Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o.

ENVIRONMENTAL PRODUCT DECLARATION

Type III · ISO 14025 · PCR: IEC 63366:2025 · PSR: IEC TS 62271-320:2025

Single-pole high-voltage outdoor disconnector MARK40-1/420 / MRI-420 with integrated earthing switch

420 kV · 2 500 A / 3 150 A / 4 000 A · Air Insulated Switchgear (AIS)

Program EPDPolska
Operator: MULTICERT Sp. z o.o.

Issue date: May 15, 2026
Validity date: May 15, 2031

1. General information

Parameter	Value
Product name	Single-pole outdoor disconnector with integrated earthing switch. Trade names: MARK40-1/420 and MRI-420. Motor operating mechanism NSO80.
Manufacturer / EPD Holder	Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. (ZWAE)
Production site	ul. Gdańska 60, 84-300 Lębork, Poland
Correspondence address	Lębork, ul. Łąkowa 2, 84-300 Poland
Contact (LCA data)	Dariusz Ligenza, Head of Technical Department, tel. +48 59 86 33 615 EPD Polska (Program Operator: Multicert Sp. z o.o.), Ul. Mydlarska 47, 04-690 Warszawa, Poland www.epd.org.pl, epd@epd.org.pl.
EPD type	Business-to-business (B2B)
EPD Number	EPD-P 02.05.2026
EPD validity	5 years from publication date
Reference year	2025
Declared unit	One single-pole outdoor disconnector (one pole)
Reference Service Life (RSL)	40 years
Verification	Independent, according to ISO 14025
Product ordering codes	V1: MARK40-1/420/4000/50/1/F50/08P25 | V2: .../UN/... or .../UR/... | V3: .../U2/...
Declaration of Conformity — MARK40	DZ.01.04.0001.v.02.2017 (PN-EN 62271-102, PN-EN 62271-1)
Declaration of Conformity — earthing switch G60	DZ.01.04.0002.v.02.2017 (PN-EN 62271-102, PN-EN 62271-1)
Liability	The EPD holder is solely responsible for the information contained in this declaration and for the evidence supporting it. Multicert Sp. z o.o. is not responsible for information provided by the manufacturer, life cycle assessment data, or supporting evidence.
Comparability	Environmental product declarations for electrical products may not be comparable if they do not comply with IEC TS 62271-320:2025 and IEC 63366:2025 or are not based on the same product category rules. More information on comparability is contained in the ISO 14025 standard.

2. Manufacturer information

Company profile

Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. (ZWAE) is a private company with 100% Polish capital, based in Lębork. The enterprise is one of the leading Polish manufacturers of medium and high voltage switching apparatus, continuing a long tradition of electrical equipment production in Lębork.

ZWAE products serve the power transmission and distribution sector. Customers include distribution network operators throughout Poland and numerous industrial and commercial entities domestically and abroad.

The company's scope of production activity includes the design and manufacture of electrical apparatus and the modernization of existing medium and high voltage power infrastructure.

Environmental policy

ZWAE operates an integrated management system certified according to ISO 9001:2015, ISO 14001:2015, and ISO 45001:2018 (Certificate No. NC-0647, issued by Polski Rejestr Statków S.A., accredited by PCA — AC 014, valid until February 12, 2029).

Certification covers both production sites: ul. Gdańska 60, Lębork and Kębłowo Nowowiejskie, ul. Łąkowa 2, Nowa Wieś Lęborska.

The company's environmental, quality, and occupational safety policies are publicly available at: https://zwae.com.pl/pl/firma/polityka-firmy.

ZWAE has adopted a Corporate Social Responsibility (CSR) strategy and publishes CSR goals and a code of ethics as part of its sustainability commitments, available at: https://zwae.com.pl/pl/zrownowazony-rozwoj

Management system certificates

Standard	Certificate No.	Certification body	Valid until
ISO 9001:2015	NC-0647	PRS S.A. (PCA AC 014)	February 12, 2029
ISO 14001:2015	NC-0647	PRS S.A. (PCA AC 014)	February 12, 2029
ISO 45001:2018	NC-0647	PRS S.A. (PCA AC 014)	February 12, 2029

3. Product description

The declared product is one single-pole outdoor disconnector with an integrated earthing switch, sold under the trade names MARK40-1/420 and MRI-420, intended for operation in high-voltage transmission networks with a rated voltage of 420 kV. The device performs disconnecting and earthing operations in a de-energized state and is part of Air Insulated Switchgear (AIS).

The disconnector is equipped with a motor operating mechanism (NSO80) and a mechanical control system enabling reliable switching even in difficult atmospheric conditions, including icing, without the use of an active heating or de-icing system. This functionality is achieved solely through mechanical solutions and drive force.

The product's construction is based on porcelain insulators combined with metal support and current-carrying elements, ensuring long-term mechanical stability, electrical properties, and weather resistance.

The product does not contain insulation gases (SF6 or substitutes), oils, or other operating fluids. No active de-icing system is used.

4. Product composition

The product primarily consists of the following material groups:

- metal elements, including hot-dip galvanized steel, aluminum, and copper current-carrying elements
- porcelain insulators
- springs and mechanical elements
- electrical contact elements
- motor operating mechanism NSO80 and auxiliary electrical elements.

The masses of individual materials contained in different product versions are presented below:

Material	V1		V2		V3	
	[kg]	[%]	[kg]	[%]	[kg]	[%]
Hot-dip galvanized steel	245.6	22.2%	368.4	29.2%	491.4	34.7%
Hot-dip galvanized cast iron	121.7	11.0%	121.7	9.6%	121.7	8.6%
Wrought aluminum	49.7	4.5%	73.4	5.8%	97.1	6.8%
Cast aluminum	48.2	4.4%	51.0	4.0%	53.7	3.8%
Porcelain	615.0	55.6%	615.0	48.7%	615.0	43.4%
Copper	11.3	1.0%	15.1	1.2%	18.8	1.3%
Stainless steel	8.7	0.8%	9.6	0.8%	10.5	0.7%
Brass	3.5	0.3%	3.5	0.3%	3.5	0.2%
Silver	0.2	0.0%	0.2	0.0%	0.2	0.0%
Plastics / polymers	2.1	0.2%	4.1	0.3%	6.1	0.4%
Total	1 106.0	100.0%	1 262.0	100.0%	1 418.0	100.0%

The product does not contain insulation gases, oils, or other operating fluids. No active de-icing system is used; reliable operation under icing conditions is ensured solely by mechanical solutions.

The product does not contain substances of very high concern (SVHC) within the meaning of REACH Regulation (EC) No. 1907/2006, nor substances restricted by the RoHS Directive 2011/65/EU. The product meets the requirements of the IEC 62474 material declaration.

5. Intended use

The product is intended for permanent outdoor installation as a switching and earthing element in high-voltage electrical substations. It enables safe disconnection and earthing of electrical network sections during normal operation, maintenance, and service work. The product is designed for long-term outdoor use and is not intended for frequent switching under load.

6. Reference market and geographical scope

This EPD covers the version of the MARK40-1/420 / MRI-420 disconnector intended for the Norwegian and Scandinavian power transmission and distribution market. The following modules are modeled using datasets and conditions representative of Norway and Scandinavia. Users operating this product in other markets should request a market-specific EPD from the manufacturer.

7. Life Cycle Assessment (LCA) information

7.1 Declared unit and variants

The declared unit is one single-pole outdoor disconnector with an integrated earthing switch (trade names: MARK40-1/420 and MRI-420), fully assembled, ready for installation and delivered to the assembly site. This EPD covers three product variants, differing in the number of integrated earthing switches and motor operating mechanisms:

Variant	Description	Earthing switches	Motor operating mechanisms (NSO80)
V1	Disconnector without earthing switch	0	1 × NSO80
V2	Disconnector with one earthing switch (UN or UR configuration)	1	2 × NSO80
V3	Disconnector with two earthing switches	2	3 × NSO80

7.2 Product ordering codes

The products covered by this EPD are identified by the following ordering codes according to the ZWAE ordering system (MARK40 ordering key, ref. doc. MARK40-VERTICAL-BREAK-DISCONNECTOR):

Variant	Ordering code	Description
V1	MARK40-1/420/2500/50/1/F50/08P25 MRI - 420/2500/50/1/F50/08P25	Single-pole, 420 kV, 2 500 A, without earthing switch, 50 kA/1 s, flat terminal F50, insulator 8 kN, 25 mm/kV
V1	MARK40-1/420/3150/50/1/F50/08P25 MRI-420/3150/50/1/F50/08P25	Analogous, 3 150 A
V1	MARK40-1/420/4000/50/1/F50/08P25 MRI-420/4000/50/1/F50/08P25	Analogous, 4 000 A
V2	MARK40-1/420/2500/UN/50/1/F50/08P25 MRI-420/2500/UN/50/1/F50/08P25	Single-pole, 420 kV, 2 500 A, with earthing switch UN (fixed contact side)
V2	MARK40-1/420/3150/UN/50/1/F50/08P25 MRI-420/3150/UN/50/1/F50/08P25	Analogous, 3 150 A
V2	MARK40-1/420/4000/UN/50/1/F50/08P25 MRI-420/4000/UN/50/1/F50/08P25	Analogous, 4 000 A
V2	MARK40-1/420/2500/UR/50/1/F50/08P25 MRI-420/2500/UR/50/1/F50/08P25	Single-pole, 420 kV, 2 500 A, with earthing switch UR (moving contact side)
V2	MARK40-1/420/3150/UR/50/1/F50/08P25 MRI-420/3150/UR/50/1/F50/08P25	Analogous, 3 150 A
V2	MARK40-1/420/4000/UR/50/1/F50/08P25 MRI-420/4000/UR/50/1/F50/08P25	Analogous, 4 000 A
V3	MARK40-1/420/2500/U2/50/1/F50/08P25 MRI-420/2500/U2/50/1/F50/08P25	Single-pole, 420 kV, 2 500 A, with two earthing switches (UN + UR)
V3	MARK40-1/420/3150/U2/50/1/F50/08P25 MRI-420/3150/U2/50/1/F50/08P25	Analogous, 3 150 A
V3	MARK40-1/420/4000/U2/50/1/F50/08P25 MRI-420/4000/U2/50/1/F50/08P25	Analogous, 4 000 A

Note: The number of poles in the ordering code ('1') indicates a single-pole order. The EPD declared unit corresponds to one pole. Both UN and UR earthing switch configurations are covered by variant V2, as they have identical mass and material composition; only the mounting position differs.

All variants have the same main current circuit with identical resistance. Within each variant, three rated current scenarios (2 500 A, 3 150 A, and 4 000 A) are considered, corresponding to different energy consumption scenarios in module B6. Differences in environmental impacts between variants V1, V2, and V3 result solely from the number of earthing switches and motor operating mechanisms, which affect material composition, transport mass, and end-of-life waste streams.

Reference masses per pole, according to product nameplates: V1 (disconnector + 1 drive, without earthing switch): 1 106 kg; V2 (disconnector + 1 earthing switch + 2 drives): 1 262 kg; V3 (disconnector + 2 earthing switches + 3 drives): 1 418 kg. These values result from the nameplate data of the MRI-420/4000/UR disconnector (disconnector 1 050 kg + earthing switch 100 kg per pole) and the NSO80 drive unit (56 kg per unit).

7.3 Standards and methodological framework

This EPD was developed within the EPD Polska program (operator: Multicert Sp. z o.o.), whose Product Category Rules (PCR) for electrical and electronic products and systems are based on IEC 63366:2025, supplemented by product-specific rules (PSR) IEC TS 62271-320:2025. The EPD meets the requirements of the following standards:

- ISO 14025:2006 — Type III environmental declarations
- ISO 14040:2006 and ISO 14044:2006 — Life cycle assessment principles and requirements
- IEC TS 62271-320:2025 — Product-specific rules (PSR) for high-voltage switchgear and controlgear
- IEC 63366:2025 — Horizontal product category rules (PCR) for electrical and electronic products and systems (EEPS)
- EN 15804+A2 — Used as the LCIA characterization framework and reporting structure; it is not the primary PCR

Life Cycle Impact Assessment (LCIA) results are calculated using EN 15804+A2 characterization factors compliant with EF 3.1. EN 15804+A2 was adopted solely as the LCIA method and reporting framework and does not constitute the primary PCR for this product.

7.4 Functional unit and Reference Service Life

The functional unit is defined as providing the disconnecting function and, where applicable, earthing function by one single-pole outdoor alternating current disconnector (MARK40-1/420 / MRI-420), with a rated voltage of 420 kV, carrying the rated continuous current without interruption for a reference service life of 40 years, in accordance with IEC 62271-102 and IEC TS 62271-320:2025. Operating conditions: outdoor installation, ambient temperature from -40 °C to +40 °C, relative humidity up to 100%, according to IEC 62271-1 (IEC TS 62271-320:2025, clause 6.8.5).

This EPD covers the following product configurations:

Parameter	Value
Rated voltage	420 kV
Rated continuous current (Ir)	2 500 A / 3 150 A / 4 000 A
Earthing switch configuration	None (V1) / one earthing switch (V2) / two earthing switches (V3)
Number of motor operating mechanisms (NSO80)	1 (V1) / 2 (V2) / 3 (V3)
Reference Service Life (RSL)	40 years (IEC TS 62271-320:2025, Table 10)
Mechanical endurance	2 000 operating cycles (Class M1)
Operating conditions	Outdoor, atmospheric, switching without load

Environmental impact results are presented separately for each combination of variant (V1/V2/V3) and rated current scenario (2 500 A / 3 150 A / 4 000 A). Modules A1–A5, B2, C, and D differ between variants due to differences in material composition, transport mass, and end-of-life waste streams. Module B6 differs between rated current scenarios and is identical for all variants V1, V2, and V3 at the same rated current, because the NSO80 drive is a passive mechanical device without energy consumption in standby mode (E_3 = 0).

The Reference Service Life (RSL) is 40 years, according to IEC TS 62271-320:2025, Table 10 (HV/HV disconnector).

The product complies with the following standards, according to the manufacturer's Declarations of Conformity issued in accordance with ISO/IEC 17050-1:2010: IEC 62271-102 (alternating current disconnectors and earthing switches, Declaration No. DZ.01.04.0001.v.02.2017 for MARK40 and DZ.01.04.0002.v.02.2017 for the earthing switch) and IEC 62271-1 (common requirements for HV switchgear and controlgear). These declarations confirm the rated parameters and performance characteristics used to define the functional unit.

The reference flow corresponds to one declared unit (one pole) performing the above function for the reference service life. The declared unit is identical to the functional unit: 1 FU = 1 DU = 1 disconnector pole.

7.5 System boundaries and life cycle stages

The LCA covers the system boundary from cradle to grave. Life cycle stages are modeled according to IEC 63366:2025 and IEC TS 62271-320:2025 and assigned to EN 15804+A2 modules as follows:

EN 15804 + A2 Module	IEC Stage	Scope
A1	RPP	Raw material extraction and processing; production of intermediate products (steel, aluminum, copper, porcelain)
A2–A3	MFG	Transport of components to the production plant; mechanical assembly; electrical integration; factory tests; packaging
A4	DST	Transport of finished product to the installation site
A5	DST	Installation on supporting structures; commissioning; waste from assembly materials
B2	USE	Periodic maintenance (inspection every 5 years over RSL, i.e., 8 inspections per RSL); lubricants; personnel transport; no component replacements required
B6	USE	Operational energy consumption: electrical conduction losses of the main circuit (E_1) and energy of the NSO80 drive anti-condensation heaters (E_2). Switching operation energy (E_4) considered negligible (§7.7.5); drive standby power consumption (E_3) = 0 (§7.7.4).
C1–C4	EOL	Deconstruction; transport to treatment facility; material recovery; recycling; residues disposal
D	BENE	Net benefits from metal recycling outside system boundaries

Modules B1, B3, B4, B5, and B7 are not applicable to this product. Module B2 covers periodic inspections according to manufacturer's manual DTR.01.04.08.PL: every 5 years or after 2000 operating cycles, whichever comes first.

Over the 40-year RSL, this corresponds to 8 inspection events. The MARK40 disconnector does not require component replacement during normal service life.

7.6 Cut-off criteria

Cut-off criteria are applied in accordance with ISO 14044:2006, clause 4.2.3.3 and IEC 63366:2025, clause 4.3.3. The following rules govern the exclusion of elementary flows and processes from system boundaries:

(a) Mass criterion: individual material or process contributions representing less than 1% of the total mass of the declared unit are excluded, provided that their cumulative contribution does not exceed 5% of the total mass.

(b) Energy criterion: individual energy inputs representing less than 1% of the total primary energy are excluded, provided that cumulative exclusions do not exceed 5% of the total primary energy.

(c) Environmental significance criterion: potentially environmentally significant processes are retained regardless of mass or energy thresholds.

This applies particularly to substances with high characterization factors for GWP, ODP, HTP, or ADPE.

Packaging materials are included in the system boundaries (Modules A5, C4). SF_6 and other insulation gases are not present. Cut-off rules have been applied consistently for variants V1, V2, and V3.

7.7 Use stage assumptions (Module B6)

7.7.1 Use stage scenario

The use stage energy scenario is defined according to IEC TS 62271-320:2025, clause 6.9.5.2, Table 10. The following parameters apply to HV/HV disconnectors. In this EPD, three rated current scenarios (2 500 A, 3 150 A, and 4 000 A) are declared, each resulting in a different equivalent operating current and energy consumption in module B6. All other scenario parameters are identical for the three current scenarios and all variants V1, V2, and V3.

Parameter	Value	Source
Reference Service Life (RSL)	40 years	IEC TS 62271-320, Table 10
Load factor (L)	35% of rated current	IEC TS 62271-320, Table 10
Use time factor (H)	100% RSL	IEC TS 62271-320, Table 10
Rated current (Ir)	2500 A / 3 150 A / 4 000 A	Product specification
Equivalent operating current (Ieq = L × Ir)	875 A / 1 102.5 A / 1 400 A	Calculated

7.7.2 Main circuit losses (E_1)

Electrical losses in the main circuit were calculated according to IEC TS 62271-320:2025, clause 6.9.5.4, Formula (16):

$$E_1 = R \times (L/100 \times I_r)^2 \times (H/100) \times 8\,760 \times RSL \times 10^{-3}\ [kWh]$$

The main circuit resistance (R) was determined from production measurements performed on all units manufactured in 2025. The resistance value is the arithmetic mean of measurements taken for this full production series. This value was used as primary input data according to the data hierarchy of IEC TS 62271-320:2025, clause 6.9.5.1 (Priority 1 — primary data from energy consumption tests on a specific device).

Explanations of symbols and values of parameters applied in the calculation are presented in the table below.

Parameter	Ir = 2 500 A	Ir = 3 150 A	Ir = 4 000 A	Data source
R — main circuit resistance (1 pole)	57.78 µΩ			Primary data — 2025 production measurements
L — load factor	35%			IEC TS 62271-320:2025, Table 10
H — use time factor	100%			IEC TS 62271-320:2025, Table 10
RSL	40 years			IEC TS 62271-320:2025, Table 10
I_r — rated continuous current	2 500 A	3 150 A	4 000 A	Product specification
$Ieq = L \times I_r$	875 A	1 102.5 A	1 400 A	Calculated
$P = R \times Ieq^2$	44.25 W	70.27 W	113.25 W	Calculated
E1 over RSL	15 501 kWh	24 609 kWh	39 682 kWh	Calculated according to formula (16)

E_1 is identical for all three product variants because the main circuit is unchanged regardless of the number of integrated earthing switches.

The high environmental impact value in module B6 results from including continuous conduction losses (E_1) throughout the reference service life of 40 years. These losses are proportional to the square of the current and are continuous, leading to their dominant share in the total life cycle result.

7.7.3 Anti-condensation heater (E_2)

Each NSO80 motor operating mechanism is equipped with two anti-condensation heaters of 25 W power each (230 VAC, 2 200 Ω):

- Heater 1 (permanently connected): operates continuously throughout the year — 8 760 h/year.
- Heater 2 (thermostat-controlled, setpoint +7°C): operates only when the ambient temperature drops below 7°C.

The number of thermostat-controlled heater operating hours was determined based on hourly temperature data from five Norwegian meteorological stations (Oslo-Blindern, Bergen-Florida, Trondheim-Voll, Tromsø, Gardermoen), provided by Meteorologisk institutt via the Frost API (frost.met.no), for the period 2001–2025. The median annual number of hours with temperature below 7°C of 4 618 h/year was taken as a representative value. Heater energy per one NSO80 drive over reference service life (RSL = 40 years):

- E_2_continuous = 0.025 kW × 8 760 h/year × 40 years = 8 760 kWh
- E_2_thermostat = 0.025 kW × 4 618 h/year × 40 years = 4 618 kWh
- E_2 (1 × NSO80) = 13 378 kWh

The total heater energy depends on the number of drives in the variant:

Variant	Number of NSO80	E_2 [kWh / RSL]
V1	1 × NSO80	13 378
V2	2 × NSO80	26 756
V3	3 × NSO80	40 134

7.7.4 Drive standby power consumption (E_3)

The NSO80 motor operating mechanism does not consume electrical energy in standby mode. The drive is a passive mechanical unit that does not consume power when not performing a switching operation. Consequently, E_3 = 0 for all product variants (V1, V2, and V3).

7.7.5 Switching operation energy (E_4)

Energy consumed during switching operations (opening and closing the disconnector) was not quantified in module B6.

Switching operations are performed rarely — usually no more than a few times per year throughout the 40-year reference service life — and each operation has a very short duration. As a result, the total energy consumption by the drive over the entire service life is negligible compared to continuous conduction losses (E_1).

This approach is consistent with IEC TS 62271-320:2025 (Table 9), which classifies drive and operation energy as having a negligible use time factor for high-voltage disconnectors.

7.7.6 Total use stage energy and GWP B6

Total electricity consumption during the use stage for Module B6 includes main circuit losses (E_1) and anti-condensation heater energy (E_2). E_3 (drive standby mode) and E_4 (switching operations) are zero or negligible for this product, as documented in clauses 7.7.4–7.7.5. Module B6 results differ between variants V1, V2, and V3 due to the different number of NSO80 drives, and thus different total power of anti-condensation heaters.

The Norwegian electricity mix was adopted as the reference scenario, with a characterization factor of 0.027 kg CO_2e/kWh (electricity market, medium voltage, Cutoff, U — NO; ecoinvent 3.9.1, EN 15804+A2 characterization factors, EF 3.1). This value reflects the low carbon emissivity of the Norwegian power grid, primarily supplied by hydropower plants.

Table 1. E_2 energy components of Module B6 per variant [kWh / RSL]

Component	V1 (1 × NSO80)	V2 (2 × NSO80)	V3 (3 × NSO80)
Continuous heater (8 760 h/year)	8760	17 520	26280
Thermostat heater (4 618 h/year)	4 618	9 236	13 854
Total E_2	**13 378**	**26 756**	**40 134**

Table 2. Total Module B6 energy per variant and current scenario [kWh / RSL]

Parameter	V1 (1 × NSO80)	V2 (2 × NSO80)	V3 (3 × NSO80)
E_1 — 2 500 A	15 501	15 501	15501
E_2	13 378	26 756	40134
E_total — 2 500 A	**28 879**	**42 257**	**55 635**
E_1 — 3 150 A	24 609	24 609	24609
E_2	13 378	26 756	40134
E_total — 3 150 A	**37 987**	**51 365**	**64 743**
E_1 — 4 000 A	39 682	39 682	39682
E_2	13 378	26 756	40134
E_total — 4 000 A	**53 060**	**66 438**	**79 816**

Electricity mix: Norwegian grid, 0.027 kg CO_2e/kWh (GWP-fossil, EF 3.1). E_3 = E_4 = 0 for all variants.

7.7.7 Maintenance assumptions (Module B2)

Periodic maintenance is modeled according to the manufacturer's manual DTR.01.04.08.PL. The required inspection interval is every 5 years or after 2,000 operating cycles, whichever comes first. Over a 40-year RSL, this results in 8 inspection events.

The MARK40 disconnector does not require any component replacements during its normal service life. The manufacturer explicitly confirms that under normal operating conditions within the reference service life, no parts replacement is necessary.

Maintenance activities include: visual inspection of current contacts and earthing switch contacts, mechanical inspection of drives and bearings, verification of bolted connections, external cleaning of insulators, lubrication of moving parts and contacts. Lubricants used per inspection event: MOBILGREASE 28 (electrical contacts) and ŁT4 bearing grease or equivalent (ball joints and pivots).

Module B2 also includes transport of the service crew to the installation site, modeled as 700 km by passenger car (round trip) per inspection event using the Norwegian dataset for passenger cars (transport, passenger car, Cut-off, U — NO; ecoinvent 3.9.1), reflecting the Norwegian market context of this EPD. Over a 40-year RSL, this corresponds to a total of 5,600 km and represents the dominant contribution to the environmental impacts of Module B2.

7.8 End-of-life assumptions

At the end of its service life, the product is dismantled by the network operator's own service crew. End-of-life scenarios are based on average European conditions. The product does not contain hazardous substances or insulation gases or liquids requiring special treatment.

Module C1 (deconstruction) includes electricity consumption during dismantling and personal protective equipment used. No additional transport for service personnel is modeled in C1, as dismantling is performed by the network operator's own maintenance crew already present at the installation site.

Material	End-of-life treatment	Recycling rate	Dataset (ecoinvent 3.9.1, Cut-off)
Steel (hot-dip galvanized)	Material recycling	90%	Steel scrap recycling
Aluminum	Material recycling	95%	Aluminum scrap recycling
Copper / brass	Material recycling	95%	Copper scrap recycling
Porcelain insulators	Landfilling in inert waste landfill	0%	Inert waste disposal
Plastics / elastomers	Landfilling of non-hazardous waste	0%	Plastic waste disposal
Packaging — wooden spacers	Landfilling of non-hazardous waste	0%	Wood waste disposal

Transport to waste treatment facility (Module C2) is modeled as road transport by truck (>16 t, EURO 6). A one-way transport distance of 50 km is assumed, according to the default EN 15804+A2 scenario for European conditions.

Waste processing (Module C3) includes mechanical sorting and separation of material fractions before recycling. Disposal (Module C4) includes landfilling of non-recyclable fractions.

7.9 Benefits beyond system boundaries (Module D)

Potential environmental benefits associated with the recycling of metals (steel, aluminum, copper, and brass) at the end of life are reported beyond the system boundaries in Module D according to EN 15804+A2 and IEC 63366:2025. The net scrap approach is applied according to EN 15804+A2, §6.4.3.3: benefits are credited only for the net amount of secondary material products exceeding the recycled content input at the product stage. Credits are calculated using primary metal production substitution with average European secondary production datasets.

7.10 Data quality and primary data hierarchy

Primary data provided by the manufacturer was applied wherever available, according to the data hierarchy established in IEC TS 62271-320:2025, clause 6.9.5.1:

- Priority 1 (primary data): Main circuit resistance — average value based on production measurements performed on all units manufactured in 2025 (R = 57.78 μΩ per pole).
- Priority 2 (normative scenarios): Load factor, use time factor, and RSL — default values from IEC TS 62271-320:2025, Table 10.
- Priority 3 (secondary data): Background processes (material production, transport, energy) — sourced from ecoinvent 3.9.1 (Cut-off system model).

Temporal representativeness: Background datasets from ecoinvent 3.9.1 have reference years from 2019 to 2022, which is considered appropriate in the absence of significant technological changes in primary metal production during this period. The manufacturer's primary data were collected in 2025 and are fully representative of current production.

Geographical representativeness: Material production datasets reflect European average conditions (RER) or global averages (GLO) when Europe-specific data are unavailable. The energy mix for Module A3 uses the Polish national grid dataset (ecoinvent 3.9.1, Cut-off, PL). Modules A4, A5, B2, C1, and B6 use Norwegian datasets, according to the declared reference market (Section 6).

Technological representativeness: Datasets for primary production of steel, aluminum, and copper reflect current European production technology. Porcelain insulator production was modeled using a generic dataset for ceramics, which is a conservative approach relative to the actual production process of electrical insulators; a product-specific dataset is missing in the ecoinvent 3.9.1 database.

Overall data quality is considered appropriate for the purposes of this EPD and independent verification.

Materials for recycling (MFR) reported in module A2+A3 represent metal scrap and turnings (steel, aluminum, copper) generated during manufacturing operations at the ZWAE plant in Kębłowo. These production waste streams are sent to external metal recycling facilities. MFR values per variant: V1 — 6.86 kg; V2 — 8.62 kg; V3 — 10.4 kg. No Module D benefits are reported from recycling waste at the production stage. Mass allocation was applied for production waste according to IEC 63366:2025, §4.2.5.1.

7.11 Additional environmental information

The following additional information is provided according to IEC TS 62271-320:2025, clause 7.5.6 and IEC 63366:2025, clause 4.6.5.

Hazardous substances: The MARK40 disconnector does not contain hazardous substances above regulatory thresholds. In particular, the product does not contain substances of very high concern (SVHC) within the meaning of REACH Regulation (EC) No. 1907/2006, nor substances restricted by the RoHS Directive 2011/65/EU. The product consists solely of hot-dip galvanized steel, aluminum, copper, and porcelain. No insulation gases (including SF6) or oils are used. The manufacturer confirms compliance with IEC 62474 material declaration requirements.

Recyclability: The disconnector is primarily constructed from recyclable metals (hot-dip galvanized steel, aluminum, copper). The manufacturer states that all major construction materials are subject to material recycling. According to current waste regulations, the manufacturer accepts returns of decommissioned units for proper disposal, in accordance with the manufacturer's manual DTR.01.04.08.PL, Section 6 (Disposal).

Dismantlability: The product is designed with dismantling in mind. All connections are bolted (no welded or permanently glued joints), enabling separation at the component level at the end of life. The dismantling sequence and tightening torque values are documented in manual DTR.01.04.08.PL.

End-of-life information: End-of-life handling instructions, material identification, and recycling tips are provided by the manufacturer in manual DTR.01.04.08.PL, Section 6 (Disposal).

7.12 LCA key assumptions — summary of modeling parameters

The following table summarizes the key parameters used for life cycle assessment modeling of the declared product in accordance with IEC TS 62271-320:2025 and IEC 63366:2025. This summary is intended to support the independent verification of the EPD.

Parameter	Value	Source / Justification
Declared unit	One single-pole outdoor disconnector (with or without earthing switch)	Product specification
Trade names	MARK40-1/420 / MRI-420	Manufacturer
Rated voltage	420 kV	Manufacturer's specification
Rated current (Ir)	2 500 A / 3 150 A / 4 000 A	Manufacturer's specification
Reference Service Life (RSL)	40 years	IEC TS 62271-320:2025, Table 10
Load factor (L)	35% of rated current	IEC TS 62271-320:2025, Table 10
Use time factor (H)	100%	IEC TS 62271-320:2025, Table 10
Equivalent operating current (Ieq)	875 A / 1 102.5 A / 1 400 A	Calculated (Ieq = 0.35 × Ir)

Main circuit resistance (R)	57.78 μΩ per pole	Primary data — arithmetic mean of 2025 production measurements
Average power losses (P = R × Ieq²)	44.25 W / 70.27 W / 113.25 W	Calculated (Joule's law)
Total main circuit losses over RSL (E1)	15 501 / 24 609 / 39 682 kWh per pole (for 2 500 / 3 150 / 4 000 A)	IEC TS 62271-320:2025, Formula (16), §6.9.5.4
Anti-condensation heater energy over RSL (E2)	V1: 13 378 kWh / V2: 26 756 kWh / V3: 40 134 kWh (independent of current scenario)	Manufacturer's data; hours T < 7°C: 4 618 h/year (median, 5 Norwegian stations, 2001–2025, Frost API MET Norway)
Total use stage energy (B6)	V1: 28 879 / 37 987 / 53 060 kWh; V2: 42 257 / 51 365 / 66 438 kWh; V3: 55 635 / 64 743 / 79 816 kWh (for 2 500 / 3 150 / 4 000 A)	Calculated (E1 + E2)
Drive standby power	0 W (passive drive, no standby consumption)	Manufacturer
Total standby consumption over RSL (E3)	0 kWh (E3 = 0 for all variants)	Calculated
Energy mix — Module A3 (production, Poland)	Polish national grid, ecoinvent 3.9.1	Polish national grid (ecoinvent 3.9.1, Cut-off, PL). Default GWP factor replaced in the LCA model with 0.599 kg CO2e/kWh (poLCA-EN-PL-2024, KOBiZE 2024), applied at the characterization stage; documented in the background LCA report.
Emission factor — electricity	0.599 kg CO2e/kWh	KOBiZE 2024 operational data, expanded with supply chain contributions (fuel supply chain, methane emissions from coal mines, infrastructure). This approach reflects the specifics of the Polish power grid, dominated by coal-fired generation.
Energy mix (A5, B2, C1, B6)	Norwegian grid, ecoinvent 3.9.1	Electricity market, medium voltage, Cut-off, U — NO
Emission factor — electricity	0.027 kg CO2e/kWh	Norwegian grid, ecoinvent 3.9.1, EN 15804+A2 EF 3.1
Maintenance interval	Every 5 years or 2,000 operating cycles	Manufacturer's manual DTR.01.04.08.PL
Number of inspections over RSL	8 inspections	Calculated (40 years / 5 years)

Component replacements	Not required during RSL	Manufacturer's manual (DTR.01.04.08.PL §5.3)
Insulation gases	None (no SF6 or substitutes)	Product design — air insulated switchgear (AIS)
Insulation liquids	None	Product design
System boundary	Cradle to grave (A1–A5, B2, B6, C1–C4, D)	IEC 63366:2025 / IEC TS 62271-320:2025
LCA characterization method	EN 15804+A2, EF 3.1	Used as LCIA framework

8. Life cycle impact assessment results

Life cycle impact assessment results are calculated using EN 15804+A2 characterization factors compliant with EF 3.1. The results are presented per declared unit (one pole) for each variant (V1, V2, V3) and three rated current scenarios (2,500 A / 3,150 A / 4,000 A) in module B6. Modules that are not applicable or insignificant for this product are omitted.

Table 1. Core environmental impact indicators — Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)														
GWP-total	kg CO2 eq.	3.28E+03	1.86E+02	1.85E+02	1.94E+00	3.00E+02	8.15E+02	1.07E+03	1.50E+03	1.45E+00	1.88E+01	1.06E+01	2.22E+00	-1.52E+03
GWP-fossil	kg CO2 eq.	3.26E+03	1.86E+02	1.84E+02	2.59E+00	3.05E+02	7.79E+02	1.03E+03	1.43E+03	2.11E+00	1.87E+01	1.07E+01	2.21E+00	-1.52E+03
GWP-bio	kg CO2 eq.	1.36E+01	8.60E-03	1.44E-01	-8.22E-01	-6.62E+00	2.95E+01	3.88E+01	5.42E+01	-8.28E-01	1.45E-02	-1.63E-01	2.78E-03	2.60E+00
GWP-luluc	kg CO2 eq.	5.27E+00	1.34E-01	9.09E-02	1.71E-01	1.49E+00	5.98E+00	7.86E+00	1.10E+01	1.71E-01	8.61E-03	1.51E-02	6.00E-04	-2.98E+00
GWP-IOBC	kg CO2 eq.	3.29E+03	1.86E+02	1.85E+02	2.82E+00	3.07E+02	8.00E+02	1.05E+03	1.47E+03	2.34E+00	1.87E+01	1.08E+01	2.21E+00	-1.53E+03
ODP	kg CFC-11 eq.	6.01E-05	3.06E-06	4.16E-06	2.30E-05	1.90E-04	2.24E-05	2.95E-05	4.12E-05	2.61E-08	4.09E-07	1.76E-07	3.57E-08	-2.09E-05
AP	mol H+ eq.	2.40E+01	4.67E+00	5.47E-01	3.42E-02	1.27E+00	3.11E+00	4.09E+00	5.72E+00	3.14E-02	3.87E-02	1.12E-01	1.90E-02	-1.18E+01
EP-fw	kg P eq.	2.01E+00	1.11E-02	1.35E-02	1.82E-03	5.19E-02	3.30E-01	4.34E-01	6.07E-01	1.72E-03	1.30E-03	5.92E-03	1.80E-04	-2.04E+00
EP-mar	kg N eq.	3.66E+00	1.17E+00	1.47E-01	4.62E-02	6.23E-01	6.38E-01	8.39E-01	1.17E+00	4.55E-02	9.62E-03	2.66E-02	8.17E-03	-2.28E+00
EP-ter	mol N eq.	4.05E+01	1.29E+01	1.53E+00	1.30E-01	3.71E+00	6.88E+00	9.05E+00	1.26E+01	1.24E-01	9.74E-02	2.97E-01	8.86E-02	-2.67E+01
POCP	kg NMVOC eq.	1.37E+01	3.53E+00	8.05E-01	1.34E-02	1.30E+00	2.06E+00	2.71E+00	3.79E+00	9.45E-03	6.05E-02	8.94E-02	2.71E-02	-8.02E+00
ADPE	kg Sb eq.	2.68E-01	1.68E-04	3.50E-04	8.09E-06	2.33E-03	5.63E-03	7.40E-03	1.03E-02	6.09E-06	4.41E-05	2.10E-04	7.45E-07	-2.15E-01
ADPF	MJ	4.00E+04	2.34E+03	2.81E+03	3.33E+01	4.02E+03	1.65E+04	2.17E+04	3.02E+04	2.35E+01	2.66E+02	1.49E+02	3.16E+01	-1.55E+04
WDP	m3 world eq.	9.61E+02	8.26E+00	1.43E+01	6.11E+01	4.74E+02	3.32E+04	4.37E+04	6.11E+04	6.09E+01	1.28E+00	2.42E+00	1.16E-01	-3.94E+02

GWP-total — Global warming potential, total; GWP-fossil — GWP, fossil fuels; GWP-bio — GWP, biogenic carbon; GWP-luluc — GWP, land use and land use change; GWP-IOBC — GWP excluding biogenic carbon (optional); ODP — Depletion potential of the stratospheric ozone layer; AP — Acidification potential; EP-fw — Eutrophication potential, freshwater; EP-mar — Eutrophication potential, marine; EP-ter — Eutrophication potential, terrestrial; POCP — Formation potential of tropospheric ozone; ADPE — Abiotic depletion potential for non-fossil resources (discl. 2); ADPF — Abiotic depletion potential for fossil resources (discl. 2); WDP — Water (user) deprivation potential (discl. 2).

Disclaimer 2 (ADPE, ADPF, WDP, ETP-fw, HTP-c, HTP-nc, SQP): The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

Table 1. Core environmental impact indicators — Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)														
GWP-total	kg CO2 eq.	4.06E+03	1.90E+02	2.07E+02	1.94E+00	3.00E+02	1.19E+03	1.45E+03	1.87E+03	1.45E+00	2.25E+01	1.38E+01	2.38E+00	-2.04E+03
GWP-fossil	kg CO2 eq.	4.04E+03	1.90E+02	2.07E+02	2.59E+00	3.05E+02	1.14E+03	1.39E+03	1.79E+03	2.11E+00	2.24E+01	1.40E+01	2.37E+00	-2.03E+03
GWP-bio	kg CO2 eq.	1.10E+01	1.53E-02	1.62E-01	-8.22E-01	-6.62E+00	4.31E+01	5.24E+01	6.78E+01	-8.28E-01	1.74E-02	-2.14E-01	3.57E-03	3.47E+00
GWP-luluc	kg CO2 eq.	6.82E+00	1.35E-01	1.02E-01	1.71E-01	1.49E+00	8.75E+00	1.06E+01	1.38E+01	1.71E-01	1.03E-02	1.98E-02	7.50E-04	-4.00E+00
GWP-IOBC	kg CO2 eq.	4.07E+03	1.90E+02	2.07E+02	2.82E+00	3.07E+02	1.17E+03	1.42E+03	1.84E+03	2.34E+00	2.25E+01	1.41E+01	2.38E+00	-2.04E+03
ODP	kg CFC-11 eq.	7.61E-05	3.15E-06	4.67E-06	2.30E-05	1.90E-04	3.28E-05	3.98E-05	5.15E-05	2.61E-08	4.90E-07	2.30E-07	3.88E-08	-2.76E-05
AP	mol H+ eq.	3.07E+01	4.68E+00	6.14E-01	3.42E-02	1.27E+00	4.56E+00	5.54E+00	7.16E+00	3.14E-02	4.64E-02	1.47E-01	2.01E-02	-1.53E+01
EP-fw	kg P eq.	2.60E+00	1.23E-02	1.51E-02	1.82E-03	5.19E-02	4.83E-01	5.87E-01	7.60E-01	1.72E-03	1.55E-03	7.78E-03	2.10E-04	-2.68E+00
EP-mar	kg N eq.	4.62E+00	1.17E+00	1.65E-01	4.62E-02	6.23E-01	9.34E-01	1.13E+00	1.47E+00	4.55E-02	1.15E-02	3.49E-02	8.53E-03	-2.97E+00
EP-ter	mol N eq.	5.10E+01	1.29E+01	1.71E+00	1.30E-01	3.71E+00	1.01E+01	1.22E+01	1.58E+01	1.24E-01	1.17E-01	3.90E-01	9.24E-02	-3.47E+01
POCP	kg NMVOC eq.	1.72E+01	3.54E+00	9.05E-01	1.34E-02	1.30E+00	3.02E+00	3.67E+00	4.74E+00	9.45E-03	7.25E-02	1.17E-01	2.84E-02	-1.05E+01
ADPE	kg Sb eq.	3.30E-01	1.80E-04	4.00E-04	8.09E-06	2.33E-03	8.23E-03	1.00E-02	1.30E-02	6.09E-06	5.29E-05	2.70E-04	8.82E-07	-2.24E-01
ADPF	MJ	4.85E+04	2.39E+03	3.16E+03	3.33E+01	4.02E+03	2.41E+04	2.93E+04	3.79E+04	2.35E+01	3.19E+02	1.95E+02	3.48E+01	-2.06E+04
WDP	m3 world eq.	1.24E+03	8.68E+00	1.61E+01	6.11E+01	4.74E+02	4.86E+04	5.91E+04	7.65E+04	6.09E+01	1.54E+00	3.17E+00	1.38E-01	-5.33E+02

GWP-total — Global warming potential, total; GWP-fossil — GWP, fossil fuels; GWP-bio — GWP, biogenic carbon; GWP-luluc — GWP, land use and land use change; GWP-IOBC — GWP excluding biogenic carbon (optional); ODP — Depletion potential of the stratospheric ozone layer; AP — Acidification potential; EP-fw — Eutrophication potential, freshwater; EP-mar — Eutrophication potential, marine; EP-ter — Eutrophication potential, terrestrial; POCP — Formation potential of tropospheric ozone; ADPE — Abiotic depletion potential for non-fossil resources (discl. 2); ADPF — Abiotic depletion potential for fossil resources (discl. 2); WDP — Water (user) deprivation potential (discl. 2).

Disclaimer 2 (ADPE, ADPF, WDP, ETP-fw, HTP-c, HTP-nc, SQP): The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

Table 1. Core environmental impact indicators – Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)														
GWP-total	kg CO2 eq.	4.83E+03	1.94E+02	2.30E+02	1.94E+00	3.00E+02	1.57E+03	1.83E+03	2.25E+03	1.45E+00	2.62E+01	1.71E+01	2.54E+00	-2.55E+03
GWP-fossil	kg CO2 eq.	4.82E+03	1.94E+02	2.30E+02	2.59E+00	3.05E+02	1.50E+03	1.75E+03	2.15E+03	2.11E+00	2.62E+01	1.74E+01	2.53E+00	-2.55E+03
GWP-bio	kg CO2 eq.	8.38E+00	2.20E-02	1.79E-01	-8.22E-01	-6.62E+00	5.68E+01	6.61E+01	8.15E+01	-8.28E-01	2.03E-02	-2.66E-01	4.35E-03	4.34E+00
GWP-luluc	kg CO2 eq.	8.37E+00	1.37E-01	1.13E-01	1.71E-01	1.49E+00	1.15E+01	1.34E+01	1.65E+01	1.71E-01	1.20E-02	2.45E-02	9.10E-04	-5.03E+00
GWP-IOBC	kg CO2 eq.	4.85E+03	1.94E+02	2.30E+02	2.82E+00	3.07E+02	1.54E+03	1.79E+03	2.21E+03	2.34E+00	2.62E+01	1.74E+01	2.54E+00	-2.56E+03
ODP	kg CFC-11 eq.	9.21E-05	3.24E-06	5.19E-06	2.30E-05	1.90E-04	4.32E-05	5.02E-05	6.19E-05	2.61E-08	5.71E-07	2.85E-07	4.20E-08	-3.43E-05
AP	mol H+ eq.	3.75E+01	4.70E+00	6.82E-01	3.42E-02	1.27E+00	6.00E+00	6.98E+00	8.60E+00	3.14E-02	5.40E-02	1.82E-01	2.12E-02	-1.87E+01
EP-fw	kg P eq.	3.19E+00	1.35E-02	1.68E-02	1.82E-03	5.19E-02	6.36E-01	7.40E-01	9.13E-01	1.72E-03	1.81E-03	9.63E-03	2.40E-04	-3.31E+00
EP-mar	kg N eq.	5.59E+00	1.17E+00	1.83E-01	4.62E-02	6.23E-01	1.23E+00	1.43E+00	1.76E+00	4.55E-02	1.34E-02	4.32E-02	8.90E-03	-3.66E+00
EP-ter	mol N eq.	6.15E+01	1.29E+01	1.90E+00	1.30E-01	3.71E+00	1.33E+01	1.54E+01	1.90E+01	1.24E-01	1.36E-01	4.83E-01	9.63E-02	-4.27E+01
POCP	kg NMVOC eq.	2.07E+01	3.56E+00	1.00E+00	1.34E-02	1.30E+00	3.97E+00	4.62E+00	5.70E+00	9.45E-03	8.45E-02	1.45E-01	2.97E-02	-1.29E+01
ADPE	kg Sb eq.	3.93E-01	1.82E-04	4.40E-04	8.09E-06	2.33E-03	1.08E-02	1.26E-02	1.56E-02	6.09E-06	6.16E-05	3.30E-04	1.02E-06	-2.32E-01
ADPF	MJ	5.70E+04	2.44E+03	3.50E+03	3.33E+01	4.02E+03	3.17E+04	3.69E+04	4.55E+04	2.35E+01	3.72E+02	2.42E+02	3.79E+01	-2.56E+04
WDP	m3 world eq.	1.52E+03	9.10E+00	1.79E+01	6.11E+01	4.74E+02	6.40E+04	7.45E+04	9.19E+04	6.09E+01	1.79E+00	3.92E+00	1.59E-01	-6.72E+02

GWP-total — Global warming potential, total; GWP-fossil — GWP, fossil fuels; GWP-bio — GWP, biogenic carbon; GWP-luluc — GWP, land use and land use change; GWP-IOBC — GWP excluding biogenic carbon (optional); ODP — Depletion potential of the stratospheric ozone layer; AP — Acidification potential; EP-fw — Eutrophication potential, freshwater; EP-mar — Eutrophication potential, marine; EP-ter — Eutrophication potential, terrestrial; POCP — Formation potential of tropospheric ozone; ADPE — Abiotic depletion potential for non-fossil resources (discl. 2); ADPF — Abiotic depletion potential for fossil resources (discl. 2); WDP — Water (user) deprivation potential (discl. 2).

Disclaimer 2 (ADPE, ADPF, WDP, ETP-fw, HTP-c, HTP-nc, SQP): The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

GWP-total is the sum of GWP-fossil, GWP-biogenic, and GWP-luluc, in accordance with EN 15804+A2 / EF 3.1. Slight numerical differences (±0.5%) may result from rounding. Additivity has been verified in the underlying LCA model

Table 2. Resource use indicators

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)														
PM	disease inc.	1.49E-03	6.32E-06	1.37E-05	2.54E-07	1.63E-05	3.36E-05	4.42E-05	6.17E-05	2.14E-07	9.42E-07	1.50E-06	4.89E-07	-1.30E-04
IRP	kBq U235 eq.	1.87E+02	1.57E+00	3.49E+00	2.67E-01	7.14E+00	7.53E+02	9.91E+02	1.38E+03	2.37E-01	4.27E-01	1.21E+00	2.99E-02	-4.57E+01
ETP-fw	CTUe	3.70E+04	1.16E+03	1.34E+03	1.11E+02	3.22E+03	6.13E+03	8.07E+03	1.13E+04	8.98E+01	1.33E+02	1.08E+02	5.56E+01	-2.69E+04
HTP-c	CTUh	1.02E-05	8.00E-08	8.04E-08	1.15E-09	2.41E-07	9.52E-07	1.25E-06	1.75E-06	8.33E-10	7.63E-09	1.44E-08	8.31E-10	-4.37E-06
HTP-nc	CTUh	1.70E-04	7.74E-07	1.70E-06	4.17E-08	3.21E-06	1.54E-05	2.03E-05	2.84E-05	3.61E-08	1.53E-07	5.46E-07	7.32E-09	-3.69E-05
SQP	dimensionless	1.54E+04	4.51E+02	2.79E+03	9.21E+01	2.08E+03	5.86E+03	7.71E+03	1.08E+04	8.98E+01	1.36E+02	3.01E+02	4.20E+01	-5.70E+03
Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)														
PM	disease inc.	1,55E-03	6,50E-06	1,54E-05	2,54E-07	1,63E-05	4,92E-05	5,98E-05	7,73E-05	2,14E-07	1,13E-06	1,97E-06	5,10E-07	-1,70E-04
IRP	kBq U235 eq.	2,29E+02	1,65E+00	3,92E+00	2,67E-01	7,14E+00	1,10E+03	1,34E+03	1,73E+03	2,37E-01	5,12E-01	1,58E+00	3,73E-02	-5,93E+01
ETP-fw	CTUe	4,82E+04	1,18E+03	1,50E+03	1,11E+02	3,22E+03	8,97E+03	1,09E+04	1,41E+04	8,98E+01	1,60E+02	1,41E+02	6,93E+01	-3,39E+04
HTP-c	CTUh	1,30E-05	8,17E-08	9,04E-08	1,15E-09	2,41E-07	1,39E-06	1,69E-06	2,19E-06	8,33E-10	9,15E-09	1,88E-08	9,23E-10	-5,94E-06
HTP-nc	CTUh	2,10E-04	8,09E-07	1,91E-06	4,17E-08	3,21E-06	2,26E-05	2,75E-05	3,55E-05	3,61E-08	1,83E-07	7,18E-07	8,48E-09	-4,51E-05
SQP	dimensionless	1,88E+04	4,77E+02	3,14E+03	9,21E+01	2,08E+03	8,57E+03	1,04E+04	1,35E+04	8,98E+01	1,63E+02	3,93E+02	4,70E+01	-7,26E+03
Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)														
PM	disease inc.	1.61E-03	6.68E-06	1.71E-05	2.54E-07	1.63E-05	6.47E-05	7.53E-05	9.29E-05	2.14E-07	1.32E-06	2.44E-06	5.30E-07	-2.20E-04
IRP	kBq U235 eq.	2.71E+02	1.74E+00	4.35E+00	2.67E-01	7.14E+00	1.45E+03	1.69E+03	2.08E+03	2.37E-01	5.97E-01	1.96E+00	4.47E-02	-7.28E+01
ETP-fw	CTUe	5.93E+04	1.21E+03	1.67E+03	1.11E+02	3.22E+03	1.18E+04	1.37E+04	1.69E+04	8.98E+01	1.86E+02	1.75E+02	8.31E+01	-4.09E+04
HTP-c	CTUh	1.59E-05	8.34E-08	1.00E-07	1.15E-09	2.41E-07	1.83E-06	2.13E-06	2.63E-06	8.33E-10	1.07E-08	2.33E-08	1.02E-09	-7.50E-06
HTP-nc	CTUh	2.60E-04	8.45E-07	2.12E-06	4.17E-08	3.21E-06	2.98E-05	3.46E-05	4.27E-05	3.61E-08	2.14E-07	8.90E-07	9.64E-09	-5.33E-05
SQP	dimensionless	2.23E+04	5.02E+02	3.48E+03	9.21E+01	2.08E+03	1.13E+04	1.31E+04	1.62E+04	8.98E+01	1.90E+02	4.85E+02	5.20E+01	-8.82E+03

PM — Particulate matter emissions, potential incidence of disease; IRP — Ionizing radiation, human health, potential exposure (discl. 1); ETP-fw — Ecotoxicity, freshwater (discl. 2); HTP-c — Human toxicity, cancer effects (discl. 2); HTP-nc — Human toxicity, non-cancer effects (discl. 2); SQP — Soil quality potential (discl. 2).

Disclaimer 1 (IRP): This indicator relates mainly to the eventual impact of low-dose ionizing radiation on human health in the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure, nor radioactive waste disposal in underground facilities.

Disclaimer 2 (ADPE, ADPF, WDP, ETP-fw, HTP-c, HTP-nc, SQP): The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

Table 3. Resource use indicators

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)														
PERE	MJ	3.77E+03	2.32E+01	4.05E+01	3.13E+01	1.93E+02	1.10E+05	1.45E+05	2.03E+05	3.07E+01	4.61E+00	2.15E+01	4.53E-01	-1.76E+03
PERM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT	MJ	3.77E+03	2.32E+01	4.05E+01	3.13E+01	1.93E+02	1.10E+05	1.45E+05	2.03E+05	3.07E+01	4.61E+00	2.15E+01	4.53E-01	-1.76E+03
PENRE	MJ	4.00E+04	2.34E+03	2.81E+03	3.33E+01	4.02E+03	1.65E+04	2.17E+04	3.02E+04	2.35E+01	2.66E+02	1.49E+02	3.17E+01	-1.55E+04
PENRM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ	4.00E+04	2.34E+03	2.81E+03	3.33E+01	4.02E+03	1.65E+04	2.17E+04	3.02E+04	2.35E+01	2.66E+02	1.49E+02	3.17E+01	-1.55E+04
SM	kg	1.48E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m3	3.23E+01	3.40E-01	4.90E-01	1.69E+00	1.35E+01	7.80E+02	1.03E+03	1.43E+03	1.68E+00	4.35E-02	8.80E-02	1.09E-02	-1.12E+01
Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)														
PERE	MJ	4.80E+03	2.48E+01	4.55E+01	3.13E+01	1.93E+02	1.61E+05	1.96E+05	2.54E+05	3.07E+01	5.53E+00	2.82E+01	5.54E-01	-2.38E+03
PERM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT	MJ	4.80E+03	2.48E+01	4.55E+01	3.13E+01	1.93E+02	1.61E+05	1.96E+05	2.54E+05	3.07E+01	5.53E+00	2.82E+01	5.54E-01	-2.38E+03
PENRE	MJ	4.85E+04	2.39E+03	3.16E+03	3.33E+01	4.02E+03	2.41E+04	2.93E+04	3.79E+04	2.35E+01	3.19E+02	1.96E+02	3.48E+01	-2.06E+04
PENRM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ	4.85E+04	2.39E+03	3.16E+03	3.33E+01	4.02E+03	2.41E+04	2.93E+04	3.79E+04	2.35E+01	3.19E+02	1.96E+02	3.48E+01	-2.06E+04
SM	kg	1.80E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m3	4.12E+01	3.71E-01	5.51E-01	1.69E+00	1.35E+01	1.14E+03	1.39E+03	1.79E+03	1.68E+00	5.21E-02	1.15E-01	1.39E-02	-1.50E+01

PERE — Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM — Use of renewable primary energy resources used as raw materials; PERT — Total use of renewable primary energy resources; PENRE — Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM — Use of non-renewable primary energy resources used as raw materials; PENRT — Total use of non-renewable primary energy resources; SM — Use of secondary material; RSF — Use of renewable secondary fuels; NRSF — Use of non-renewable secondary fuels; FW — Use of net fresh water.

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)														
PERE	MJ	5.83E+03	2.63E+01	5.05E+01	3.13E+01	1.93E+02	2.13E+05	2.47E+05	3.05E+05	3.07E+01	6.44E+00	3.49E+01	6.55E-01	-3.00E+03
PERM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT	MJ	5.83E+03	2.63E+01	5.05E+01	3.13E+01	1.93E+02	2.13E+05	2.47E+05	3.05E+05	3.07E+01	6.44E+00	3.49E+01	6.55E-01	-3.00E+03
PENRE	MJ	5.70E+04	2.44E+03	3.50E+03	3.33E+01	4.02E+03	3.17E+04	3.69E+04	4.55E+04	2.35E+01	3.72E+02	2.42E+02	3.79E+01	-2.56E+04
PENRM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ	5.70E+04	2.44E+03	3.50E+03	3.33E+01	4.02E+03	3.17E+04	3.69E+04	4.55E+04	2.35E+01	3.72E+02	2.42E+02	3.79E+01	-2.56E+04
SM	kg	2.12E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m3	5.02E+01	4.01E-01	6.11E-01	1.69E+00	1.35E+01	1.50E+03	1.75E+03	2.16E+03	1.68E+00	6.07E-02	1.43E-01	1.69E-02	-1.87E+01

PERE — Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM — Use of renewable primary energy resources used as raw materials; PERT — Total use of renewable primary energy resources; PENRE — Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM — Use of non-renewable primary energy resources used as raw materials; PENRT — Total use of non-renewable primary energy resources; SM — Use of secondary material; RSF — Use of renewable secondary fuels; NRSF — Use of non-renewable secondary fuels; FW — Use of net fresh water.

Table 4. Waste categories and output flows

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)														
HWD	kg	9.28E-01	1.66E-02	1.73E-02	1.00E-04	3.02E-02	2.66E-02	3.50E-02	4.88E-02	7.33E-05	1.68E-03	8.10E-04	1.90E-04	-7.44E-02
NHWD	kg	5.73E+00	5.36E-02	6.61E-02	1.17E+01	1.50E-01	7.01E-01	9.22E-01	1.29E+00	1.26E-03	7.65E-03	1.15E-02	6.60E+02	-3.69E-01
RWD	kg	4.67E-02	3.69E-04	8.40E-04	6.22E-05	1.74E-03	1.63E-01	2.15E-01	3.00E-01	5.47E-05	1.00E-04	3.10E-04	7.12E-06	-1.14E-02
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	6.86E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.34E+02	0.00E+00	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)														
HWD	kg	1.15E+00	1.81E-02	1.95E-02	1.00E-04	3.02E-02	3.89E-02	4.73E-02	6.11E-02	7.33E-05	2.02E-03	1.07E-03	2.00E-04	-9.54E-02
NHWD	kg	8.34E+00	5.50E-02	7.42E-02	1.17E+01	1.50E-01	1.03E+00	1.25E+00	1.61E+00	1.26E-03	9.17E-03	1.50E-02	6.77E+02	-4.85E-01
RWD	kg	5.73E-02	3.88E-04	9.50E-04	6.22E-05	1.74E-03	2.39E-01	2.90E-01	3.76E-01	5.47E-05	1.30E-04	4.00E-04	8.91E-06	-1.47E-02
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	8.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.68E+02	0.00E+00	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

HWD — Hazardous waste disposed; NHWD — Non-hazardous waste disposed; RWD — Radioactive waste disposed; CRU — Components for re-use; MFR — Materials for recycling; MER — Materials for energy recovery; EEE — Exported electrical energy; EET — Exported thermal energy.

Indicator	Unit	RPP	MFG	DST		USE	USE			EOL				BENE
		A1	A2+A3	A4	A5	B2	B6 2500A	B6 3150A	B6 4000A	C1	C2	C3	C4	D
Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)														
HWD	kg	1.38E+00	1.96E-02	2.16E-02	1.00E-04	3.02E-02	5.12E-02	5.96E-02	7.34E-02	7.33E-05	2.35E-03	1.32E-03	2.20E-04	-1.16E-01
NHWD	kg	1.10E+01	5.65E-02	8.24E-02	1.17E+01	1.50E-01	1.35E+00	1.57E+00	1.94E+00	1.26E-03	1.07E-02	1.85E-02	6.93E+02	-6.01E-01
RWD	kg	6.78E-02	4.08E-04	1.05E-03	6.22E-05	1.74E-03	3.14E-01	3.66E-01	4.51E-01	5.47E-05	1.50E-04	5.00E-04	1.07E-05	-1.81E-02
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	1.04E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.02E+02	0.00E+00	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

HWD — Hazardous waste disposed; NHWD — Non-hazardous waste disposed; RWD — Radioactive waste disposed; CRU — Components for re-use; MFR — Materials for recycling; MER — Materials for energy recovery; EEE — Exported electrical energy; EET — Exported thermal energy.

Table 5 (informative) - Aggregated GWP indicator results for the three disconnector variants broken down by rated current (kg CO_2e per declared unit (1 pc.)).

Indicator	Rated current	Variant V1 — Disconnector without earthing switch (1 × NSO80 drive)			Variant V2 — Disconnector with one earthing switch (2 × NSO80 drive)			Variant V3 — Disconnector with two earthing switches (3 × NSO80 drive)		
		Cradle to gate	Cradle to grave	Module D	Cradle to gate	Cradle to grave	Module D	Cradle to gate	Cradle to grave	Module D
		Σ RPP+MFG	Σ RPP+MFG+DST+USE+EOL	BENE	Σ RPP+MFG	Σ RPP+MFG+DST+USE+EOL	BENE	Σ RPP+MFG	Σ RPP+MFG+DST+USE+EOL	BENE
GWP-total	2 500 A	3 469	4 803	-1 522	4 247	5 989	-2 035	5 026	7 175	-2 548
	3 150 A		5 060			6 246			7 432	
	4 000 A		5 485			6 671			7 857	
GWP-fossil	2 500 A	3 450	4 755	-1 522	4 229	5 925	-2 035	5 009	7 096	-2 547
	3 150 A		5 000			6 171			7 342	
	4 000 A		5 407			6 578			7 748	
GWP-bio	2 500 A	14	35	3	11	46	3	8	57	4
	3 150 A		44			55			66	
	4 000 A		60			71			82	
GWP-luluc	2 500 A	5	13	-3	7	18	-4	9	22	-5
	3 150 A		15			20			24	
	4 000 A		18			23			27	

[1] Craddle to gate (Σ RPP+MFG) = raw materials and materials (A1) + transport and manufacturing (A2+A3).

[2] Cradle to grave (Σ RPP+MFG+DST+USE+EOL) = full life cycle A–C; the value depends on the rated current scenario and electricity consumption during the USE phase (B6).

[3] BENE = module D — benefits from metal recycling beyond the system boundaries. Do not add to the cradle-to-grave value.

9. Interpretation of results

General

The life cycle of the MARK40-1/420 disconnector is characterized by two dominant contributions to environmental impacts: raw material production (RPP+MFG stages) and operational energy consumption (USE stage, Module B6).The relative importance of these two stages depends strongly on the rated current scenario, as main circuit losses are proportional to the square of the operating current.

RPP — Raw material preparation and production (Module A1)

The RPP stage is dominated by the production of structural steel (hot-dip galvanized), aluminum current-carrying components, and porcelain insulators.

These three material groups constitute the majority of GWP-fossil, AP, EP, and ADPF in module A1.

The use of secondary materials (SM) — recycled steel and aluminum — partially offsets the burden resulting from primary material production.

GWP-biogenic in module A1 reflects the biogenic carbon content in wooden packaging (EUR pallet and cardboard).

Differences between variants V1, V2, and V3 in the RPP stage result solely from the additional mass of earthing switch components and motor operating mechanisms: each earthing switch adds approximately 100 kg, and each additional NSO80 drive adds 56 kg per pole.

MFG — Manufacturing (Module A2+A3)

Module A2 is dominated by deep-sea maritime transport of porcelain insulators and metal fittings imported from Asia, which constitutes the majority of transport-related impacts. The impacts of Module A3 are relatively modest and reflect assembly operations at the ZWAE production plant in Kębłowo. The electricity consumed in module A3 is modeled using the Polish national energy mix with a GWP factor of 0.599 kg CO_2e/kWh, reflecting the coal-dominated nature of Polish electricity production.

DST — Distribution (Modules A4 and A5)

Module A4 includes road transport from Kębłowo to Szczecin, the Świnoujście–Ystad ferry crossing, and further road transport to the installation site in Trondheim, Norway (totaling approximately 1,560 km by road + 280 km by ferry). Module A5 includes assembly on supporting structures and commissioning, including electricity consumption and waste from assembly materials (wooden packaging disposed of as non-hazardous waste).

USE — Operational energy and maintenance (Modules B2 and B6)

Module B6 represents the largest single contribution to GWP-fossil and primary energy consumption in the entire life cycle for the 3,150 A and 4,000 A rated current scenarios. At 4,000 A and a load factor of 35%, main circuit losses amount to 39,682 kWh per pole over the 40-year RSL. At 2,500 A, losses are reduced to 15,501 kWh, and the relative contribution of B6 to the total life cycle GWP decreases significantly.
Module B6 results differ between variants V1, V2, and V3 due to the different number of NSO80 drives, and thus different total energy of anti-condensation heaters (E_2). E_3 (drive standby mode) and E_4 (switching operations) are zero for all variants — details in points 7.7.4–7.7.5. The Norwegian energy mix (0.027 kg CO_2e/kWh) results in relatively low GWP-fossil impacts from B6, reflecting the hydropower-dominated Norwegian power system.
Module B2 impacts are dominated by the transport of the service crew to the installation site, modeled as 700 km by passenger car (round trip) per inspection event, over 8 inspection events within the RSL (totaling 5,600 km). Lubricants have a marginal contribution to B2 impacts. No component replacements are required during the RSL

EOL — End of life (Modules C1–C4)

Module C1 includes electricity consumption and personal protective equipment used during dismantling. Modules C2–C3 include transport to waste treatment facilities and material separation. The dominant waste stream in module C4 is porcelain insulator material, which is disposed of in an inert waste landfill due to the lack of viable recycling routes. Metal components (steel, aluminum, copper, brass) are directed to material recycling in an amount of 90–95%.

Non-hazardous waste disposed (NHWD) in module C4 is dominated by porcelain landfilling and is therefore significantly higher than in other modules. This is a characteristic feature of outdoor disconnectors with porcelain insulators and does not reflect hazardous waste generation.

BENE — Benefits beyond the system boundaries (Module D)

Module D reports net environmental benefits from the recycling of metal components at the end of life, calculated using the net scrap approach in accordance with EN 15804+A2 §6.4.3.3. Benefits are significant for GWP-fossil, ADPF, AP, and EP indicators, partially offsetting the impacts of the RPP+MFG stages. The magnitude of Module D benefits increases from V1 to V3 proportionally to the additional metallic mass of the earthing switches and drives.

The absence of SF_6 or any insulation gas eliminates gas-related GWP contributions from Modules A1–A3, leaks in the use phase, and end-of-life management, which constitutes a significant distinguishing feature compared to gas-insulated switchgear alternatives.

10. Literature and standards

Norms and regulations

ISO 14025:2006 — Environmental labels and declarations — Type III environmental declarations — Principles and procedures

ISO 14040:2006 — Environmental management — Life cycle assessment — Principles and framework

ISO 14044:2006 — Environmental management — Life cycle assessment — Requirements and guidelines

ISO/IEC 17050-1:2010 — Conformity assessment — Supplier's declaration of conformity — Part 1: General requirements

IEC TS 62271-320:2025 — High-voltage switchgear and controlgear — Part 320: Environmental aspects and life cycle assessment principles for high-voltage switchgear and controlgear

IEC 63366:2025 — Environmental aspects of electrical and electronic products and systems — Horizontal life cycle assessment (LCA) rules

EN 15804:2012+A2:2019 — Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products

IEC 62271-102:2018 — High-voltage switchgear and controlgear — Part 102: Alternating current disconnectors and earthing switches

IEC 62271-1:2017 — High-voltage switchgear and controlgear — Part 1: Common specifications for alternating current switchgear and controlgear

IEC 62474:2018 — Material declaration for products of and for the electrotechnical industry

Software and databases

GreenDelta GmbH (2024). openLCA 2.x — life cycle assessment software. Berlin, Germany. www.openlca.org

ecoinvent Association (2023). ecoinvent database v3.9.1, system model: Allocation, cut-off by classification. Zurich, Switzerland. www.ecoinvent.org

Program EPD

Multicert Sp. z o.o. (2024). General Programme Instructions of the EPD Poland Programme. Warsaw, Poland. www.epd.org.pl

Manufacturer documentation

Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. (2017). Instrukcja Montażu i Eksploatacji — Napowietrzny odłącznik sieczny MARK40, Nr DTR.01.04.08.PL. Lębork, Polska.

Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. (2017). Deklaracja Zgodności Nr DZ.01.04.0001.v.02.2017 — Napowietrzny odłącznik MARK40 (IEC 62271-102, IEC 62271-1), wydana 10 sierpnia 2017. Lębork, Polska.

Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. (2017). Deklaracja Zgodności Nr DZ.01.04.0002.v.02.2017 — Napowietrzny uziemnik G60 (IEC 62271-102, IEC 62271-1), wydana 10 sierpnia 2017. Lębork, Polska.

Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o. Klucz zamówieniowy MARK40 — MARK40-ODLACZNIK-SIECZNY (konfiguracja produktu i kody zamówieniowe). Lębork, Polska.

11. Verification and certification

This environmental product declaration has been independently verified in accordance with ISO 14025. The verification includes the background LCA study, the EPD document, and compliance with the applicable product category rules.

Verifier	Izabela Sztamberek-Sochan, PhD.
Verification date	May 15, 2026
EPD Program Operator	Multicert Sp. z o.o. — EPD Polska

12. EPD Polska Certificate

Program EPD Polska
Operator: MULTICERT Sp. z o.o.

ZWAE

CERTIFICATE

TYPE III EPD DECLARATION

(ENVIRONMENTAL PRODUCT DECLARATION)

Reg. No. EPD-P 02.05.2026

EPD Environmental Product Declaration
EPD VERIFIED
EPD POLAND

This document confirms that the Environmental Product Declaration developed by **Zakład Wytwórczy Aparatów Elektrycznych Sp. z o.o.** for

single-pole high-voltage outdoor disconnector MARK40-1/420 / MRI-420 with integrated earthing switch

covered by declarations of conformity with standards:
IEC 62271-102 and **IEC 62271-1**,

complies with the requirements of **IEC 63366:2025, IEC TS 62271-320:2025** and **ISO 14025**, and the data contained therein have been prepared correctly.

The Declaration was published on May 15, 2026 and is valid until May 15, 2031, or until it is deregistered or its publication on the website www.epd.org.pl is discontinued.

Authenticity of this certificate can be confirmed in.
the public register at www.epd.org.pl

Izabela Sztamberek-Sochan, Ph.D.
EPD Polska Verifier

MULTICERT JEDNOSTKA CERTYFIKACYJNA

Grzegorz Suwara
CEO Multicert Sp. z o.o.

Warsaw, May 15, 2026