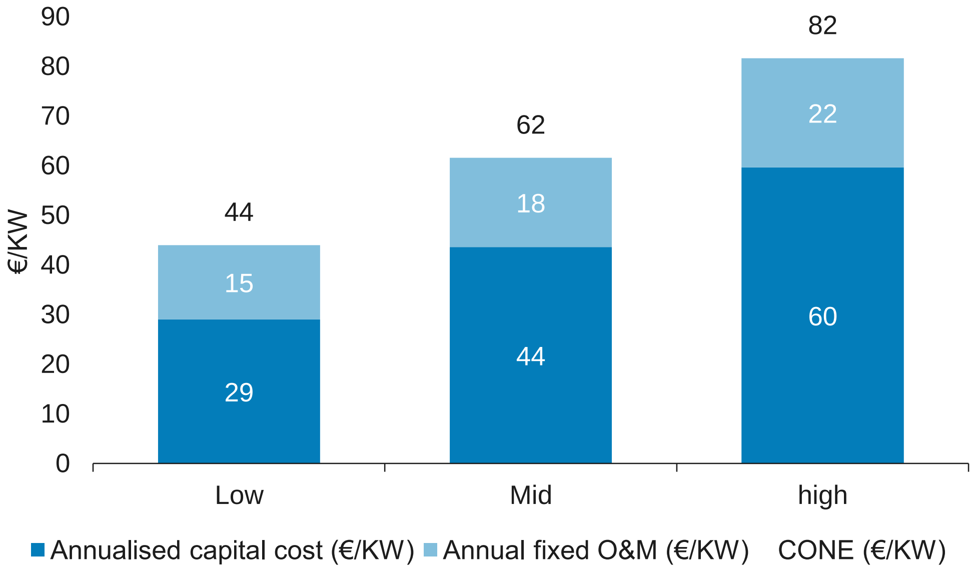
Classifying some of the extreme low and high parameters of the European benchmarking exercise as outliers we end up with a representative range for the underlying parameters. These are presented in Table 3.

Based on the narrowed down parameter ranges we estimate a European CONE benchmark for OCGT technology, presented as a range in Figure 8. The mid scenario is equal to **62 €/kW**, and is within the range of **44 - 82 €/kW**.

Table 4: European CONE parameter ranges

	Low	Mid	High
Investment (€/KW)	400	500	600
WACC	5%	6%	7%
Technical lifetime	22	20	18
Annualised capital cost (€/KW)	29	44	60
Annual fixed O&M (€/KW)	15	18	22
CONE (€/KW)	44	62	82

Figure 8: European CONE benchmark for OCGT



Source: FTI-CL
Notes: The table and figure show the European CONE benchmark for OCGT technology, with monetary units in real 2019 euros.

BOTTOM-UP CAPITAL COST ESTIMATION FOR AN OCGT IN ESTONIA

By the combination of Estonian-specific capital cost investments based on Kiisa plant and the European benchmarks based on bottom-up capital cost estimates for an OCGT, we derive an Estonia-specific OCGT capital cost estimate equal to **520 €/kW.** The detailed parameters and assumptions are summarized in Table 5.

Table 5: Investment costs of OCGT plant in Estonia

OCGT Plant Cost Breakdown	Value	Note	Assumption
EPC contract price (mEUR)	146.72	Benchmark from the UK	Bottom-up engineering studies, e.g. DECC, 2016. Leigh Fisher and Jacobs: Electricity Generation Cost Update
Pre-licensing costs, Technical and design (mEUR)	8.80	Development costs - 6% of EPC	
Regulatory + licensing + public enquiry (mEUR)	1.03	Utilities costs - 0.7% of EPC	
Gas interconnection costs (mEUR)	4.23	Same as Kiisa	Gas grid connection 1.5mEUR, 7km pipeline 390 kEUR/km
Electrical interconnection costs (mEUR)	1.00	5km, 10km and 20km 110kV line in low, mid and high	110kV line 90k€/km and 200kEUR for connection to existing substation
Site procurement costs (mEUR)	0.03	Same as Kiisa	8.5 hectares of land, 3kEUR/hectare
Total (mEUR)	**162**		
Total/EUR/MW	**520,272**		

Source: FTI-CL
Notes: The table shows capital investment costs for OCGT in Estonia..

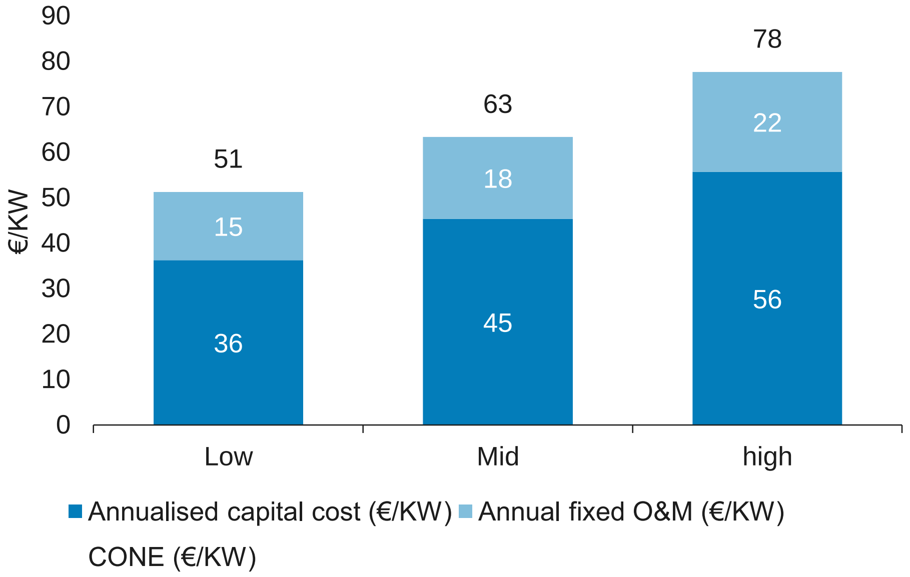
CONE BASED ON ESTONIAN OCGT AND KIISA BENCHMARKS

Using Estonian-specific benchmarks of OCGT and engines technologies results in a CONE range between **51 – 78 €/kW** for the Estonian OCGT, with the central point of **63 €/kW.**

Table 6: Parameter ranges behind the Estonian CONE for OCGT based on Kiisa and OCGT bottom-up capital costs

	Low	Mid	High
Investment (€/KW)	500	520	560
WACC	5%	6%	7%
Technical lifetime	22	20	18
Annualised capital cost (€/KW)	36	45	56
Annual fixed O&M (€/KW)	15	18	22
CONE (€/KW)	51	63	78

Figure 9: Estonian CONE for OCGT based on Kiisa and OCGT bottom-up capital costs



Source: FTI-CL

Notes: The table and figure show de-rated CONE ranges for Estonia with monetary values in real 2019 euros.

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WE ESTIMATE THE LOLE TARGET TO BE 9 H/Y, COMPRISED IN A RANGE OF 6 - 12 H/Y DEPENDING ON CONE AND VOLL

The value of LOLE target corresponds to the ratio between the value of CONE and the value of VOLL.

Based on the estimated ranges of the CONE and the VOLL, we estimate the LOLE target to be **9 hours per year** within an overall range between **6 - 12 hours/year** on average. The range of the LOLE target is driven by the following factors:

- A low Value of Lost Load and a high cost of building new generation suggest that additional capacity investment is justified if the number of hours of load curtailment is expected to be high
- Conversely, a high Value of Lost Load and a low cost of building new generation suggest that additional capacity investment is economically justified if the number of hours of load curtailment is expected to be low

Table 7: Reliability standard for Estonia expressed as LOLE, based on the ranges of the estimated CONE and VOLL

Reliability standard in LOLE (hours/year)		**CONE (€/KW-year)**		
		low	central	high
		51	*63*	*78*
VOLL (€/kWh)	*6.5*	7.8	9.7	12.0
	7.3	7.0	**8.6**	10.7
	8.5	6.0	7.4	9.2

Source: FTI-CL

Notes: LOLE reliability standard for Estonia, expressed in yours/year, based on the ratio of cost of new entry (CONE) and value of lost load (VOLL).

A SUPPLEMENTARY RELIABILITY REQUIREMENT BASED ON EENS COULD BE DEVELOPED

How to set the cap of EENS?

There is no economically justified target for the normalized EENS

However, to comply with the requirement of CEP to have the Reliability Standard based on both LOLE and EENS, one could consider an additional criteria for the Reliability Standard based on the normalized EENS derived from the empirical relationship between LOLE and EENS.

EENS target for a given LOLE value

Assuming the LOLE target is achieved, EENS normalized by demand may vary depending on the market conditions, e.g. demand variations, RES production variations and forced outages of transmission and generation capacity.

A supplementary Reliability Standard can be determined to provide an additional “safety net” ensuring that the achieved EENS normalized by the demand is within the confidence interval of the EENS that could be expected for the LOLE target. The secondary EENS target could be applied as follows:

- When adequacy assessment suggest that capacity level results in an expected LOLE below LOLE target, expected normalised EENS is calculated
- The system is considered adequate if both LOLE target and the supplementary normalised EENS targets are met

Estimation of the relationship between LOLE and EENS

We use two sources of data to assess the relationship between LOLE and EENS and the variation of EENS for a given LOLE:

- **Cross-country variation.** ENTSO-E MAF’s results of average LOLE and EENS normalised by demand for all European bidding zoned presented in the MAF 2018 and MAF 2019 reports in the Base Case scenarios in 2020(1) and 2025 and the Low Carbon scenario for 2025. This data is expected to provide more variation as it would include the variation due to country-specific portfolio composition.
- **Within-country variation.** ENTSO-E MAF’s results of LOLE and EENS normalised b demand for Estonia for 43 climate years 1982 to 2016, obtained for 2025 in Base Case and in Low Carbon scenarios in MAF 2018 and MAF 2019 analyses. This data is expected to provide less variation mostly limited to the impact of the climate variation on the same portfolio.

EENS AND LOLE RELATIONSHIP DERIVED FROM ESTONIAN MAF DATA

Original data

- Initial data show a positive relationship between the LOLE and EENS
- However, the variation is increasing with LOLE, suggesting that a log transformation may be necessary for LOLE and EENS data to have distributions closer to normal

Log transformed data

- After log transformation, the relationship between LOLE and EENS becomes more uniform, with constant variation and normal distributions
- We use a linear regression to derive a relationship between the EENS and LOLE

Figure 10: Original data on LOLE and EENS, Low Carbon scenario

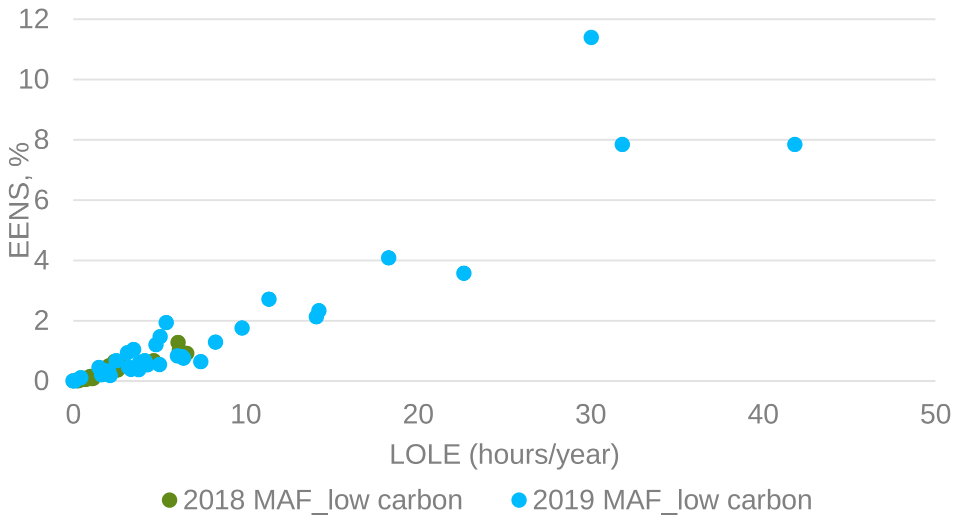
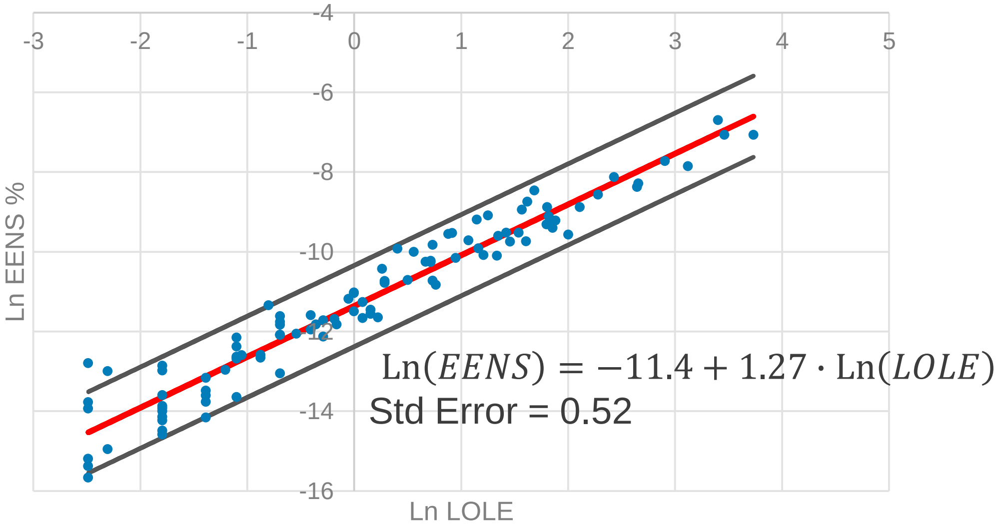


Figure 11: Relationship between LOLE and EENS, MAF 18/19 Estonia



$$\mathrm{Ln}(EENS) = -11.4 + 1.27 \cdot \mathrm{Ln}(LOLE)$$

Std Error = 0.52

EENS AND LOLE RELATIONSHIP DERIVED FROM CROSS-COUNTRY MAF DATA

Original data

- Initial data show a positive relationship between the LOLE and EENS
- Similarly to the Estonian data, the variation is increasing with LOLE, suggesting that a log transformation may be necessary for LOLE and EENS data to have distributions closer to normal

Log transformed data

- After log transformation, the relationship between LOLE and EENS becomes more uniform, with constant variation and normal distributions
- The regression results in a similar relationship between LOLE and EENS but a higher standard error

Figure 12: Original data on LOLE and EENS, MAF 2018

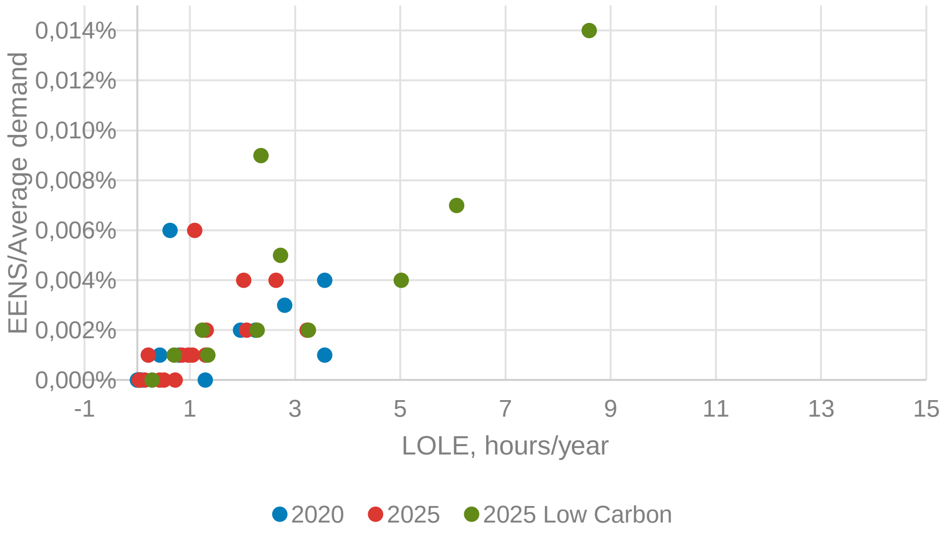
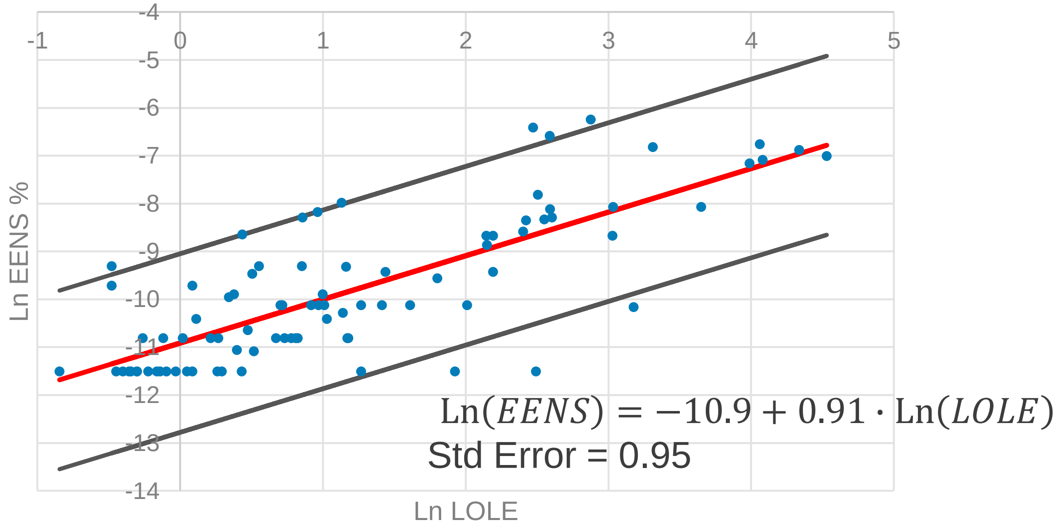


Figure 13: Relationship between LOLE and EENS, MAF 18/19 cross-country



$$\text{Ln}(EENS) = -10.9 + 0.91 \cdot \text{Ln}(LOLE)$$

Std Error = 0.95

EENS SECONDARY RELIABILITY PROPOSED FOR ESTONIA

EENS confidence intervals

- Regressions using Cross-country and Estonian data suggest similar average relationship (normalised EENS of 0.0119% - 0.0135% and 1.15-1.63GWh for 9 hours LOLE)
- However, for the same LOLE value of 9 hours, cross-country data suggests a larger variation of normalised EENS resulting in a higher upper bound of the confidence interval (0.0872%) than the one based on the Estonian data (0.053%)
- Tables 8 and 9 show normalised and absolute EENS for three levels of LOLE: 6 hours, 9 hours and 12 hours.

Secondary reliability standard

- We propose setting the secondary reliability standard using the average of the upper bound of the normalised EENS confidence interval for a given LOLE obtained from two analyses:
  - Such normalised EENS target will be higher than the one obtained from Estonian data ensuring that as long as LOLE target is met, it would not indicate lack of adequacy in most current scenarios of Estonian system (given by climate years and outages)
  - Such normalised EENS target will be lower than the one obtained from Cross-country data, suggesting that this EENS target could become limiting in case structural changes in the Estonian system materially increase EENS variation
- For a LOLE target of 9 hours, such normalised EENS target could be 0.07%, which corresponds to 6GWh

Table 8: EENS CI for 6h/9h/12h LOLE based on Cross-country data

LOLE	Normalised EENS - central, %	Normalised EENS - low, %	Normalised EENS - high, %	EENS - high, GWh
6	0.0093%	0.0014%	**0.0602%**	5.12
9	0.0135%	0.0021%	**0.0872%**	7.41
12	0.0175%	0.0027%	**0.1133%**	9.63

Table 9: EENS CI for 6h/9h/12h LOLE based on Estonian data

LOLE	Normalised EENS - central, %	Normalised EENS - low, %	Normalised EENS - high, %	EENS - high, GWh
6	0.0114%	0.0041%	**0.0316%**	2.69
9	0.0191%	0.0069%	**0.0530%**	4.51
12	0.0276%	0.0100%	**0.0765%**	6.50

Table 10: Proposed secondary Reliability Standard based on EENS

LOLE	Normalised EENS target, %	EENS target, GWh
6	**0.046%**	3.9
9	**0.070%**	6.0
12	**0.095%**	8.1

OTHER SUPPLEMENTARY RELIABILITY STANDARDS, E.G. LOLE95 SHOULD DO NOT HAVE BETTER ECONOMIC PROPERTIES

Supplementary reliability standard used in Belgium

Two complementary reliability standards are used in Belgium:

- **LOLE criterion**: An expected number of hours of capacity insufficiency for a statistically normal year. Adequacy criteria suggests LOLE < 3 hours.
- **LOLE95 criterion**: An expected number of hours of capacity insufficiency for a statistically abnormal year. Adequacy criteria suggests LOLE95 < 20 hours.

Possible justification of a supplementary criterion based on LOLE95

Using a reliability criterion based on LOLE95 in addition to average LOLE may have several possible justifications:

- Account for the skewed distribution of LOLE across statistical years with most LOLE occurring during abnormal years
- Provide a safety net ensuring that LOLE remains under control in abnormal years

Potential issues with LOLE95

One can identify several issues in calculation and implementation of a supplementary criterion based on LOLE95:

- Robust calculation of LOLE95 requires large samples of statistical years, which may not be always available
- There is redundancy between LOLE95 and an average LOLE since average LOLE takes into account all years including abnormal ones.
- LOLE95 could turn out to be more restrictive than main reliability standard based on average LOLE (e.g. LOLE of 20 in 5% abnormal years and 0 in 95% normal years results in average LOLE of 1)
- A safety-net supplementary criterion based on EENS could also capture variation across statistical years

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WELFARE LOSS FROM DEVIATIONS FROM THE RELIABILITY STANDARD

As part of this project, Elering is interested to quantify the **loss of economic welfare** resulting from the deviations from the Reliability Standard. Indeed, as long as Estonian Reliability Standard is derived from the maximization of the social welfare, any deviation from the Reliability Standard should lead to a loss in the social welfare.

The magnitude of this loss could be an important **factor for policy decisions**. For example, a decision to introduce a capacity mechanism to ensure that the achieved LOLE meets the Reliability Standard could be driven by the assessment of the welfare loss resulting in case the Energy Only Market is expected to achieve a LOLE that is significantly higher than the Reliability Standard. Similarly, a political decision to reach a Reliability Standard that is higher than the optimal one could be informed by the assessment of the welfare impact of such a decision.

Optimal volume of installed capacity can be found in the intersection of:

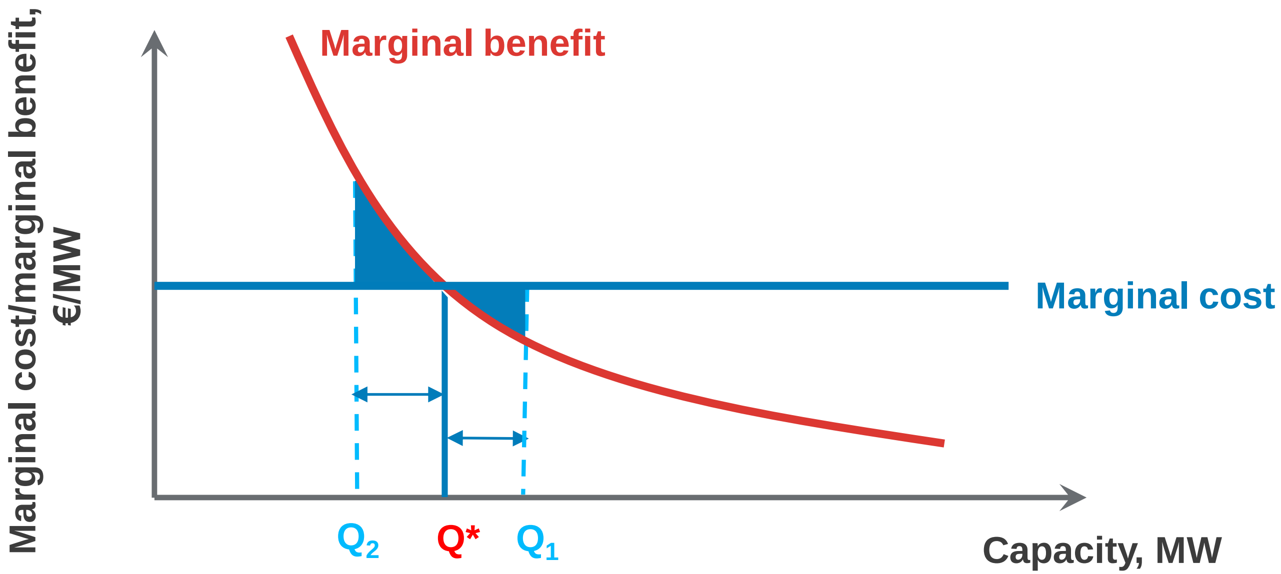
- Marginal cost of **additional capacity (CONE)**, and;
- Marginal benefit for customers – value of reduction in **unserved energy (EENS * VOLL)**

The welfare reduction resulting from deviations from optimal capacity level is given by the area between the two curves

- Too much capacity will cost more than the benefit provided to customers
- Too little capacity will result in higher cost of outages to customers than the cost of capacity

This suggests that welfare impact analysis requires assessing the sensitivity of EENS to capacity around the equilibrium point.

Figure 14: Welfare variation resulting from the Reliability Standard deviation



WE USE A PROBABILISTIC APPROACH BASED ON DATA FROM MAF AND ELERING

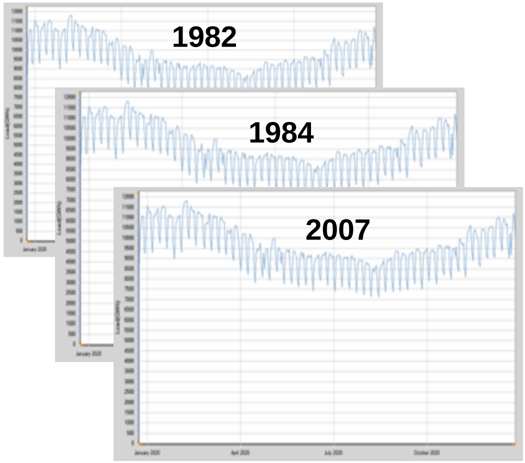
For the quantification of the social welfare resulting from the deviations from the Reliability Standard, we run a probabilistic adequacy analysis consistent with ENTSO-E's Midterm Adequacy Forecast (Figure 15), using:

- Estonian demand and RES generation profiles for three representative climate years identified by ENTSO-E's clustering analysis among 34 samples; and
- The probability of forced outages of the largest interconnectors and power plants in Estonian system.

In particular, for various values of remaining de-rated Estonian capacity, we estimate the expected LOLE based on the variation of RES generation and demand, as well as probability distribution of available capacity of largest interconnectors and power plants in Estonian power system.

Figure 15: Probabilistic adequacy analysis consistent with ENTSO-E's MAF

1) Demand and RES generation



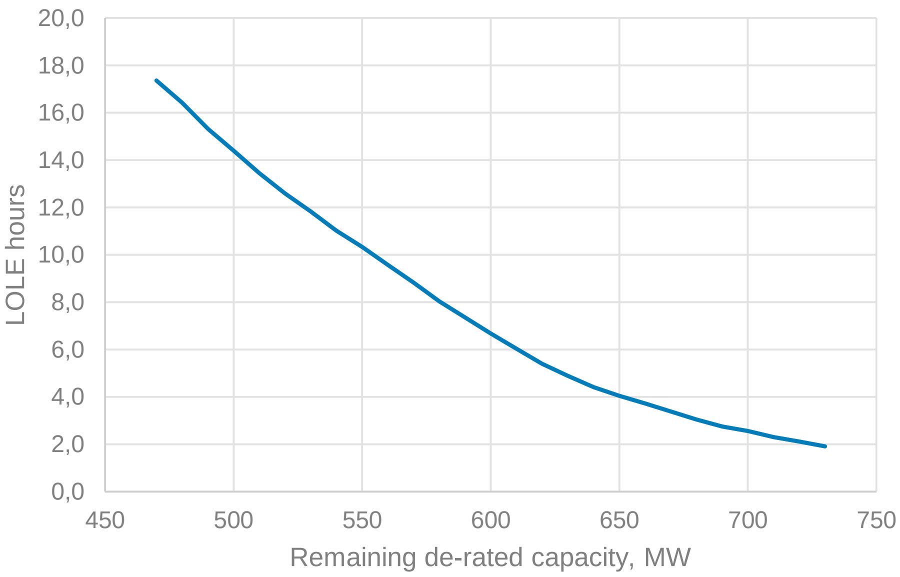
Use of three representative climate years for demand and RES production profiles identified by ENTSO-E's clustering analysis among 34 samples

2) Availability of largest interconnectors and plants

Capacity element	Installed capacity, MW	Outage rates
EstLink 2	650	3%
EstLink 1	350	3%
Auvere TG1	274	5%
Kiisa	250	5%

This creates 16 states of combined availability of four main capacity elements and probabilities assuming no correlation of outages

Figure 16: Probabilistic assessment of expected LOLE as a function of remaining de-rated capacity



Note: Remaining de-rated capacity represents the combined capacity of Estonian power system excluding the four largest interconnectors and plants adjusted for its expected availability during the stress event.

WELFARE SENSITIVITY ANALYSIS BASED ON THE PROBABILISTIC LOLE CURVE

Welfare sensitivity analysis approach

Further, we assess the sensitivity of welfare ∆W resulting from various values of de-rated Estonian capacity as follows (Figure 17):

- Assess the remaining de-rated capacity corresponding to the Reliability Standard LOLE
- Calculate variation of LOLE and EENS resulting from deviation of the remaining de-rated capacity
- Evaluate welfare variation as:

$$\Delta W = \Delta EENS \times VOLL - \Delta Capacity \times CONE$$

  - LOLE above target would imply that the cost of additional energy not served outweighs the savings on the cost of additional capacity
  - LOLE below target wold imply that the cost of additional capacity outweighs the savings on the cost of energy not served

Welfare variation results

The central results are provided by the set of main assumptions on demand profile, RES production profiles, RES installed capacity, and probabilities of outages of main capacity resources in Estonia. These results suggest (Figure 18):

- LOLE is quite sensitive to volumes of capacity, a 120MW additional capacity is sufficient to decrease LOLE from 9 to 3 hours and a deficit of 70MW capacity can increase LOLE from 9 to 15 hours.
- Deviations from the Reliability Standard by 3 hours of LOLE implies a welfare variation within 0.5M€ per year
- Welfare variation reaches 3M€ per year for LOLE of 3 or 17 hour per year

Figure 17: Welfare variation calculation, 2025

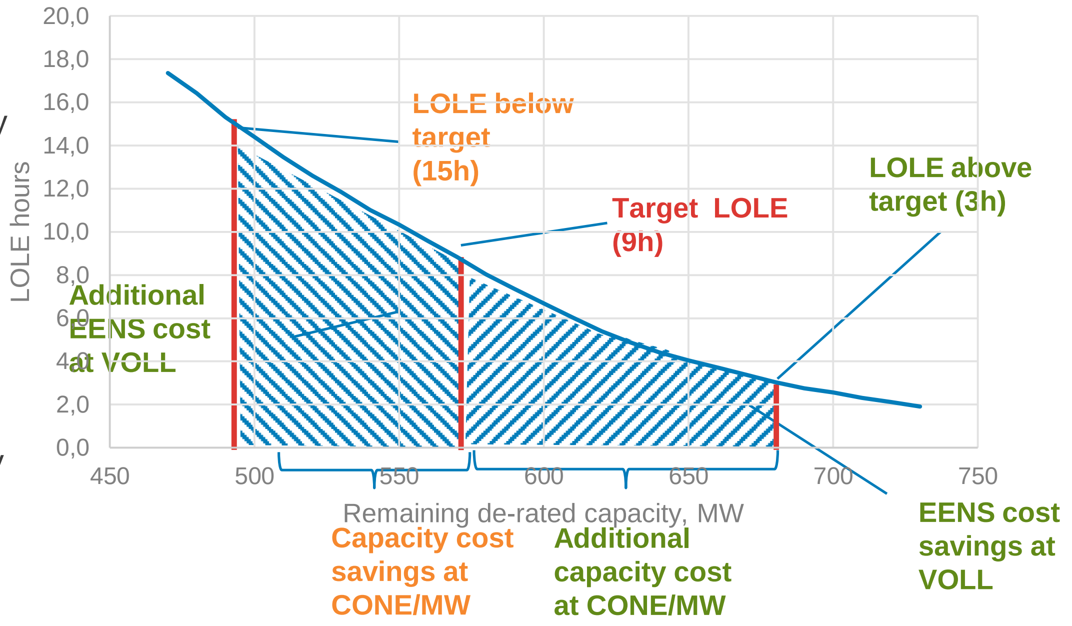
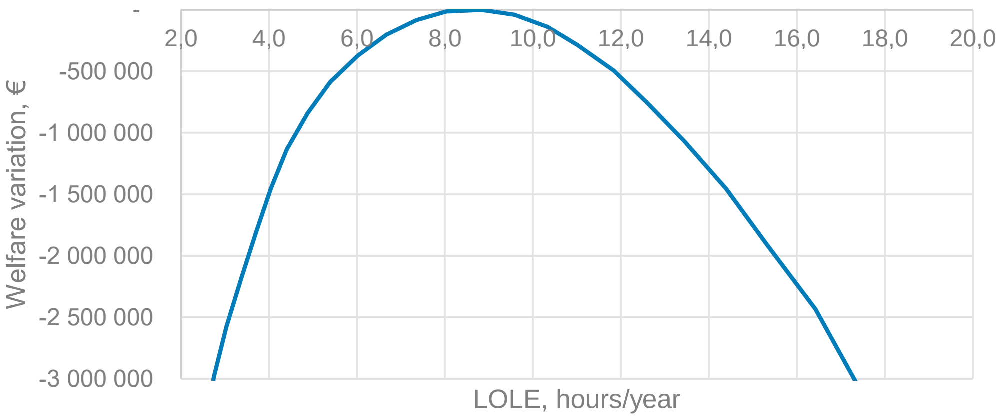


Figure 18: Welfare variation, 2025



ALTHOUGH THE LOLE CURVE IS SENSITIVE TO ASSUMPTIONS, WELFARE VARIATION IS QUITE STABLE

Sensitivities

We analyse the sensitivity of the results to the probability of forced outages of the main capacity elements:

- Increase of the EstLink1 outage rate from 3% to 5% or 7%
- Increase of EstLink2 outage rate from 3% to 5% or 7%

Sensitivity results

The sensitivity analysis suggests that:

- LOLE corresponding to remaining de-rating capacity varies significantly across sensitivities. LOLE sensitivity is highest when remaining capacity is low and LOLE is high
- However, there is relatively little sensitivity of the welfare variation analysis. This is because welfare costs and the benefits are impacted by the sensitivity scenarios in the same direction.

Figure19: LOLE sensitivity, 2025

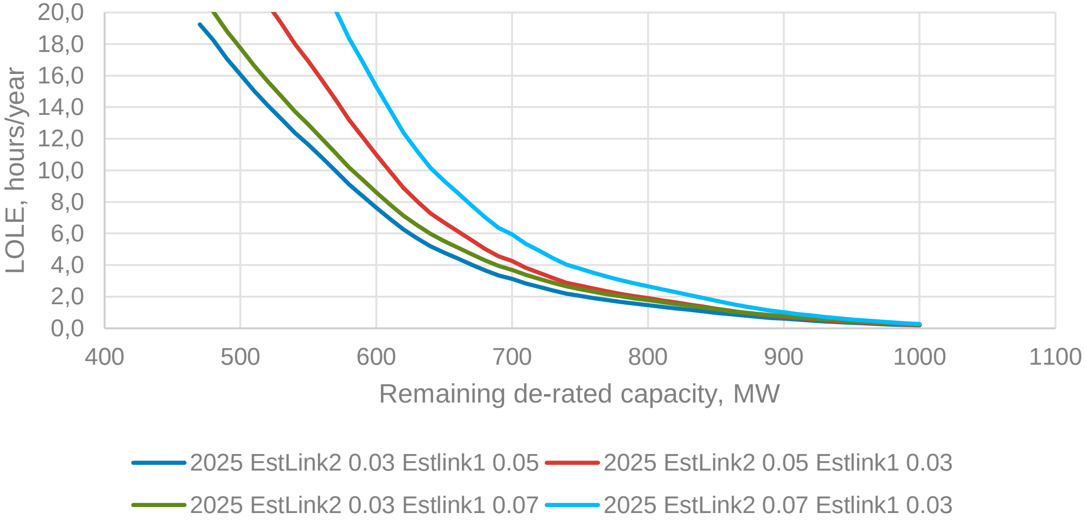
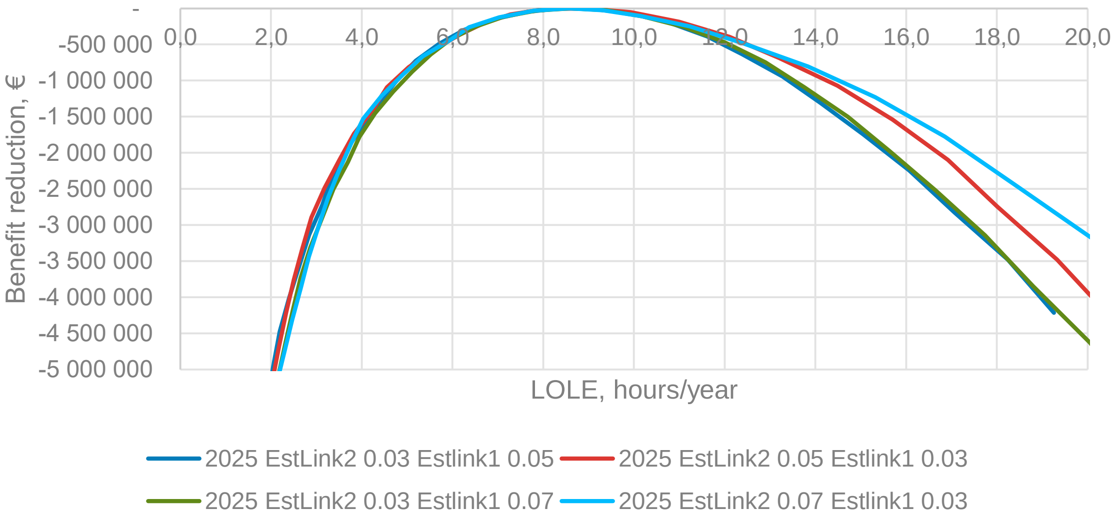


Figure20: Welfare variation sensitivity, 2025



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CONCLUSION

Reliability Standard for Estonia

- The main Reliability Standard for Estonia should be based on LOLE target set according to the economic criteria of welfare maximization at CONE/VOLL
- VOLL for Estonia can be estimated in the range between 6.5€/kWh and 8.5€/kWh with the central point at 7.3€/kWh
- CONE for Estonia an be estimated in the range between 51 and 78 with the central point at 63€/MW
- As a result, LOLE target determining the main Reliability Standard should be in the range between 6 and 12 with the central value of 9 hours.
- A secondary Reliability Standard can be determined based on the statistical relationship between LOLE and EENS in a way to ensure EENS value within the confidence interval for the LOLE target.
- Based on the MAF data for Estonia and across European countries, we derive the EENS target to be in the range between 0.053% and 0.087% with the average of 0.07%.

Welfare variation

- Deviations from the Reliability Standard by 3 hours of LOLE in each direction implies a welfare variation within 0.5M€ per year
- Welfare variation reaches 4M€ per year for LOLE of 3 or 20 hour per year
- This result is mainly driven by the shape of the demand profile and RES production and is robust with respect to the assumptions on outages of main Estonian capacity elements.

Our team

Fabien Roques
Executive Vice President, Compass Lexecon
froques@compasslexecon.com
+33 1 53 05 36 29

Dmitri Perekhodtsev
Vice President, Compass Lexecon
DPerekhodtsev@compasslexecon.com
+33 1 53 05 36 24

Petr Spodniak
Economist, Compass Lexecon
pspodniak@compasslexecon.com
+358 453 59 65 65

REAL PRE-TAX WACC FOR ESTONIA IS IN THE RANGE OF 4.4% TO 6.8%

Element of WACC calculation	Value	Comments
Risk free rate	-0.59%/1.41%	German 10y bond yield, current and 10-year
Equity Beta	1.1/0.7	Bloomberg/Estonian Competition Authority
Equity Risk Premium (ERP)	5.89%/5.00%	Damodaran/Estonian Competition Authority
Country Risk Premium (ERP)	0.69%/0.79%	Damodaran/Estonian Competition Authority
Gearing	42%/50%	Bloomberg/Estonian Competition Authority
Debt premium	1.56%/2.25%	Bloomberg/Damodaran
Tax rate	20%	EE
Inflation in the euro area	1.40%	EC
CoD	2.62%/4.72%	
CoE	5.7%/8.7%	
WACC nominal pre-tax	5.87%/8.27%	
WACC real pre-tax	**4.4%/6.8%**	