

NdFeB Magnets in Dutch Onshore Wind Turbines

Report

Colophon

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NOTE ON THE USE OF AI

Many of us are exploring what role large language models can play in research. As an experiment in what can be automated and at which points people should be involved, the research and the writing of this report (apart from this note) were done by AI agents running in a custom harness, albeit with a fair amount of direction from the researchers.

EXECUTIVE SUMMARY

The main generators of Dutch onshore wind turbines contained an estimated 730 tonnes of NdFeB magnet material at the end of 2025, within a range of 530 to 1,010 tonnes. Most of the installed onshore capacity is in turbines whose main generators are built without permanent magnets. Note that this report uses the mass of whole NdFeB magnets, not the mass of the neodymium contained in the magnets.

The magnet material is concentrated in a few wind farms. Windpark Fryslân (268 tonnes), N33 (103 tonnes) and Westermeerwind (101 tonnes), all with Siemens or Siemens Gamesa direct-drive turbines, together contain 64% of the magnet material. Windpark Fryslân and Westermeerwind stand in the IJsselmeer, so about half of the material is in inland water.

Three quarters of the material is in turbines installed in 2020 to 2024. Turbines installed up to 2014 contain about 12 tonnes, so under an assumed lifetime of 25 years almost no magnet material reaches nominal end of life before 2040. The 2020 to 2024 cohorts reach nominal end of life in 2045 to 2049, including 268 tonnes in Windpark Fryslân in 2046.

Two further quantities are less certain. First, turbines for which the generator type could not be established could contain additional magnet material. If all the turbines that could have permanent-magnet generators turn out to have such generators, that material would amount to about 245 tonnes. The largest part, 60 to 140 tonnes, would be in 117 MW of turbines whose rating and rotor diameter match or come close to a direct-drive permanent-magnet model. Second, magnets outside the main generators, for example in tower fittings, amount to an estimated 20 to 460 tonnes. This very wide estimate is based on manufacturer data from Vestas only, and its upper value assumes that turbines of at least 1 MW from other manufacturers contain as much as the largest Vestas value.



INTRODUCTION

This report estimates the amount of NdFeB magnet material in onshore wind turbines in the Netherlands, the wind farms where that material is located, and the years in which the material could become available for recycling. The report was prepared at the request of the Ministry of Economic Affairs and Climate Policy.

The EU Critical Raw Materials Act lists rare earth elements for permanent magnets among the strategic raw materials (European Union, 2024). The same regulation sets a benchmark for 2030 that recycling capacity in the EU is capable of producing at least 25% of the EU's annual consumption of strategic raw materials (European Union, 2024). Magnets in decommissioned wind turbines are one possible source

of such recycled material. How much this source can contribute to the 2030 benchmark depends on the amount of magnet material in the fleet, its distribution over wind farms, and the age of the turbines that contain the material.

The chapter Data and methods describes the inventory, the estimation methods, and the AI-assisted research process and its checks. The Results present the estimates, the Discussion examines their uncertainties, and the Conclusions summarise the findings. Appendix A gives the calculation details behind the methods, the results and the discussion, and Appendix B gives the annual installation cohorts.

DATA AND METHODS

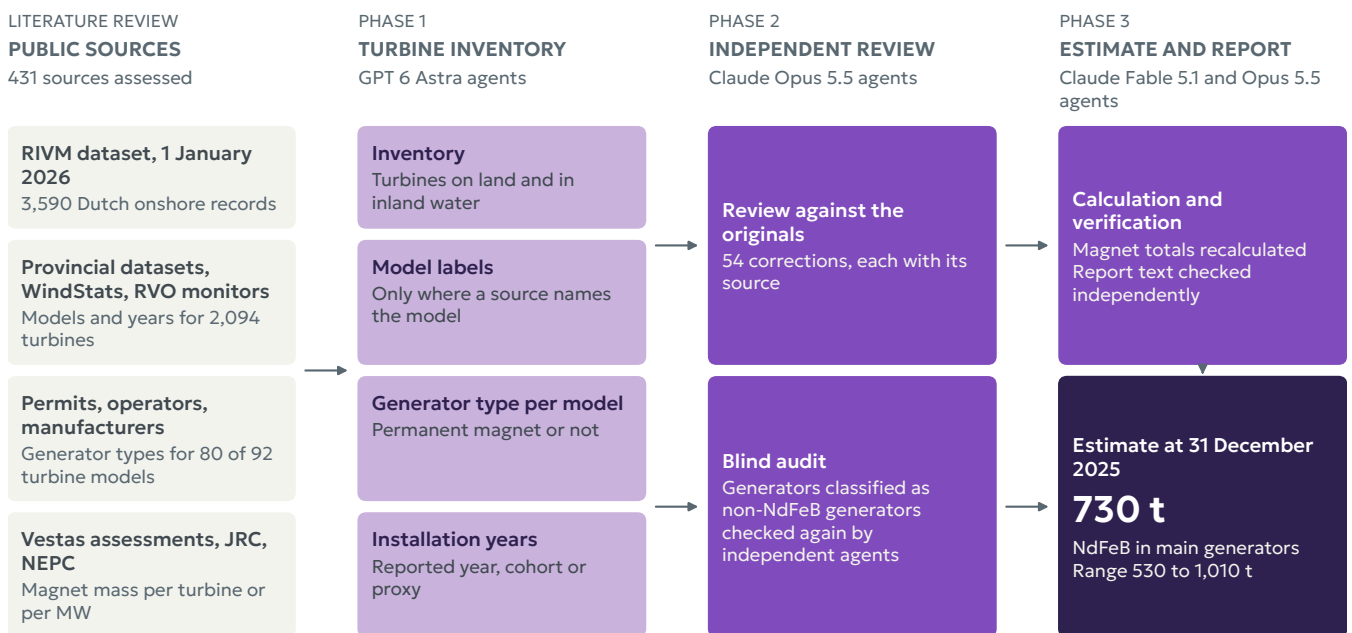


Figure 1 | Overview of the sources, turbine inventory, independent checks and NdFeB stock estimate.

Polaris-CRM assessed 431 public sources for this estimate: the turbine datasets of RIVM, the provinces and WindStats, the RVO monitors, permits, operator and manufacturer documents, turbine databases, news items and the literature on magnet mass (Appendix A).

Scope and definitions

The estimate covers wind turbines on land and in inland water in the Netherlands. In this report, onshore wind covers both, and turbines in inland water are reported separately, so that a result for land alone is also available. Offshore turbines and turbines in neighbouring countries are outside the scope of the stock estimate, although the section *Offshore wind*

context compares the onshore stock with the magnet requirement for new offshore capacity. The reference date is 31 December 2025. Installed turbines that were inactive at the reference date are within the scope.

NdFeB magnet material refers to the mass of complete magnets, not to the neodymium or other rare earth elements in those magnets. The main generator converts mechanical energy from the rotor into electrical energy. In a permanent-magnet generator, permanent magnets provide the magnetic field. We assume that all permanent magnets are NdFeB. Magnets elsewhere in a turbine, for example in tower fittings, are estimated separately (see *Magnets outside the main generator* in this chapter).

Turbine inventory

The inventory is based on the national wind-turbine dataset of RIVM, dated 1 January 2026, which records the location, rated power, rotor diameter and hub height of each turbine (RIVM, 2026). Of the 3,590 records for turbines on land and in inland water, we excluded four turbines known to have been removed and two duplicate records, leaving 3,584 turbines with 7,037 MW. Of these, 161 turbines (659 MW) stand in inland water, according to the ground type recorded by RIVM. The inventory also contains 1,139 small turbines below 0.1 MW, with 28 MW in total.

For several wind farms, the RIVM dataset gives planning values instead of the ratings of the turbines as built, for example 3.0 MW for V126 turbines at Windpark Zeewolde that were built at 3.8 MW. We corrected the rating where a source gave the rating as built, except for turbines with an unresolved generator type (see *Turbine models and generator types*), which keep the RIVM rating. Models and installation years were corrected in the same way. In total, 53 corrections were applied (Appendix A).

For turbines of at least 0.1 MW, the corrected inventory contains 2,445 turbines with 7,008 MW, compared with about 2,547 turbines with 7,054 MW reported by RVO for 31 December 2025 (RVO, 2026).

Turbine models and generator types

The drivetrain and the generator type were classified separately. In a direct-drive turbine, the rotor turns the main generator without a gearbox, so the generator runs at rotor speed and has a large diameter (NEPC, 2026). In a geared turbine, a gearbox raises the speed, so that a smaller and faster generator can be used. The Vestas V162 of the EnVentus platform combines a medium-speed gearbox with a permanent-magnet generator (Vestas, 2019). In this report, such a drivetrain is called semi-direct drive, and "geared" refers to a drivetrain with any other gearbox.

Three generator types are distinguished: permanent-magnet, electrically excited and induction generators. The last two are built without permanent magnets. Direct-drive and geared turbines are both built with and without permanent-magnet generators.

A model was assigned to a turbine only where a source names the model for that wind farm or position. The sources include provincial turbine datasets, the RVO monitor appendices that list the turbines installed each year, environmental impact reports and permits, municipal documents, operator websites, manufacturer pages, turbine databases and news items. Of the 3,584 turbines, 2,706 (6,094 MW) have a model label. Proxy evidence, such as a shared municipality, a nearby position or a rating and rotor diameter that match a

known model, was not used to assign a model. The rating and rotor diameter were used instead to estimate the largest amount of magnet material that turbines with an unresolved generator type could contain (see *Unresolved generator types*).

The generator type was classified per model and variant. Enercon builds its direct-drive turbines with electrically excited generators, apart from the recent EP5 platform, which uses permanent magnets (Enercon, 2011; Enercon, 2014; Enercon, n.d.). Siemens and Siemens Gamesa direct-drive turbines and the Lagerwey L136 use permanent-magnet generators (Siemens, 2013; Siemens Gamesa, 2018; Lagerwey, n.d.). Geared turbines mostly use induction generators, for example the Nordex N117 and N131 and the Vestas V136-4.2 (Nordex, n.d.; Vestas, 2022).

The classification assigns permanent-magnet generators to 1,520 MW, electrically excited generators to 1,253 MW and induction generators to 3,168 MW. Where the sources do not establish the generator type, the turbine is recorded as having an unresolved generator type, the term used in the rest of this report. Turbines with an unresolved generator type account for 1,096 MW, of which 942 MW (86%) consists of turbines without a model label.

Magnet mass per MW and per turbine

Because no model-specific magnet mass was found for most direct-drive models in the Dutch fleet, we assume 700 kg of NdFeB magnet material per MW of rated power for these models. Literature values for direct-drive generators range from about 500 to 1,200 kg/MW (JRC, 2020; JRC, 2024; NEPC, 2026). For the range of the estimate, we use 500 to 900 kg/MW for Siemens models and 500 to 1,200 kg/MW for other direct-drive models (Appendix A).

Two models have model-specific values. For the Vestas V162, the manufacturer's life-cycle assessment reports 8 tonnes of magnets for a reference plant of sixteen 6.2 MW turbines, or 500 kg per turbine, including magnets used to attach fittings inside the tower (Vestas, 2023a). For the GE Haliade-X prototype at Maasvlakte, the NEPC values for the Haliade-X design give about 10 tonnes (NEPC, 2026). The two model-specific values together account for 54 tonnes, or 7% of the total estimate.

Magnets outside the main generator

Wind turbines also contain magnets outside the main generator, for example to attach fittings inside the tower. Vestas states that the towers of all its new turbine models contain magnets (Vestas, n.d.), and its life-cycle assessments of turbines without permanent magnets in the main generator report 67 kg (V117-3.3) to 233 kg

(V90-3.0) of magnets per turbine (Vestas, 2013; Vestas, 2014). Of the other manufacturers checked (Nordex, Siemens Gamesa, GE, Enercon and Senvion), none was found to publish such a mass. Nordex lists magnets in the bill of materials of its induction-generator turbines without giving a mass, and for the other manufacturers it is unknown whether they use such magnets.

We apply the Vestas range to Vestas turbines of at least 1 MW, apart from the V162, whose tower magnets are already included in the main-generator estimate, and assume 0 to 233 kg for turbines of other manufacturers of at least 1 MW. The rules for smaller turbines and for magnets in pitch and yaw motors are in Appendix A. The result is an order-of-magnitude estimate, based on far weaker evidence than the estimate for the main generators.

Installation years and nominal end of life

Installation years were obtained in several ways. Most of them come from the WindStats dataset of wind-turbine locations (WindStats, n.d.), the turbine datasets of the provinces (Provincie Flevoland, n.d.; Provincie Groningen, n.d.; Provincie Noord-Holland, n.d.; Provincie Overijssel, n.d.; Provincie Zuid-Holland, n.d.) and the RVO monitors, and the others from public documents such as the websites of operators and wind farms. Some are reported years of construction, placement or realisation of a turbine or of its wind farm, or a cohort year taken from the wind farm to which a turbine belongs. Others are proxies: the year of first operation, or the start date of the turbine in a registry such as the WindStats dataset. A start date in a registry does not establish when the turbine was erected. Proxies date 46% of the capacity, most of it (39%) by a start date in a registry (Appendix A). Turbines installed in the same year form an installation cohort. Turbines without a usable installation year, 2% of the capacity, are retained in the stock at the reference date as a separate undated group, but excluded from the annual installation and nominal end-of-life series.

To illustrate when the material could become available, we assume a 25-year lifetime and assign each dated cohort a nominal end-of-life year 25 years after installation. The 25 years are the lower end of the typical range of 25 to 30 years given by NREL (Kreider et al., 2024), but the 25-year lifetime is an illustrative assumption, not a measured average for Dutch turbines. Median lifetimes estimated from European decommissioning data are longer: about 32 years for European onshore wind turbines (Mc Govern et al., 2025) and 29 years for Danish onshore turbines (Bech Abrahamsen et al., 2024).

Research process and quality assurance

This report was researched and drafted by Polaris-CRM, the proprietary agentic research platform for critical raw materials research. AI agents assembled the turbine inventory from public sources, identified models and installation years, classified generators and calculated magnet masses. Separate agents checked the source evidence, turbine classifications, installation years, national totals and calculations. The checks included a blind audit of turbines classified as having main generators without permanent magnets (Figure 1).

Most of the capacity is classified as having main generators without permanent magnets, so an error in that classification would leave magnet material out of the estimate. A blind audit tested this classification. The audit divided the turbines into groups with the same model label, municipality and rating, which usually correspond to one wind farm. Agents received the location, rating, rotor diameter and hub height of each group, without the model assigned in the inventory, and identified the model from provincial turbine datasets, RVO monitors, permits and operator websites, and the generator type from manufacturer documents and, for some models, a turbine database. Two rounds covered 153 groups with 1,288 turbines and 4,275 MW, or 98% of the 4,377 MW then classified as having main generators without permanent magnets.

The audit found no permanent-magnet generator in any audited group. Four groups had a wrong model label. In three of them, the turbines identified have generators without permanent magnets, and the fourth is the removed prototype position discussed in the section *Completeness of the inventory*. The audit tests the model labels of the inventory, but not the public sources on which both the inventory and the audit depend. For all but one group, the agents also recorded whether they had read their sources in the original document or only through a search result or a page summary. The source that names the model was read in the original for 133 of the 153 groups (3,878 of 4,275 MW), and a statement of the generator type for 121 groups (3,665 MW). The review logged twenty-three errors, all corrected except two rating differences for which the sources conflict, neither of which affects the magnet estimate.

RESULTS

Table 1 | NdFeB magnet material in main generators by technology group, 31 December 2025. Values are rounded.

Technology group	Turbines	Capacity (MW)	NdFeB, central (t)	NdFeB, range (t)
Siemens and Siemens Gamesa, direct drive	184	711.2	497.8	355.6–640.1
Other direct drive (Enercon EP5, Lagerwey, Leitwind, Vensys, small turbines)	773	257.5	180.3	128.8–309.0
GE Haliade-X prototype, direct drive	1	14.0	10.1	9.6–10.4
Vestas V162, semi-direct drive	91	537.0	43.7	41.0–46.4
Total, permanent-magnet generators	1,049	1,519.7	731.9	534.9–1,005.9

Table 2 | NdFeB magnet material in main generators by location. Location is taken from the ground type recorded for each turbine in the RIVM dataset. Values are rounded.

Location	Capacity (MW)	Direct drive NdFeB (t)	Semi-direct drive NdFeB (t)	NdFeB, central (t)	NdFeB, range (t)
Land	6,378.0	319.5	43.7	363.2	271.6–531.9
Inland water	658.7	368.7	0.0	368.7	263.4–474.0
Total	7,036.7	688.2	43.7	731.9	534.9–1,005.9

NdFeB magnet material in main generators

The main generators of the turbines whose generator type is established contained an estimated 730 tonnes of NdFeB magnet material at 31 December 2025, with a range of 530 to 1,010 tonnes (Table 1). Of this amount, direct-drive permanent-magnet generators account for 688 tonnes, including 498 tonnes in Siemens and Siemens Gamesa direct-drive turbines, and the V162 turbines account for 44 tonnes.

At the average neodymium share of 28.5% reported for wind-turbine magnets by JRC (2020), the central estimate corresponds to about 210 tonnes of contained neodymium. Applying the same share to the lower and upper magnet estimates gives about 150 to 285 tonnes of neodymium.

The magnet material is concentrated in a few wind farms (Figure 2). Windpark Fryslân (89 turbines, 268 tonnes), N33 (35 turbines, 103 tonnes) and Westermeerwind (48 turbines, 101 tonnes) together contain 64% of the magnet material in the central estimate. All three have Siemens or Siemens Gamesa direct-drive turbines.

Land and inland water

Turbines in inland water, with 659 MW of capacity, contain about 370 tonnes, with a range of 260 to 470 tonnes (Table 2). These turbines account for half of the central estimate of magnet stock but less than a tenth of the installed capacity. All of the inland-water material is in Windpark Fryslân and Westermeerwind, which stand in the IJsselmeer. Turbines on land, with 6,378 MW, contain about 360 tonnes (270 to 530 tonnes).

Unresolved generator types

The generator type remains unresolved for 1,096 MW (Table 3). The results of the two preceding sections count magnet material only in turbines whose generator type is established, and in that respect they are a conservative assessment. If all unresolved turbines that could have permanent-magnet generators had such generators, their magnet material would amount to about 245 tonnes, and the upper value of the estimate would rise from about 1,010 to about 1,250 tonnes. This addition leaves out the 524 MW for which no permanent-magnet model matches the rating and rotor diameter (Table 3).

For 710 MW, the first three rows of Table 3, the evidence indicates generators without permanent magnets. The screen in the second row uses RIVM ratings and rotor diameters, some of which are planning values or differ from other sources, so some turbines in that part could still have permanent-magnet generators (Appendix A).

For 117 MW, the rating and rotor diameter match or come close to a direct-drive permanent-magnet model, or sources conflict about the model. If these turbines have permanent-magnet generators, they would add 60 to 140 tonnes.

The 207 MW of geared model families that were also offered with permanent-magnet generators would contain about 32 tonnes even if all of them had such generators, because a geared permanent-magnet generator contains far less magnet material per MW than a direct-drive generator. We apply the 180 kg/MW that Vestas reports for the V90-2.0 GridStreamer (Vestas, 2011) to the 154 MW of turbines rated 2.0 MW that fit the Vestas 2.0 MW GridStreamer platform, and the V162 value of 81 kg/MW to the other 53 MW.

- Turbine with NdFeB magnets in the main generator
- Turbine below 0.1 MW with NdFeB magnets: 707 turbines, together 1% of the NdFeB
- Turbine without NdFeB magnets in the main generator

NdFeB magnet material per location

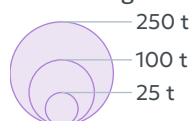


Figure 2 | Dutch onshore wind turbines with and without NdFeB magnets in the main generator, and the magnet material per location. The area of a bubble is proportional to the magnet material of a location in the central estimate, for locations with at least 5 tonnes. Map based on CBS (n.d.-a, n.d.-b).

The 180 kg/MW includes tower magnets, which the next section also counts for these turbines, so the two amounts partly overlap. The turbines that fit the EWT DirectWind models (57 MW) would add 29 to 69 tonnes if they had direct-drive permanent-magnet generators.

Their design derives from an earlier Lagerwey turbine with an electrically excited generator, so we judge such a generator most likely. The 5 MW of small turbines flagged as possible permanent-magnet turbines would add about 3 tonnes at 700 kg/MW.

Table 3 | Capacity with an unresolved generator type, by the evidence available, 31 December 2025. Possible additions are the magnet material the part would contain if all of its turbines had permanent-magnet generators, under the condition stated in the last column.

Part of the unresolved capacity	Capacity (MW)	Evidence	Possible addition (t)
A source, or for 12 MW only the rating and rotor diameter, indicates a model without permanent magnets	180	The model is confirmed by a source for 85 MW	None
No direct-drive permanent-magnet model matches the rating and rotor diameter	524	Screen on the RIVM rating and rotor diameter. The ratings are planning values for some wind farms, and some rotor diameters differ from other sources (Appendix A)	None, according to the screen
Small turbines below 0.1 MW	6	–	None
The rating and rotor diameter match or come close to a direct-drive permanent-magnet model, or sources conflict about the model	117	–	58.7–140.8 at 500 to 1,200 kg/MW
Geared model families that were also offered with permanent-magnet generators	207	Vestas used permanent-magnet generators in the V112-3.0 and the 2.0 MW GridStreamer platform (Vestas, n.d.), and its assessment of the V90-2.0 GridStreamer reports 180 kg/MW for generator and tower magnets together (Vestas, 2011)	About 32: the 154 MW of 2.0 MW Vestas candidates at 180 kg/MW and the rest at the V162 value of 81 kg/MW
The rating and rotor diameter fit the EWT DirectWind models	57	EWT's documents describe the generator as synchronous without stating the excitation	28.7–68.8 if direct-drive permanent magnet
Small turbines flagged as possible permanent-magnet turbines	5	–	About 3 at 700 kg/MW
Total	1,096		

Magnets outside the main generator

Under the assumptions described in Data and methods, magnets outside the main generators amount to an estimated 20 to 460 tonnes. The lower value includes magnets in Vestas turbines only, whereas most of the upper value is assigned to turbines of other or unknown manufacturers, for which no published quantities were found. The range is wide because, apart from Nordex, it is unknown whether these manufacturers use magnets outside the main generator. For example, no Enercon statement was found on whether its concrete and hybrid towers use magnets to attach fittings.

Installation years and nominal end of life

Installation years are available for the turbines that contain 99% of the magnet material in the central estimate and 98% of the capacity. The remaining 7 tonnes is in turbines below 0.1 MW, which make up 1,067 of the 1,138 undated turbines. Because the undated turbines were already installed at the reference date, their nominal end of life under the fixed 25-year assumption falls no later than 2050, but the missing

installation years prevent an annual allocation. For 39% of the capacity, the installation year is a start date in a registry, so the cohort of a turbine in Figure 3 can differ from the year in which the turbine was erected.

Three quarters of the magnet material (539 tonnes, with a range of 390 to 740 tonnes) is in turbines installed in 2020 to 2024. Turbines installed up to 2014 contain about 12 tonnes, because only 17 MW of the 1,704 MW dated to that period has permanent-magnet generators. Turbines installed in 2015 to 2019 contain 174 tonnes. The 2021 cohort contains the most magnet material, 286 tonnes, of which 268 tonnes is in Windpark Frysân (Appendix B).

With the assumed 25-year lifetime (Figure 4), the first dated magnet material reaches nominal end of life in 2037 (3.6 tonnes), followed by 1.6 tonnes in 2038, 6.3 tonnes in 2039 and about 20 tonnes in 2040. In 2041, with the 2016 cohort, the annual amount rises to 129 tonnes, of which 101 tonnes is in Westermeerwind. The 2020 to 2024 cohorts reach nominal end of life in 2045 to 2049.

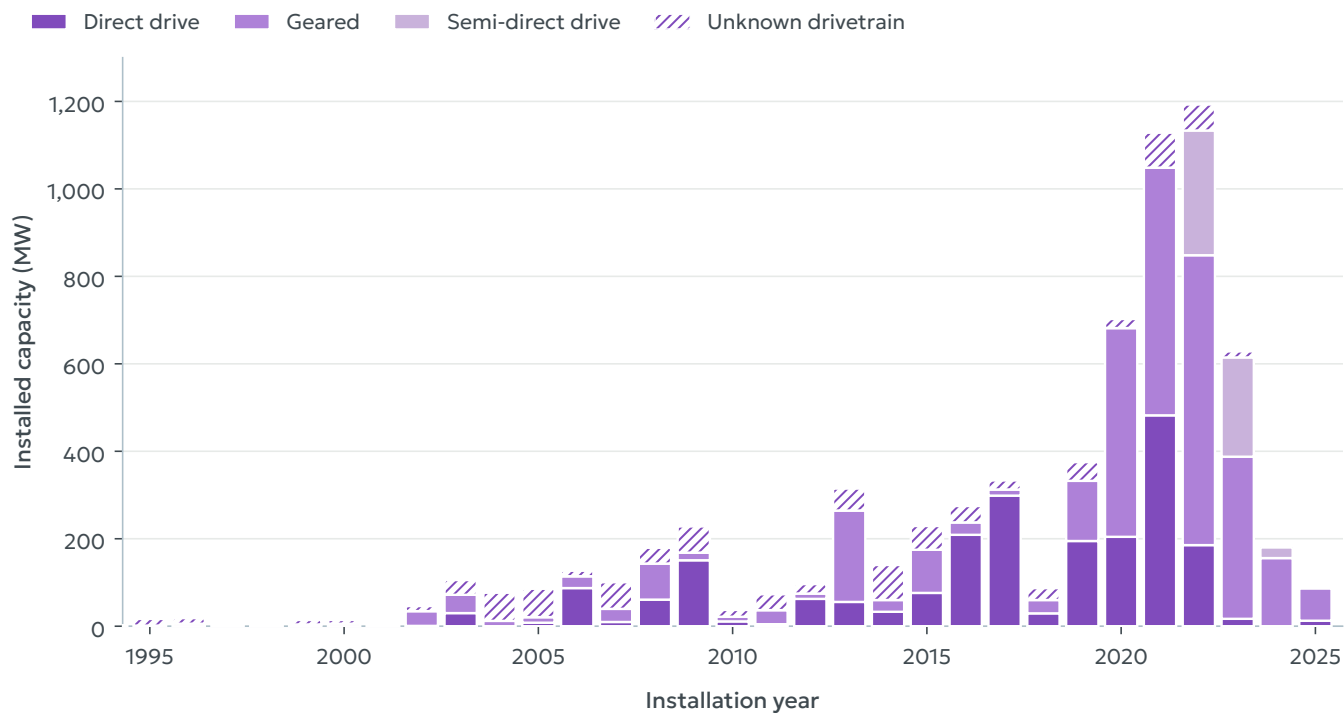


Figure 3 | Installed capacity by installation year and drivetrain at 31 December 2025. Colours distinguish drivetrain types, and hatching marks unknown drivetrains. Capacity includes turbines with unresolved generator type. The 114 MW with an unknown installation year is not shown in the bars. The 4.0 MW installed before 1995 is not shown.

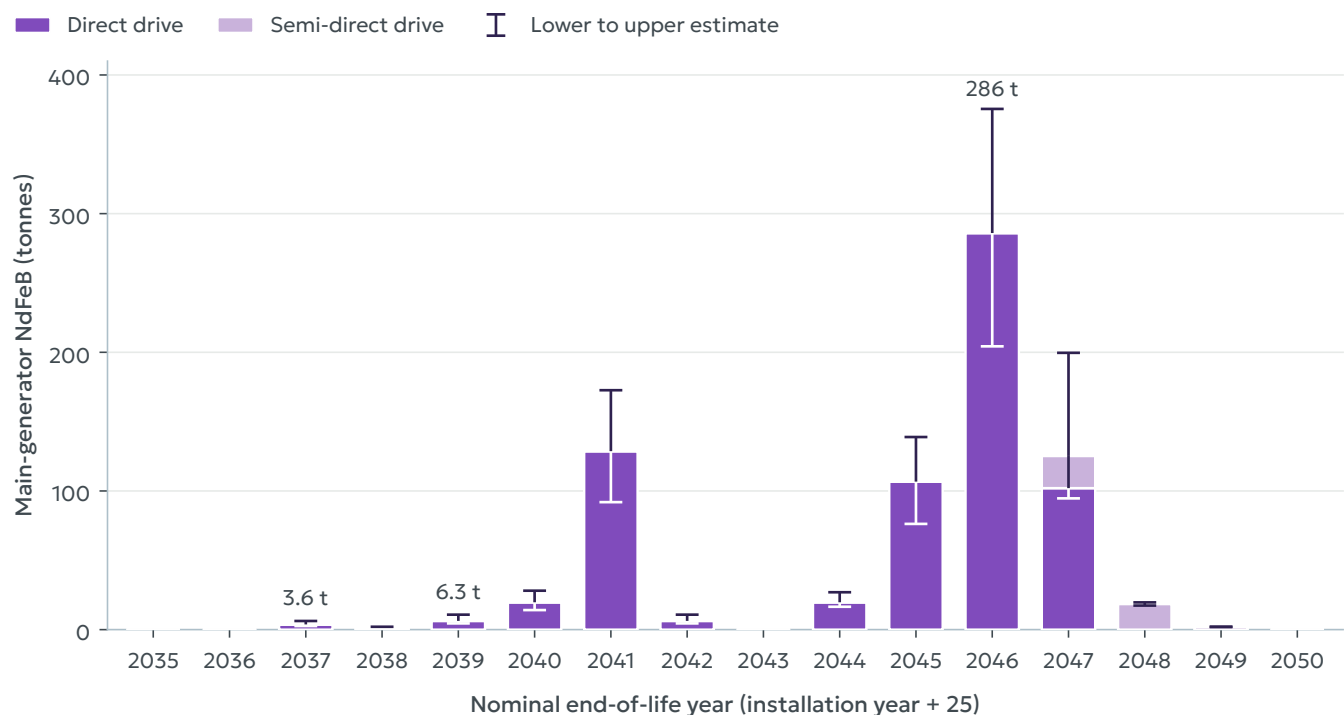


Figure 4 | Main-generator NdFeB magnet material by nominal end-of-life year under a fixed 25-year lifetime. Stacked bars show the central estimate by drivetrain, and whiskers show the lower and upper estimates. The 7 tonnes with an unknown installation year is not shown in the bars.

DISCUSSION

The two main uncertainties are the magnet mass per MW of direct-drive generators, which determines the amount of magnet material (see *Uncertainty in the estimate*), and the lifetime of the turbines, which determines when the material reaches end of life (see *Timing and availability for recycling*).

Uncertainty in the estimate

Among the quantified uncertainties, the magnet mass per MW of direct-drive generators is the largest. Between the lower and upper values, the estimate for direct-drive generators differs by about 465 tonnes. The conditional additions from the unresolved capacity total up to about 245 tonnes if every candidate turbine had a permanent-magnet generator (see *Unresolved generator types*). These additions include no magnet material for the 524 MW for which no direct-drive permanent-magnet model matches the rating and rotor diameter. That comparison depends on RIVM ratings that are planning values for some wind farms and on RIVM rotor diameters that differ from other sources for some turbines, so some of these turbines could still have permanent-magnet generators (Appendix A). The blind audit tested the capacity then classified as having main generators without permanent magnets and found no permanent-magnet generator in the 98% of that capacity that it covered.

The manufacturer's value for the V162 is about half of the JRC generic value for geared permanent-magnet generators, about 175 kg/MW when converted to magnet mass (JRC, 2024). The magnet mass of the V162 generator alone is lower still, because the Vestas value includes the tower magnets. Applying the JRC value would add about 50 tonnes, and the range of this estimate does not include that alternative. However, the Vestas life-cycle assessment of the V150-6.0, a turbine of the same platform, gives a similar 78 kg/MW (Vestas, 2023b). The Vestas value is therefore consistent within the platform, and we retain the Vestas value. The reason for the difference from the generic value has not been established.

Model-family classifications do not establish the generator variant of every installed turbine. For this estimate, the variant matters mainly for the 207 MW of geared families that were also offered with permanent-magnet generators (see *Unresolved generator types*).

For Sweden, Savvidou and Johnsson (2023) estimate about 180 kg of NdFeB magnet material per MW of installed wind capacity in 2020, against about 100 kg/MW for the Dutch onshore fleet in this report (Appendix A).

Completeness of the inventory

For turbines of at least 0.1 MW, the inventory is 46 MW below the RVO total. One turbine built in 2025, Windturbine Borg (4.5 MW), is missing from the inventory. Twelve turbines at Windpark Zeewolde with an unresolved generator type keep their RIVM ratings, and their combined capacity is therefore 5.6 MW lower than in the turbine dataset of the province of Flevoland. We have not identified the turbines that account for the remaining 36 MW, 0.5% of the capacity in scope, but this capacity is small compared with the effect of the uncertainty in the magnet mass per MW.

Presence at the reference date is inferred from the RIVM dataset for most of the fleet. The main risk is that turbines removed during 2025 remain in the dataset. One such turbine is the GE prototype at the Wieringermeer test field, which was removed in September 2025. Whether a successor stood there at the reference date has not been established, so the position (5.3 MW) is excluded from the stock (Appendix A). Twenty Enercon E-48 turbines in Hollands Kroon (16 MW) have a recorded end date of 1 January 2026, one day after the reference date. These turbines remain in scope, but their main generators are electrically excited.

Timing and availability for recycling

A fixed lifetime of 25 years defines a timing scenario, not a forecast of retirements or of recoverable magnet material. Turbines can be replaced earlier through repowering or operate longer through life extension. Reuse of a turbine or a generator postpones the availability of its magnets for recycling, and losses in collection and processing reduce the amount of material recovered.

Applying JRC's lifetime model to our onshore inventory reduces the estimated NdFeB outflow in 2026 to 2050 from about 720 to 282 tonnes (Table 4). JRC assumes a median lifetime of about 32 years (Mc Govern et al., 2025). Bech Abrahamsen et al. (2024) find a median lifetime of 29 years for Danish onshore turbines.

JRC's own Netherlands projection is about 480 tonnes over the same period (JRC, 2026a), compared with 282 tonnes in our calculation using JRC's lifetime model. Our inventory covers onshore turbines present at the end of 2025, whereas JRC includes onshore and offshore turbines installed through 2023 (JRC, 2026b). The comparison does not isolate the contribution of offshore turbines.

Because Windpark Fryslân, N33 and Westermeerwind contain 64% of the magnet material (see *NdFeB magnet material in main generators*), the amount that becomes available in 2041, 2045 and 2046 depends

Table 4 | NdFeB magnet material reaching end of life in 2026–2050, by turbine inventory and lifetime assumption. Values are rounded. Our two calculations exclude the undated material. The JRC projection is converted from neodymium to NdFeB magnet mass as described in Appendix A. These are end-of-life quantities before collection and recycling losses.

Calculation	Turbine inventory	Lifetime assumption	NdFeB outflow (t)
Our main scenario	Our dated onshore fleet, present at end-2025	Fixed 25 years	720
Our recalculation using JRC's lifetime model	The same dated onshore fleet	JRC onshore distribution, median about 32 years	282
JRC's Netherlands projection	JRC onshore and offshore fleet, installations through 2023	JRC distributions, with five years added to the offshore median	480

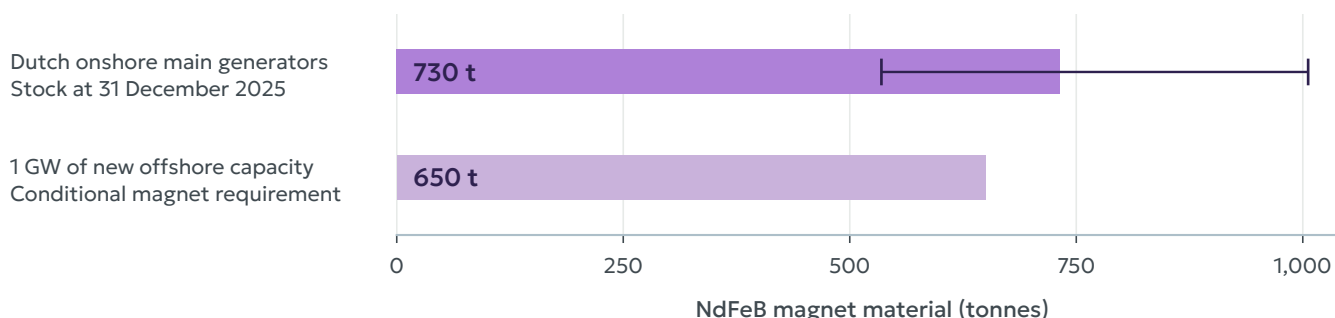


Figure 5 | Dutch onshore magnet stock at 31 December 2025 compared with the magnet requirement for 1 GW of new offshore capacity at 650 kg NdFeB/MW (Sprecher et al., 2026, pp. 28 and 44). The whisker shows the range of the onshore estimate, which includes the V162 tower magnets described in Appendix A. Values are rounded.

mainly on when these wind farms are repowered, extended or decommissioned, rather than on the average lifetime of the turbines in the fleet. For planning recycling capacity, this timing and the concentration in a few wind farms are more informative than the national total.

Offshore wind context

The Koersvaste Middenweg scenario projects 91 GW of total Dutch wind capacity in 2050, including onshore and

offshore wind, the majority being offshore (Copper8, 2026, Table 2).

For offshore turbines, the intensity of 650 kg NdFeB/MW used in Sprecher et al. (2026) gives a requirement of about 650 tonnes of magnets per GW of new capacity (Sprecher et al., 2026, pp. 28 and 44). Our central estimate of 730 tonnes in the existing Dutch onshore fleet is equivalent to the magnet requirement for about 1.1 GW of new offshore capacity at that intensity (Figure 5).

CONCLUSIONS

Dutch onshore wind turbines contained an estimated 730 tonnes of NdFeB magnet material in their main generators at the end of 2025 (530 to 1,010 tonnes). If all unresolved turbines that could have permanent-magnet generators had such generators, the upper value would be about 1,250 tonnes. This value leaves out the 524 MW of unresolved turbines for which no direct-drive permanent-magnet model matches the rating and rotor diameter. For magnets elsewhere in the turbines, the order-of-magnitude estimate is 20 to 460 tonnes. Half of the main-generator material is in two wind farms in the IJsselmeer. With an assumed 25-year lifetime, almost none of the main-generator material reaches nominal end of life before 2040, and most of the main-generator material reaches nominal end of life in 2045 to 2049. By 2030, the benchmark year of the Critical Raw Materials Act, none of the dated main-generator material has reached nominal end of life.

Some magnet material becomes available before its nominal end-of-life year: occasionally a turbine reaches end of life much sooner because of an accident or another problem, and, as far as we are aware, recyclers already process a small number of wind-turbine generators with NdFeB magnets.

Among the quantified uncertainties, the estimate is most sensitive to the magnet mass per MW of direct-drive generators. Therefore, model-specific magnet masses for the Siemens Gamesa turbines of Windpark Fryslân and N33 and the Siemens turbines of Westermeerwind, which the manufacturer or the operators could provide, would narrow the range more than further work on the inventory. Improving the estimate of magnets outside the main generator would require quantities from manufacturers other than Vestas.

APPENDIX A CALCULATION DETAILS

Inventory and corrections

The RIVM dataset contains 3,590 records of turbines on land and in inland water in the Netherlands. Four of them are turbines that have been removed, and two are duplicates of other records. The GE 5.3-158 prototype at position PW7 of the Wieringermeer test field was removed on 1 September 2025 according to the WindStats dataset of the province of Noord-Holland. The RIVM record for the position (5.3 MW, 175 m rotor, 150 m hub height) does not match the dimensions of the removed prototype (158 m rotor, 121 m hub height), and the RIVM dimensions may be the permit maxima of the zoning plan. No successor has been established, so the position is excluded from the stock. The remaining 3,584 records form the inventory.

The inventory has 54 corrections: 16 to ratings, 21 to models or generator classifications and 17 to installation years. One of them concerns the excluded position PW7 and is superseded by the exclusion, so 53 are applied. Each correction records its source, a locator in the source, a short quotation and a note that the agent read the original document. The largest rating corrections concern Windpark Zeewolde, where the RIVM dataset gives ratings below those as built for 79 Vestas turbines: 21 V117 turbines run at 4.3 MW rather than 3.6 MW, 33 V126 turbines at 3.8 MW rather than 3.0 MW, 20 V136 turbines at 4.3 MW rather than 4.2 MW and five V110 turbines at 2.2 MW rather than 2.0 MW. The capacity of the wind farm as built is therefore about 44 MW higher than the RIVM ratings. Two smaller rating differences, at Delfzijl-Zuid and Oostzeedijk, were left uncorrected because the sources conflict. Neither affects the magnet estimate.

Number of sources

In the count of 431 sources, the parts of one dataset count as one source, for example the layers of one map service or the data resources of one statistics table. Counted by web address, the sources number 449.

Magnet mass values

The literature values behind the assumed 700 kg/MW are as follows. JRC gives 180 ± 30 kg of neodymium and 35 kg of praseodymium per MW for direct-drive permanent-magnet generators (JRC, 2024). At the 28.5% neodymium share that JRC reports for wind-turbine magnets (JRC, 2020), the neodymium content corresponds to 526 to 737 kg of magnet material per MW, or 649 to 860 kg/MW if the praseodymium is counted with the neodymium. The NEPC gives about 1,520 kg of magnet material for a 3 MW Siemens direct-drive turbine in a worked example, 12.7 kg per pole

assembly over 120 poles, or about 507 kg/MW, and 800 kg/MW for the Siemens 3.0-101 and 3.0-113 in its Table A1 (NEPC, 2026). The highest Siemens value in that table is 900 kg/MW, for the D10 platform, calculated from magnet assembly drawings. The NEPC also states a general range of 800 to 1,200 kg/MW for direct-drive generators. The lower value of 500 kg/MW used here is the NEPC example rounded down. The upper values of 900 kg/MW for Siemens models and 1,200 kg/MW for other direct-drive models are the highest Siemens value and the upper end of the general range.

For the Vestas V162, the life-cycle assessment of the V162-6.2 reports 8 tonnes of magnets for a reference plant of sixteen turbines and 99.2 MW (Vestas, 2023a). Eight tonnes over sixteen turbines gives 500 kg per turbine, or 469 to 531 kg if the reported value was rounded to whole tonnes. The value is applied per turbine to the 54 V162 turbines rated 6.0 or 6.2 MW, which use the V162-6.2 hardware, and per MW (80.6 kg/MW) to the 37 V162-5.6 turbines, whose generator may differ from that of the V162-6.2 because the upgrade from 5.6 to 6.0 MW in 2020 involved changes to the generator. The reported amount includes the magnets used to attach fittings inside the tower. Vestas does not report these tower magnets separately, so they are counted with the main generator. The assessment does not state whether the amount refers to bare magnets or to magnets with their steel housings. The life-cycle assessment of the V150-6.0, a turbine of the same platform, reports 8 tonnes for 17 turbines and 102 MW, or 78 kg/MW (Vestas, 2023b).

For the GE Haliade-X prototype at Maasvlakte, the NEPC lists 840 kg/MW for the 12 MW design and 800 kg/MW for the 13 MW design and for the Haliade-X in general (NEPC, 2026). The central value of 10.1 tonnes is 840 kg/MW at 12 MW. The lower and upper values, 9.6 and 10.4 tonnes, apply 800 kg/MW to 12 and 13 MW. The prototype was updated to 14 MW by November 2021 (GE Renewable Energy, 2021), and whether the design values apply to the updated turbine is unresolved.

The model-specific values account for 53.8 tonnes of the 731.9 tonnes in the central estimate: 43.7 tonnes for the V162 turbines and 10.1 tonnes for the Haliade-X prototype. The other 678.1 tonnes, 93%, is calculated at 700 kg/MW.

Savvidou and Johnsson (2023) report 500 tonnes of neodymium for 9.7 GW of Swedish wind capacity in 2020, which corresponds to about 180 kg of NdFeB magnet material per MW at a neodymium share of 28.5% (JRC, 2020).

Table A1 | Values per turbine for magnets outside the main generator.

Turbines	Lower value (kg)	Upper value (kg)	Basis
Vestas, at least 1 MW, other than the V162	67	233	The Vestas life-cycle assessments of the V117-3.3 (2 tonnes for 30 turbines) and the V90-3.0 (7 tonnes for 30 turbines), which attribute the magnets to fittings inside the tower (Vestas, 2013; Vestas, 2014)
Vestas V162	0	0	Included in the main-generator value (see <i>Magnet mass values</i>)
Other or unknown manufacturers, at least 1 MW	0	233	No published mass. Nordex lists magnets in the bill of materials of its induction-generator turbines without a mass or location. A Siemens Gamesa environmental product declaration does not mention magnets, and nothing was found for GE, Enercon or Senvion. The upper value is the Vestas maximum
Turbines of 0.1 to 1 MW	0	67	The lowest Vestas value as a ceiling (assumption)
Turbines below 0.1 MW	0	0	Left out of the estimate
Pitch and yaw motors, per turbine of at least 1 MW	0	10	An allowance for a few permanent-magnet motors at about 0.16 kg of magnet per kW of motor rating. The motor ratings and counts are assumptions, not sourced, and whether the Vestas magnet values already include motor magnets is unknown

Magnets outside the main generator

Table A1 gives the values per turbine used for magnets outside the main generator.

The lower value of the estimate, 23 tonnes, includes magnets in Vestas turbines only. Of the upper value of 464 tonnes, about 340 tonnes is assigned to turbines of at least 1 MW of other or unknown manufacturers, including turbines with an unresolved generator type, on the assumption that each contains the Vestas maximum of 233 kg plus the 10 kg allowance for pitch and yaw motors. Enercon's concrete and hybrid towers may not use magnets to attach fittings to a steel wall. If Enercon turbines do not contain magnets outside the main generator, the upper value would fall to about 365 tonnes.

Installation years and lifetime

Table A2 gives the kind of evidence behind the installation years. For 1,206 turbines (2,742 MW), the year is the start date of the turbine in a registry: the WindStats dataset or the provincial datasets of Noord-Holland and Zuid-Holland, which are taken from WindStats (WindStats, n.d.). The start date in these records is not defined as the date of erection. A year of realisation or completion of a wind farm does not date each of its turbines. The year of a turbine also does not date a replacement generator. The Enercon E-160 prototype at the Wieringermeer test field, erected in 2020, had received a new generator by April 2021 (Windtech International, 2021), and its magnet material, 3.9 tonnes in the central estimate, is counted in the 2020 cohort.

NREL gives a typical wind-turbine lifetime of 25 to 30 years (Kreider et al., 2024). Vestas assumed a plant

lifetime of 20 years in its 2011 life-cycle assessment of the V90-2.0, which corresponds to the design life of that turbine, and noted that a number of its turbines had exceeded the design life (Vestas, 2011). Neither gives the mean retirement age of Dutch onshore turbines. JRC fitted a Weibull distribution (scale 32.9 years, shape 8.9) to the decommissioned share of each installation year's European onshore capacity, from data on 50,758 wind farm projects (Mc Govern et al., 2025). For the section *Timing and availability for recycling*, we apply this distribution to each installation cohort still installed at the reference date.

The Netherlands series in JRC (2026a) sums to about 138 tonnes of neodymium in 2026 to 2050. Dividing by the neodymium share of 28.5% gives about 480 tonnes of NdFeB magnet material (JRC, 2020).

The screen of the unresolved capacity

The 1,096 MW with an unresolved generator type was divided into the classes of Table 3 by comparing the rating and rotor diameter of each turbine with direct-drive permanent-magnet products and with geared model families that were also offered with permanent-magnet generators, and by checking the sources that name a model for the wind farm. For 524 MW, no direct-drive permanent-magnet product matches both the rating and the rotor diameter. This screen depends on the RIVM ratings, which are planning values for some wind farms, and on the RIVM rotor diameters, some of which differ from other sources. Three Lagerwey L100 turbines at Het Hogeland, for example, are recorded with a 90 m rotor. Seven unlabelled 2.3 MW turbines at Bernhardweg II in Middelburg, Spoorwind II in Staphorst and Andorraweg in Vlissingen are recorded with a 70 m

Table A2 | Turbines and capacity by the kind of evidence for the installation year. Values are rounded.

Kind of evidence	Turbines	Capacity (MW)
Reported year of construction, placement or installation	480	1,852.9
Reported year of realisation or completion	505	1,301.5
Cohort year of the wind farm	113	531.5
First year of operation (proxy)	142	495.3
Start date in a registry (proxy)	1,206	2,741.6
Undated	1,138	113.9
Total	3,584	7,036.7

rotor, which matches no direct-drive permanent-magnet product of that rating. Other sources list all seven as Lagerwey turbines (WindStats, n.d.; The Wind Power, n.d.-a, n.d.-b, n.d.-c). The six at Bernhardweg II and Spoorwind II are Lagerwey L82 turbines with an 82 m rotor (The Wind Power, n.d.-b, n.d.-c; Wind Systems, 2018). The L82 has a direct-drive permanent-magnet generator (Lagerwey, 2016), so the six turbines are counted as direct-drive permanent-magnet turbines. No source names the model of the turbine at Andorraweg, and the sources give its rating as 2.0, 2.05 or 2.3 MW (WindStats, n.d.; The Wind Power, n.d.-a; WindBASE, n.d.). The turbine is therefore counted in the class of turbines whose rating and rotor diameter match or come close to a direct-drive permanent-magnet model, or about whose model the sources conflict. Of the screened capacity, 227 MW is in turbines with rotor diameters of about 52, 54 or 70 m, and 59 MW in turbines with 90 m rotors, all but one rated 3.0 MW, in

Halderberge, Tholen, Roosendaal and Coevorden among other municipalities. The screen alone cannot exclude that a turbine in this part of the fleet with a planning rating is a direct-drive permanent-magnet turbine, and the blind audit did not cover these turbines, because they are not classified. Twenty-nine unlabelled turbines rated 2.0 MW with 90 m rotors (58 MW) fit the Vestas V90-2.0 GridStreamer, which has a permanent-magnet generator (Vestas, 2011), and are counted in the class of geared model families that were also offered with permanent-magnet generators. The permanent-magnet generator belongs to the GridStreamer generation of that platform (Vestas, n.d.). Vestas lists the V90-2.0 and the V90-2.0 GridStreamer as separate models (Vestas, 2011), and its 2015 assessments of the V100-2.0 and V110-2.0 state that these turbines use a single-fed induction generator without rare earth elements (Vestas, 2015a; Vestas, 2015b). Which generation the 29 turbines belong to has not been established.

APPENDIX B ANNUAL INSTALLATION COHORTS

Table B1 | Capacity and main-generator NdFeB magnet material by installation year, for turbines in scope at 31 December 2025. Capacity is separated by drivetrain type. Years without a dated turbine in scope are omitted. Values are rounded.

Installation year	Direct drive (MW)	Geared (MW)	Semi-direct drive (MW)	Unknown drivetrain (MW)	Total (MW)	NdFeB, central (t)	NdFeB, range (t)
1988	0.0	0.0	0.0	0.3	0.3	0.0	–
1989	0.0	0.2	0.0	0.3	0.5	0.0	–
1990	0.0	0.0	0.0	0.3	0.3	0.0	–
1991	0.0	0.1	0.0	0.2	0.2	0.0	–
1992	0.0	0.1	0.0	0.5	0.6	0.0	–
1993	0.0	0.1	0.0	0.5	0.6	0.0	–
1994	0.0	0.8	0.0	0.8	1.6	0.0	–
1995	0.0	1.5	0.0	15.3	16.7	0.0	–
1996	0.0	5.8	0.0	12.7	18.5	0.0	–
1997	0.0	4.8	0.0	5.0	9.8	0.0	–
1998	0.6	3.8	0.0	3.6	8.0	0.0	–
1999	0.0	4.1	0.0	10.2	14.3	0.0	–
2000	0.0	5.7	0.0	8.7	14.4	0.0	–
2001	0.6	5.4	0.0	2.4	8.4	0.0	–
2002	0.8	33.8	0.0	11.5	46.1	0.0	–
2003	30.0	41.8	0.0	33.7	105.5	0.0	–
2004	0.0	12.3	0.0	64.3	76.5	0.0	–
2005	8.1	12.8	0.0	64.8	85.6	0.0	–
2006	87.2	27.1	0.0	12.5	126.8	0.0	–
2007	9.7	30.0	0.0	60.8	100.5	0.0	–
2008	60.8	82.6	0.0	36.0	179.4	0.0	–
2009	150.8	17.5	0.0	59.9	228.2	0.0	–
2010	11.0	10.7	0.0	15.6	37.3	0.0	–
2011	4.6	32.3	0.0	36.2	73.0	0.0	–
2012	62.5	12.3	0.0	21.5	96.3	3.6	2.6–6.2
2013	55.6	209.0	0.0	50.2	314.7	1.6	1.2–2.1
2014	33.0	27.0	0.0	80.0	140.0	6.3	4.5–10.8
2015	76.2	98.7	0.0	54.3	229.2	19.7	14.1–28.1
2016	209.0	28.5	0.0	37.4	274.8	128.7	91.9–172.7
2017	298.6	14.1	0.0	20.6	333.3	6.3	4.5–10.8
2018	29.4	30.6	0.0	27.0	87.0	0.0	–
2019	194.9	137.6	0.0	42.7	375.1	19.7	16.5–27.0
2020	204.4	477.4	0.0	20.7	702.5	106.8	76.3–138.9
2021	482.2	566.4	0.0	79.8	1,128.4	286.0	204.3–375.5
2022	185.5	662.8	285.2	59.4	1,192.9	125.3	94.7–199.6
2023	16.9	370.7	227.0	13.8	628.4	18.5	17.4–19.6
2024	0.0	155.8	24.8	0.0	180.6	2.0	1.9–2.1
2025	12.6	74.3	0.0	0.0	86.9	0.0	–
Undated	12.7	24.4	0.0	76.7	113.9	7.3	5.2–12.5
Total	2,237.4	3,222.6	537.0	1,039.7	7,036.7	731.9	534.9–1,005.9

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