PSI

PSI - PAUL SCHERRER INSTITUT

Environmental burdens of electricity production

PSI contribution to the Axpo project «Axpo Energy Reports»

Christian Bauer, Romain Sacchi

02.02.2026

Technology Assessment group, Laboratory for Energy Systems Analysis (LEA), PSI Centers for Nuclear Engineering and Sciences & Energy and Environmental Sciences

www.psi.ch/ta

Contact:

christian.bauer@psi.ch

Contents

1 Zusammenfassung

Dieser Bericht beinhaltet eine Übersicht zu den Umweltauswirkungen einiger Stromproduktionstechnologien in der Schweiz heute, 2035 und 2050. Das Technologieportfolio umfasst Wind- und Fotovoltaik-Kraftwerke, Gaskraftwerke betrieben mit Erdgas, Biomethan, und Wasserstoff, mit CO_2-Abscheidung und -Speicherung sowie neue Kernkraftwerke. Die Umweltauswirkungen sind mittels Ökobilanz-Methodik über den gesamten Lebenszyklus der Kraftwerke berechnet. Das berechnete Set an Umweltindikatoren beinhaltet Treibhausgasemissionen, Landnutzung, Schäden an Ökosystemen, hochradioaktive und toxische nicht radioaktive Abfälle sowie eine Auswahl so genannter «Kritischer Rohstoffe» (Nickel, Kobalt, Lithium und Neodymium). Diese Umweltindikatoren sind neben der Stromproduktion auch für die Herstellung von stationären Lithium-Ionen- und Natrium-Ionen-Batterien berechnet.

Die Ergebnisse zeigen, dass Wind- und auf Dächern montierte Fotovoltaik-Kraftwerke bei den hier berechneten Umweltindikatoren insgesamt die geringsten Auswirkungen verursachen und bei keinem der Indikatoren im Vergleich zu den anderen Technologien nennenswerte Belastungen verursachen. Mit Ausnahme von hochradioaktiven Abfällen ist dies auch für Kernkraftwerke der Fall. Freiflächen-Fotovoltaikanlagen haben gegenüber Dachanlagen den Nachteil, dass sie zusätzlichen Landverbrauch aufweisen. Dies kann, je nach Art der genutzten Flächen, nachteilige Auswirkungen auf Ökosysteme nach sich ziehen. Weiter weisen die Freiflächenanlagen einen höheren Infrastrukturaufwand zur Installation der Module auf, was beispielsweise etwas höhere Treibhausgasemissionen und Abfallaufkommen verursacht. Gaskraftwerke sind differenziert zu betrachten: Mit Erdgas betrieben weisen sie die in diesem Technologievergleich mit Abstand höchsten Treibhausgasemissionen auf. Auch die Anwendung von CO_2-Abscheidung und -Speicherung reduziert diese Emissionen lediglich um rund 60% (bei angenommenen 50% Flüssiggas in der Erdgasversorgung). Dies liesse sich auf maximal etwa 80% steigern, falls ausschliesslich Erdgas via Pipeline aus Norwegen bezogen würde. Die Nutzung von Biomethan und Wasserstoff in Gaskraftwerken reduziert die Treibhausgasemissionen mehr als 90%, sofern wie hier angenommen das Biomethan aus biogenen Reststoffen stammt und der Wasserstoff via Wasserelektrolyse mit Strom aus Fotovoltaikanlagen produziert wird. Bei den kritischen Rohstoffen weisen Wind- und Fotovoltaik-Kraftwerke tendenziell einen höheren Verbrauch auf als Kern- und Gaskraftwerke, wobei dazu noch eine vertiefte Betrachtung der Versorgungsrisiken für alle Technologien empfohlen wird, da die vier ausgewählten Metalle und die angewandte Methodik naturgemäss nur beschränkte Schlussfolgerungen hinsichtlich Versorgungsrisiken zulassen.

Der Vergleich der Umweltauswirkungen der Herstellung der verschiedenen Batterien zeigt, dass die Ergebnisse stark von der Technologie abhängen. Generell kann festgestellt werden, dass sich ein geringerer Gehalt an Metallen wie Nickel und Kobalt positiv auf die Umweltbelastungen auswirkt, da die Gewinnung und Aufbereitung dieser Rohstoffe relativ hohe Umweltbelastungen verursachen. Technologischer Fortschritt bei den Batterien etwa in Form von gesteigerter spezifischer Energiedichte wird die herstellungsbedingten Umweltbelastungen in Zukunft deutlich reduzieren. Abschliessende Aussagen, welche Art von Batterien aus Umweltperspektive bevorzugt zur Anwendung kommen sollten, lassen sich basierend auf der vorliegenden Analyse nicht ziehen; sie werden erst möglich, wenn auch das Nutzungsprofil der Batterietechnologien berücksichtigt wird, wodurch auch Parameter wie Stromverluste und Lebensdauern der Batterien in die Bewertung einfliessen.

Zukünftige Arbeiten im Bereich der Umweltbelastungen der Stromversorgung sollten das Stromversorgungssystem insgesamt abbilden, da der Blick auf einzelne Technologien nur beschränkt aussagekräftig ist. Hierzu können Energiesystemmodellierung und Ökobilanzen kombiniert werden. Eine solcherart integrierte Analyse könnte tägliche und saisonale Produktionsprofile sowie das Zusammenspiel einzelner Technologien inkl. Stromspeicherung berücksichtigen und die Umweltbelastungen verschiedener Optionen zur Stromversorgung der Schweiz insgesamt abbilden.

2   Summary

This report provides an overview of the environmental burdens of various electricity generation technologies in Switzerland today, in 2035, and in 2050. The technology portfolio includes wind and photovoltaic power plants, gas-fired power plants operated with natural gas, biomethane, and hydrogen, with CO_2 capture and storage, as well as new nuclear power plants. The environmental burdens are quantified using Life Cycle Assessment (LCA) methodology over the entire value chains of the power plants. The calculated set of environmental indicators includes greenhouse gas emissions, land use, damage to ecosystems, high-level radioactive and toxic non-radioactive waste, and a selection of so-called "critical raw materials" (CRM) (nickel, cobalt, lithium, and neodymium). These environmental indicators are calculated for the production of stationary lithium-ion and sodium-ion batteries in addition to electricity production.

The results show that wind and rooftop photovoltaic power plants have the lowest overall impact in terms of the environmental indicators calculated here and do not cause any significant pollution in comparison with the other technologies in any of the indicators. With the exception of high-level radioactive waste, this is also the case for nuclear power plants. Ground-mounted photovoltaic systems have the disadvantage over rooftop systems in that they require additional land use. Depending on the type of land used, this can have adverse effects on ecosystems. Furthermore, ground-mounted systems require more infrastructure to install the modules, which results in slightly higher greenhouse gas emissions and waste generation, for example. Gas-fired power plants must be viewed in a differentiated manner: when powered by natural gas, they have by far the highest greenhouse gas emissions in this technology comparison. Even the use of CO_2 capture and storage reduces these emissions by only around 60% (assuming 50% liquefied gas in the natural gas supply). This could be increased to a maximum of around 80% if natural gas were sourced exclusively via pipeline from Norway. The use of biomethane and hydrogen in gas-fired power plants reduces greenhouse gas emissions by more than 90%, provided that, as assumed here, the biomethane comes from biogenic residues and the hydrogen is produced via water electrolysis using electricity from photovoltaic systems. In terms of critical raw materials, wind and photovoltaic power plants tend to consume more than nuclear and gas-fired power plants. However, a more in-depth analysis of the supply risks for all technologies is recommended, as the four metals selected and the methodology used naturally allow only limited conclusions to be drawn regarding supply risks.

A comparison of the environmental impacts of manufacturing different types of batteries shows that the results depend heavily on the technology used. In general, it can be concluded that a lower content of metals such as nickel and cobalt has a positive effect on environmental burdens, as the extraction and processing of these raw materials cause relatively high environmental impacts. Technological advances in batteries, for example, in the form of increased specific energy density, will significantly reduce the environmental impact of manufacturing in the future. Based on the present analysis, it is not possible to draw any conclusive statements as to which type of batteries should be preferred from an environmental perspective; this will only be possible once the usage profile of battery technologies is also taken into account, which will allow parameters such as power losses and battery life to be included in the assessment.

Future work in the field of environmental impacts of electricity supply should reflect the electricity supply system as a whole, as looking at individual technologies alone is of limited significance. Energy system modeling and LCA can be combined for this purpose. Such an integrated analysis could take into account daily and seasonal production profiles as well as the interaction of individual technologies, including electricity storage, and depict the environmental impact of various options for electricity supply in Switzerland as a whole.

3   Introduction

3.1   Background

As part of their "Axpo Energy Reports" project, Axpo is investigating four electricity generation technologies to secure (winter) electricity supply in Switzerland: wind power plants, photovoltaic systems, new nuclear power plants, and gas-fired power plants; further, hydrogen production via water electrolysis and its use in gas power plants, and electricity storage in stationary batteries are explored. The aim is to evaluate these technologies objectively and transparently, covering costs, security of supply, environmental impact, and macroeconomic effects. The objective is to develop a consistent, science-based set of indicators to compare technologies across key political, economic, environmental, and social issues.

The Technology Assessment group at PSI, part of the Laboratory for Energy Systems Analysis (PSI-LEA[1]), contributes to this project by providing environmental performance indicators for power generation, hydrogen production, and battery production based on environmental Life Cycle Assessment (LCA). As Axpo is supposed to analyze different future scenarios, these environmental performance indicators are provided in a forward-looking (referred to as "prospective") manner for the period 2025-2050.

3.2   Content of this report

This report provides a brief description of the methodology (section 4) for quantifying environmental performance indicators, along with the methods and tools used for this purpose. Further details are available in the cited literature and are not explained here, as method and tool development have not been part of this contract. Next, technologies and their performance are specified (section 5). Further, results for environmental performance indicators are presented and discussed (section 6). The Appendix (section 9) contains the complete set of numerical results.

---

[1] https://www.psi.ch/en/lea

4   Methodology: Prospective Environmental Life Cycle Assessment (*p*LCA)

4.1   Goal and scope

The environmental performance indicators are quantified for new power plants and batteries to be installed in Switzerland. On the one hand, for units that correspond to the current state of the art and could be built today or in the near future ("year 2025"), and on the other hand, for hypothetical units at the expected state-of-the-art in 2035 and 2050. For the calculation of environmental indicators relating to material and energy supply chains, future units are embedded in Swiss and global economic systems that represent a development towards the goal of net-zero greenhouse gas (GHG) emissions, as demonstrated in (Hahn Menacho, Sacchi, Bauer, Moretti, et al., 2025) based on (Panos et al., 2024; Sacchi & Hahn Menacho, 2024).

It is important to consider a forward-looking perspective, reflecting both the potentially differing technology-specific development potential and the fact that some technologies will take longer to reach maturity. Furthermore, it is in Axpo's interest to reflect the future state of the art in their scenarios.

The environmental indicators for the individual technologies are quantified using environmental (prospective) Life Cycle Assessment (LCA) in line with established procedures (ISO, 2006a, 2006b). LCA is the method of choice for quantifying the environmental burdens of goods and services over their entire life cycles (Hauschild et al., 2018). In the case of electricity production, this includes construction, operation and disposal of power plants with associated complete material and energy supply chains; for batteries, this includes their manufacture and disposal or recycling – the environmental impact of battery operation results from the operational lifetime of the batteries, the type of electricity stored and storage losses, and can be taken into account by Axpo in scenarios. Thanks to comprehensive LCA, the environmental impact (i.e., emissions to the environment and use of natural resources) of all relevant processes in the material and energy supply chains for the construction, operation, and disposal [2] of the power plants is considered. Version v3.11 of the ecoinvent database [3] is used as the source for LCA background data, with the system model "allocation, cut-off by classification" (Wernet et al., 2016). The prospective LCA framework *premise* (Sacchi et al., 2022), building upon the ecoinvent LCA database, is used to calculate the indicator set for 2025, 2035, and 2050, in conjunction with Swiss and global net-zero scenarios (Hahn Menacho, Sacchi, Bauer, Moretti, et al., 2025) to map the decarbonization of the national and international economy, which means that for 2035 and 2050, we assume a specific technological development of the Swiss and global economic system in line with ambitious climate targets, which is reflected by changes in the unit processes of the used background LCI data (Panos et al., 2024; Sacchi & Hahn Menacho, 2024). Such a development is reflected in, for example, increasing shares of renewable power generation technologies in the European and global power supply, further electrification of passenger and freight on-road transport, and the use of synthetic non-fossil fuels in shipping.

4.2   Functional units

Functional units (FU) applied here to quantify the environmental burdens are the following:

- 1 TWh of electricity produced by the power plants (at the power plants, without any power transmission, distribution, or storage)

---

[2] The term "disposal" includes any kind of end-of-life treatment of infrastructure. In general, metal components are assumed to be recycled, and non-recyclable elements are to be disposed of via waste incineration or waste deposits. Usually, end-of-life treatment is performed in the same geographical region as the installation and operation of infrastructure.
[3] www.ecoinvent.org

- 1 kWh of electricity gross storage capacity for batteries (manufacturing-related environmental burdens and material consumption only, without battery operation)

4.3   Life Cycle Inventories (LCI)

Life cycle inventories are covered as part of Section 5.

4.4   Life Cycle Impact Assessment (LCIA)

The "Environmental Footprint, v3.1" method (European Commission, 2021), as implemented in the ecoinvent database, provides several midpoint indicators, of which the following are used to quantify:

- Impacts on climate change, i.e., greenhouse gas emissions (measured in kilograms of CO_2 equivalents, applying a time horizon of 100 years)
- land use in terms of overall land occupation (measured in m^2-year)

ReCiPe 2016, v1.03 (H), endpoint – ecosystem quality, is used to quantify:

- damage to ecosystems in terms of species lost (measured in species loss-year, that is, the integration of species loss over time)

Waste indicators are calculated from the total life cycle inventory results, with two categories representing radioactive and non-radioactive waste:

- hazardous non-radioactive waste: kilograms of waste deposited underground[4]
- radioactive waste: m^3 of highly radioactive waste to be stored in geological nuclear waste repositories[5]

Critical Raw Material (CRM) demand is quantified using cumulative life-cycle inventory results for individual materials, as recently demonstrated by Hahn Menacho, Sacchi, Bauer, Moretti, et al. (2025) for prospective scenarios of the development of the Swiss energy system.

The following selected materials are considered:

- Lithium – primarily used in batteries,
- Cobalt – used mainly in batteries,
- Nickel – used mainly in alloys, catalysts, and batteries,
- Neodymium – representing rare earth elements, used in a broad range of energy technologies and applications, e.g., electric motors, wind turbines.

Demand for all these materials is expected to increase substantially with the transition of the energy system (Hahn Menacho, Sacchi, Bauer, Moretti, et al., 2025; Hahn Menacho, Sacchi, Bauer, Panos, et al., 2025). Further, all these CRM are economically important for Europe and subject to relatively high supply risks (European Commission, 2023; International Energy Agency, 2025).

---

[4] This non-radioactive hazardous waste corresponds to waste which needs to be stored in underground deposits due to its hazardous characteristics and cannot be disposed of via, e.g., municipal waste incineration.
[5] In our LCA model, such radioactive waste is only generated by nuclear power plants.

5 Technology specification and Life Cycle Inventories (LCI)

LCA-based environmental performance indicators are quantified for power generation and stationary battery storage capacity.

5.1 Power generation

Four key technologies for electricity production with few variants are evaluated, all to be operated in Switzerland:

1) Wind turbines – reference years 2025, 2035, and 2050
2) Solar photovoltaic (PV) plants – reference years 2025, 2035, and 2050
3) Combined Cycle gas power plants – reference years 2035 (biomethane and natural gas), and 2050 (biomethane, natural gas with CCS, and hydrogen)
4) Nuclear power plants – reference year 2050

5.1.1 Wind turbines

The life cycle inventories represent medium-sized onshore wind turbines (based on a 2 MW model, using a gearbox[6]), which are expected to be installed in Switzerland today and in the future[7]. They are operated under average Swiss wind conditions, with expected yield improvements driven by technology development. The capacity factors used for the LCA are specified in line with the economic assessment in the "Axpo Energy Reports" project. The corresponding full-load hours are provided in Table 5.1. Assumed lifetime is 25 years.

Table 5.1: Full load hours and capacity factors of onshore wind turbines applied in this assessment.

Onshore wind turbines, 2 MW rated power, Switzerland	2025	2035	2050
Annual full load hours [hours/year]	1539	1700	1974
Capacity factor [%]	17.6	19.4	22.5

5.1.2 Solar photovoltaic (PV) plants

We distinguish between rooftop[8] and open-ground[9] installations. Open-ground installations refer to PV plants installed on the Swiss plateau ("Mittelland"), not to alpine constructions. Both PV plant types are operated under average Swiss conditions, with capacity factors specified in line with the economic assessment in the "Axpo Energy Reports" project, and provided in Table 5.2. Assumed lifetime is 30 years.

Table 5.2: Full load hours and capacity factors of solar PV installations applied in this assessment.

	2025	2035	2050
Roof-top PV plants (monocrystalline-Si)			
Annual full load hours [hours/year]	950	950	950
Capacity factor [%]	10.3	10.3	10.3
Open-ground PV plants (monocrystalline-Si)			
Annual full load hours [hours/year]	1000	1000	1000
Capacity factor [%]	10.8	10.8	10.8

---

[6] The alternative, direct-drive/permanent magnets technology, mainly deployed offshore, uses much higher quantities of rare earth elements.

[7] Corresponding unit process of the ecoinvent database: "electricity production, wind, 1-3MW turbine, onshore" (Switzerland).

[8] Corresponding unit process of the ecoinvent database: "electricity production, photovoltaic, at 3 kWp slanted-roof, single-Si, panel, mounted" (Switzerland).

[9] Corresponding unit process of the ecoinvent database: "electricity production, photovoltaic, at 560 kWp open ground, single-Si" (Switzerland).

5.1.3   Gas power plants

The LCI represents modern combined-cycle gas power plants[10]. For 2050, an option with carbon capture and storage (CCS) with CO_2 transport via pipeline to depleted gas fields in the North Sea is included, based on Volkart et al. (2013). Besides natural gas, biomethane and hydrogen are included as potential fuels. That hydrogen is imported via a dedicated hydrogen pipeline from Spain over 1,500 kilometers (see section 5.2). By default, results in this report (section 6) are shown for power plants operating 2'000 hours per year. Power plant net efficiencies (Table 5.3) depend on the fuel and on whether CCS is implemented or not, and are specified in line with the economic assessment. All environmental burdens are assigned to the electricity produced. The power plant's lifetime is assumed to be 25 years.

For natural gas supply in 2035 and 2050, it is assumed that 50% of the supply is imported from Norway via pipeline, and 50% from the US as LNG. Norwegian gas corresponds to "clean gas from the neighborhood", while LNG imported from the US is energy-intensive and associated with comparatively high methane emissions. Results are shown for both of these options separately in the section 6.7.

Table 5.3: Gas power plant net efficiencies. Efficiencies are expressed relative to the lower heating value (LHV) of the fuel.

Net electric efficiencies of gas power plants using different fuels [%]	2035	2050
Natural gas	62	62
Natural gas with CCS	44.6	44.6
Biomethane	62	62
Hydrogen	59	59

5.1.4   Nuclear power plants

The LCI represents a potential European Pressurized Reactor (EPR)[11] to be operational in 2050, based on (Simons & Bauer, 2012). The reactors are assumed to operate at 7446 full-load hours per year and to have conservative lifetimes of 60 years[12].

5.2   Hydrogen production

Hydrogen is used as a fuel in Combined Cycle (CC) gas power plants installed in 2050. For hydrogen production, Proton Exchange Membrane (PEM) electrolyzers used for water electrolysis are evaluated (Bauer et al., 2022), with life cycle inventories based on Bareiß et al. (2019). These PEM electrolyzers split water into hydrogen and oxygen, using electricity as an energy source. The oxygen is released to the atmosphere, and waste heat is not valorized, leaving the environmental burdens entirely assigned to the main product, hydrogen.

According to Axpo's scenarios, hydrogen for CC power plants will be imported, produced in Spain using electricity from PV power plants operating under average Spanish conditions. Hydrogen is assumed to be imported to Switzerland via 1,500 km of hydrogen pipelines[13]. Temporal dynamics in hydrogen production are not considered, and the electrolyzers are assumed to be operated in continuous mode. The electrolyzer consumes 54 kWh of electricity per kg of hydrogen produced. Hydrogen storage is not considered. Hydrogen transport via pipeline is associated with minor hydrogen emissions due to

---

[10] Corresponding unit process of the ecoinvent database: "electricity production, natural gas, combined cycle power plant" (Switzerland).
[11] The economic part of the "Axpo Energy Reports" project also includes an AP1000 Westinghouse reactor. Due to a lack of corresponding LCI, we refrain from performing an LCA. Based on a parametric LCA model for nuclear power generation (Gibon & Menacho, 2023), it can be expected that LCA results for both reactor types do not exhibit fundamental differences.
[12] Lifetime of nuclear reactors exhibits a minor influence on LCA results of nuclear power generation (Gibon & Menacho, 2023).
[13] It is assumed that by 2050, a large-scale, European hydrogen pipeline network will exist. Only a fraction of pipeline construction-related environmental burdens is assigned to the hydrogen transported to the Swiss gas power plant, in proportion to this hydrogen vs. the overall hydrogen transport volumes.

leaks (i.e., about 0.7% of the mass transported)[14]. Power from the on-site PV installation is used to initially compress the hydrogen before injection, while intermediate re-compression steps along the pipeline every 250 km are powered with average European electricity.

5.3 Stationary batteries

Three different types of stationary batteries are evaluated here:

1) Lithium-ion, Nickel-manganese-cobalt-oxide (NMC)
2) Lithium-ion, Lithium-iron-phosphate (LFP)
3) Sodium-ion (Na-ion)

While further battery technologies exist (e.g., Vanadium Redox-flow batteries), we limit our evaluation to the technologies mentioned above, as these can be considered the most mature and seem to profit most from technological development and upscaling in the automotive sector (ams - automotive manufacturing solutions, 2024; McKinsey, 2024; Nichols, 2025). We do not differentiate between small-scale, home-owned batteries and large-scale utility batteries, as reliable information on associated differences in LCI data is missing.

Life cycle inventories for the Li-NMC battery are sourced from the ecoinvent database[15]. Battery cells are made of a nickel-manganese-cobalt (NMC_{811}) cathode, a graphite-based anode, a liquid electrolyte, and a porous plastic separator. Battery production involves assembling cells with the Battery Management System (BMS) and additional materials for the casing/electronics. The inventory is modelled according to (Dai et al., 2018), which presents a battery pack with gross pack energy of 23.5 kWh made of 140 3.6V-46Ah prismatic cells, with a specific energy of 0.28 kWh/kg cell in 2020, increasing to 0.34 kWh/kg cell in 2050.

Life cycle inventories for the Li-LFP battery are sourced from the ecoinvent database[16]. The inventory is modelled according to (Dai et al., 2017, 2018), which presents a battery pack weighing 203 kg, with a gross pack energy of 23.5 kWh, comprising 137 3.6V-46Ah prismatic cells. Cells are made of a lithium iron phosphate (LFP) cathode and a graphite-based anode, a liquid electrolyte, and a porous plastic separator. Battery cell energy density of 0.16 kWh/kg cell in 2020, increasing to 0.22 kWh/kg cell in 2050.

Life cycle inventories for the Na-ion battery are based on (S. Zhang et al., 2024). The NMMT//HC battery is a cylindrical 21700 sodium-ion cell that uses a layered oxide NMMT cathode and a fossil-based hard carbon (HC) anode. The NMMT cell operates at 3.2V, delivers a cell capacity of 2748mAh, and has a specific energy of 0.16 kWh/kg of battery cell in 2020, increasing to 0.20 kWh/kg of battery cell in 2050.

The most important future development regarding the environmental footprint of batteries will be an increase in their specific energy density, i.e., the kWh of storage capacity per kilogram of battery. The development of this specific energy implemented in the LCA here is based on the projections for all battery technologies provided by (Hasselwander et al., 2023)[17].

---

[14] As hydrogen acts as an indirect greenhouse gas. Some studies, therefore, assign a global warming potential (GWP_{100}) of 11.6 to hydrogen emissions (Sand et al., 2023). As uncertainties regarding leakage and resulting warming are high, we refrain from this.

[15] Corresponding unit process of the ecoinvent database: "market for battery, Li-ion, NMC811, rechargeable".

[16] Corresponding unit process of the ecoinvent database: "market for battery, Li-ion, LFP, rechargeable".

[17] Further details regarding battery technology specifications and life cycle inventories can be found here: https://premise.readthedocs.io/en/latest/transform.html#mobile-batteries

6 Results

This section provides an overview of the results, i.e., the quantification of environmental performance indicators for power generation technologies and batteries. Results for wind and PV plants are provided for 2025, 2035, and 2050; gas power plants are assumed to be operated with natural gas as fuel in 2035 and 2050 (with CCS in 2050), as well as biomethane in 2035 and 2050, and hydrogen in 2050; nuclear power is only shown as an option in 2050. Complete numerical results for all options in the relevant reference years, including those quantified per MW installed power generation capacity, are provided in the Appendix (section 9, Table 9.1). All visualized results contain a breakdown of emissions occurring within Switzerland ("CH"), and abroad ("non-domestic"); this split of emissions is a result of the location of each unit process of the LCA in each of the power generation or battery technologies life cycles – unit processes categorized as "Swiss", i.e., located in Switzerland, generate direct emissions in Switzerland, those located anywhere else generate non-domestic emissions.

6.1 Impacts on climate change – greenhouse gas emissions

Figure 6.1 and Figure 6.2 show GHG emissions of power generation and battery manufacturing.
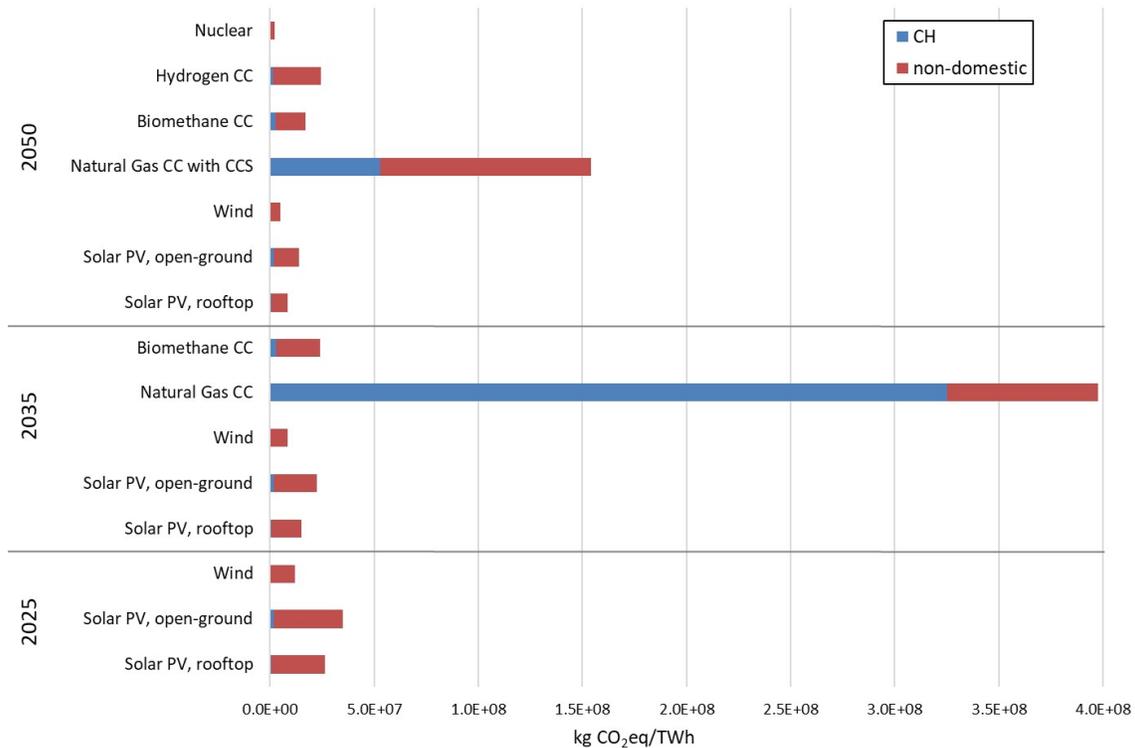
Figure 6.1: Greenhouse gas emissions per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent emissions within Switzerland, the red segments represent emissions along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.

Electricity from natural gas power plants causes the highest emissions, especially if not equipped with CCS, while electricity from renewables and nuclear causes the lowest. CCS considerably reduces the emissions of the natural gas power plant, but supply chain-related GHG emissions from CCS are also substantial, resulting in a total reduction of about 60%. Using hydrogen in 2050 instead of natural gas in a combined cycle power plant would – with the assumptions taken here – reduce life cycle GHG emissions by about 85%, as hydrogen production and import to Switzerland result in relatively low GHG emissions, mostly due to the electricity consumption of the electrolyzer (provided by large-scale PV installations), and electricity consumption assumed to be provided by the average European grid

for hydrogen transport. Using biomethane instead of natural gas reduces GHG emissions by about 90%, if biomethane is, as assumed here, produced predominantly using residual biomass. GHG emissions caused by renewables will go down substantially until 2050, due to both technological improvements and the trend toward phasing out fossil fuels in Europe and globally. Apart from natural gas power plants, none of the technologies included here generate significant domestic GHG emissions.

The main source of life cycle GHG emissions (mainly CO_2) is the combustion of fossil fuels for all power generation technologies – for natural gas power plants, direct combustion-related CO_2 emissions dominate; for all other technologies, fossil fuels are burned to provide energy throughout various steps in the life cycle, from resource extraction and refining to manufacturing of power plant components. The share of fossil fuels as an energy source overall is assumed to decline, but nevertheless, not be reduced to zero by 2050 globally.

Figure 6.2: Greenhouse gas emissions per kWh electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent emissions caused within Switzerland, the red segments represent emissions along value chains abroad.

Greenhouse gas emissions from battery production are between 40 and 100 kg CO_2eq/kWh of storage capacity today. According to this analysis, they will drop to 20-30 kg CO_2eq/kWh by 2050, driven by both technological improvements and the trend toward phasing out fossil fuels in Europe and along the battery manufacturing supply chain (i.e., in China and other Asian countries). Reductions are more pronounced for Li-ion batteries than for Na-ion batteries; their GHG emissions are already lowest today. Practically all GHG emissions from batteries are caused outside Swiss borders, as production is assumed to take place entirely abroad. Only GHG emissions related to battery installation in Switzerland, e.g., the balance-of-plant system, show as domestic emissions – these are slightly higher for Na-ion batteries and for Li-ion batteries, mainly due to the superior energy density of Li-ion batteries: Na-ion batteries have a significantly lower volumetric density than Li-ion batteries (~-40%)

and also appear to have a lower round-trip efficiency (85-92% vs. 92-98%) and cycle-life (2,000-3,000 vs. 4,000-10,000 cycles); these aspects are not considered in the chosen functional unit.

As for power generation, life cycle GHG emissions are mainly caused by fossil fuel combustion throughout the battery production value chains: on the one hand, as energy carriers in metal mining and refining, on the other hand, for the provision of heat and electricity in battery cell production.

6.2 Land use

Figure 6.3 and Figure 6.4 show land occupation of power generation and battery manufacturing. In this comparison, electricity production from burning hydrogen and from open-ground PV installations results in the highest land use. Unlike open-ground installations, rooftop PV plants do not cause direct land use, as the roof area is not assigned to the PV panels but to the buildings. For the open-ground PV plants, direct land use due to open-ground installations in Switzerland is the most important contributor. As module efficiency increases, this direct land use will decrease in the future. The electricity from hydrogen combustion causes substantial land use beyond Swiss borders, predominantly due to open-ground PV installations in Spain that supply electricity to the electrolyzer, and (to a much less important extent) indirectly due to electricity consumption, e.g., for hydrogen transport to Switzerland via pipeline. Land use from biomethane combustion results mainly from the small share of wood used as feedstock for biomethane production (only 2%; the rest is produced via upgrading of biogas from anaerobic digestion of biogenic waste), and even if this wood is assumed to be harvested in sustainable ways, forests do occupy land. For all other technologies, land use is distributed over all infrastructure needed along the power generation value chains and is also associated with fossil fuel extraction, metal and mineral mining, and waste disposal.

Figure 6.3: Land occupation per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent land use within Switzerland, and the red segments represent land use along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.

Batteries cause the vast majority of land use along their production and supply chains, mostly due to metal and mineral mining, including disposal of associated waste. Further land use is due to the

extraction of fossil fuels, which are needed as energy carriers along the value chains. As Na-ion batteries contain fewer metals than the Li-ion batteries included here, overall land use is also smaller.
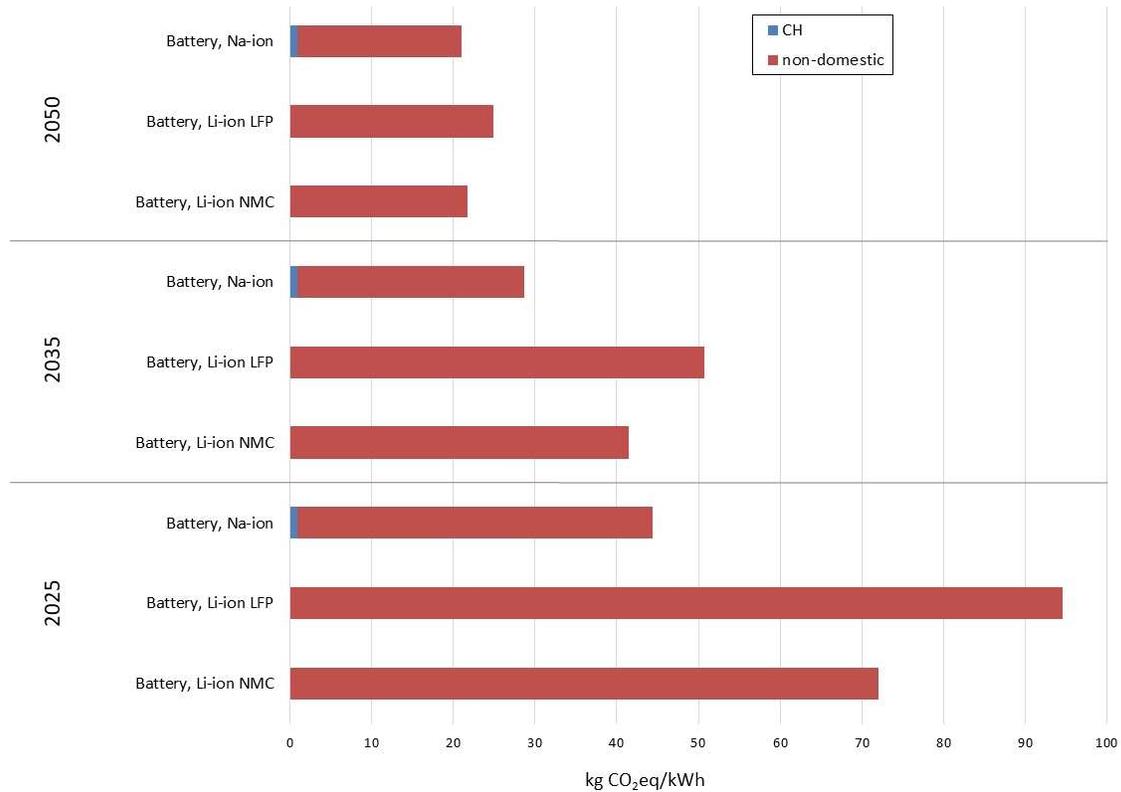

Figure 6.4: Land occupation per kWh electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent land use within Switzerland, and the red segments represent land use along value chains abroad.

6.3 Damage to ecosystems

Figure 6.5 and Figure 6.6 show ecosystem impacts from power generation and battery manufacturing. Damage to ecosystems is caused by a broad range of burdens and impacts – for example, pollutant emissions into air, soil, and water, land and water use, and impacts on climate change. The sources of these burdens and damages are often well distributed over the value chains of power generation technologies. Among the technologies compared here, the natural gas CC plant and the hydrogen combustion power plant cause the greatest ecosystem damage – mostly due to greenhouse gas emissions in the case of natural gas production, land use, and water consumption associated with hydrogen production. In general, damages occur both within Switzerland and abroad. Natural gas power plants cause ecosystem damage primarily through their direct impacts on climate change (i.e., their CO_2 emissions from natural gas combustion), while using hydrogen as fuel results in ecosystem damage mainly due to land occupation by PV plants in Spain. Open-ground PV installations in Switzerland mainly cause ecosystem damage by occupying land in Switzerland. Roof-top PV, wind, and nuclear power plants cause the least ecosystem damage, with no single outstanding source of ecosystem damage.

Results for ecosystem damage from battery manufacturing and installation are very similar to those for GHG emissions and land use. Also, ecosystem damage is mostly associated with metal mining and refining, including associated waste disposal.
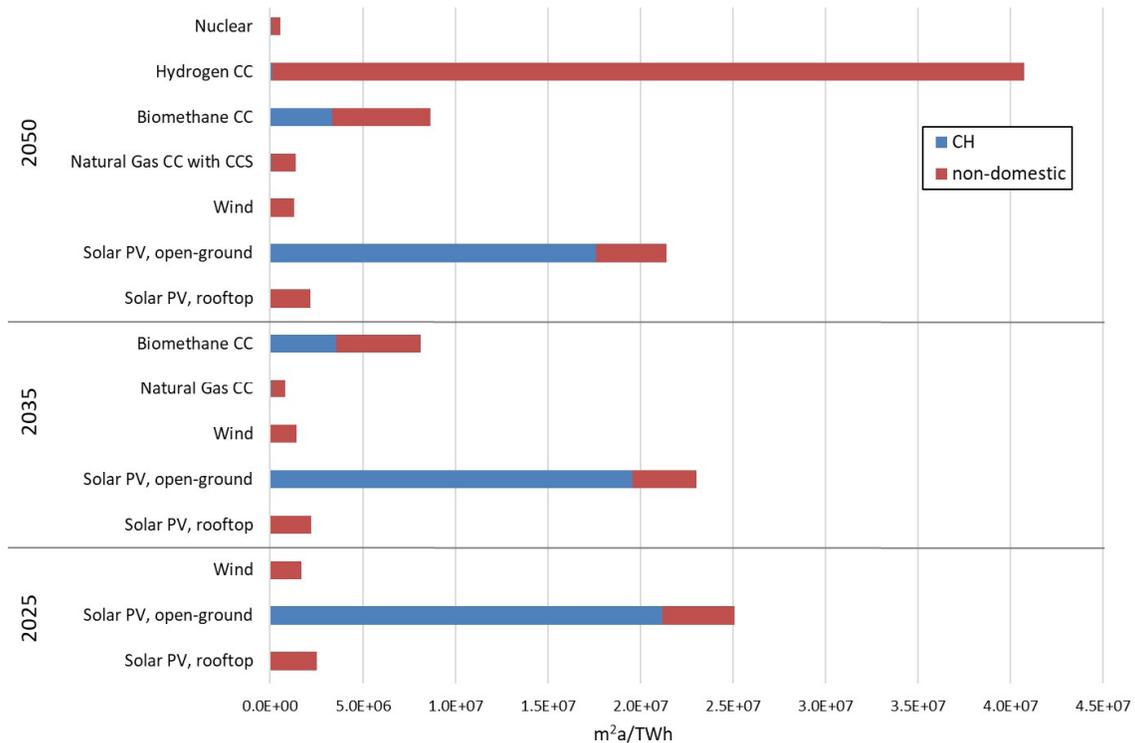
Figure 6.5: Ecosystem damages per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent burdens causing ecosystem damage within Switzerland; the red segments, those along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.

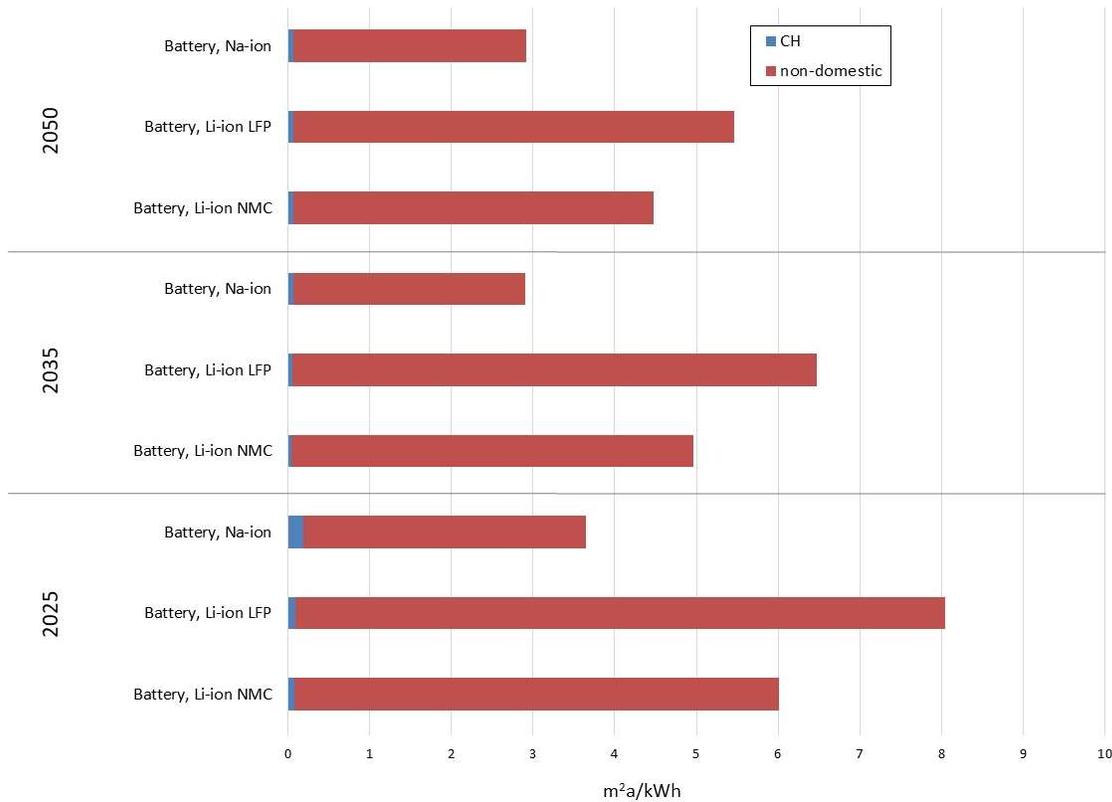**Figure 6.6: Ecosystem damages per kWh of electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent ecosystem damages within Switzerland, and the red segments represent ecosystem damages along value chains abroad.**

6.4 Hazardous waste, non-radioactive

Figure 6.7 and Figure 6.8 show non-radioactive hazardous waste due to power generation and battery manufacturing. This non-radioactive hazardous waste requires storage in underground deposits due to its hazardous characteristics and cannot be disposed of via conventional means (e.g., municipal waste incineration).

These wastes are almost exclusively caused along the power generation-related value chains abroad. In the case of an open-ground PV power plant, these wastes are mostly related to copper refining, with copper also needed for electrical installations throughout the entire economy. In the case of a combined-cycle power plant using hydrogen as fuel, the toxic waste is also related to iridium mining and refining, with iridium needed for the electrolyzer; to the steel supply chain, with steel used for hydrogen pipelines; and to tailings from copper refining, with copper needed for electrical installations. As opposed to other environmental burdens quantified, there is no clear reduction trend towards 2050. This is due to the assumed massive electrification of the economy, which leads to a generally increasing demand for metals and minerals; the associated mining activities are an important source of hazardous waste. In the far future, some of this electrification-related infrastructure might be recycled, which is not taken into account in this analysis. Still, as long as demand for such infrastructure remains increasing, demand for primary metals and minerals will exceed the supply of secondary metals.

Battery production-related toxic waste is mainly generated by metal and mineral mining and refining. Thus, the quantities of such hazardous wastes are higher for Li-ion batteries than for Na-ion batteries, since the latter contain lower amounts of critical raw materials.

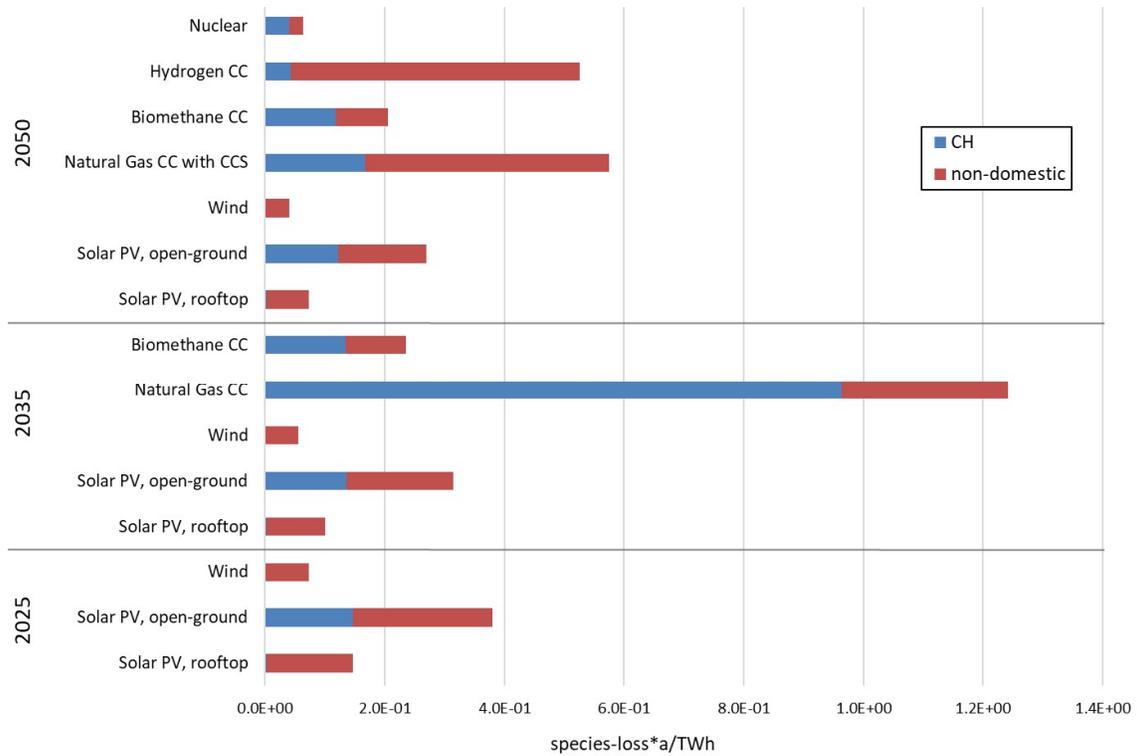**Figure 6.7: Non-radioactive hazardous waste per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent waste generated within Switzerland, the red segments represent waste generated along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.**
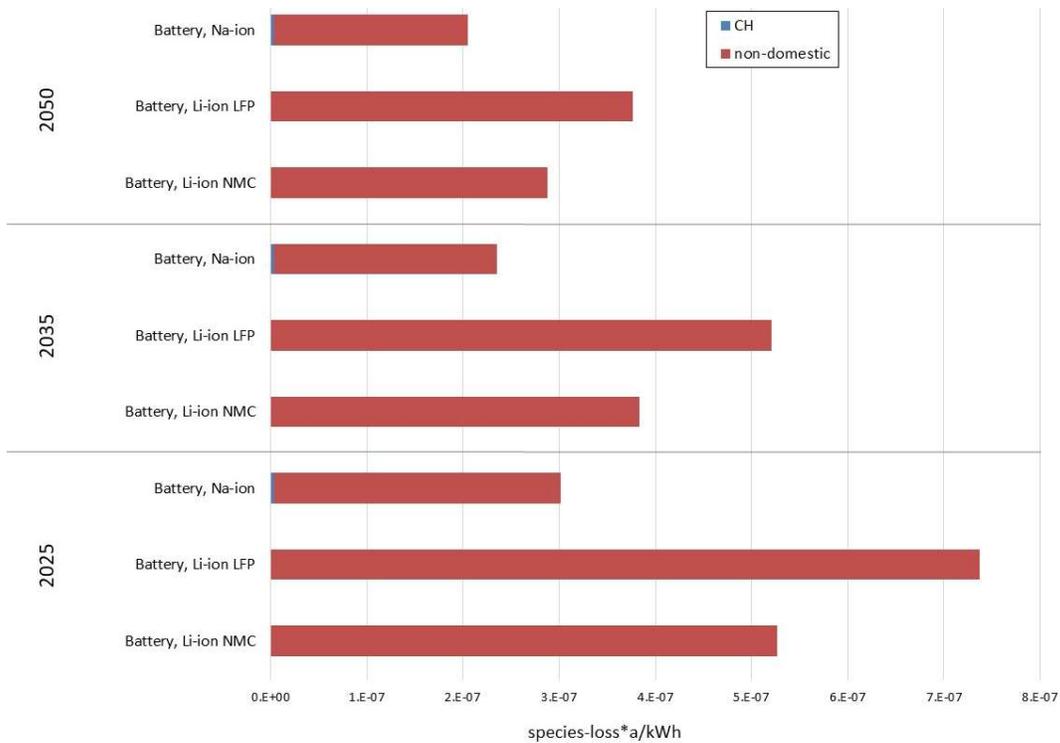
Figure 6.8: Non-radioactive hazardous waste per kWh electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent waste generated within Switzerland, the red segments represent waste generated along value chains abroad.

6.5   Radioactive waste

Figure 6.9 and Figure 6.10 show high-level radioactive hazardous waste to be disposed of in a geological repository due to power generation and battery manufacturing. In our LCA model, such radioactive waste is only generated by nuclear power plants. Therefore, these results (except for electricity from Swiss nuclear power) reflect the use of nuclear power along the value chains – most visible for the hydrogen and biomethane combined cycle plants. Here, the radioactive waste originates from nuclear power used in the European electricity grid, as grid electricity is used as an energy supply for hydrogen transport via pipeline, as well as for biomethane production. Compared to the direct use of nuclear power, the volumes of such indirectly caused high-level radioactive waste are very small.

Figure 6.9: High-level radioactive waste per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent waste generated within Switzerland, the red segments represent waste generated along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.

Figure 6.10: High-level radioactive waste per kWh electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent waste generated within Switzerland, the red segments represent waste generated along value chains abroad.

6.6 Metal demand: lithium, nickel, cobalt and neodymium

Figure 6.11 to Figure 6.14 show metal demand per TWh of electricity generated with the different power generation technologies, in 2025, 2035, and 2050.

In general, demand for these materials for electricity generation technologies is small in absolute terms. Cobalt and nickel are needed in special types of steel and electric equipment, and demand is highest for power generation using hydrogen, open-ground PV installations, and wind turbines, as these technologies need most of these special steel types. Demand for these materials is expected to decline slightly in the future. The opposite is true for lithium, whose demand will be increasing according to our analysis; however, these power generation technologies do not directly require lithium, and the rising demand is an indirect effect of the electrification of the entire economy, which comes with the use of more and more batteries for both mobility and stationary electricity storage. Neodymium is, in this comparison, primarily used in magnets for wind turbines. This drives the comparatively high demand for future natural gas-based and hydrogen-based electricity production in the combined-cycle plant (with CCS in the case of natural gas), as wind power is an (increasingly) important technology in the European electricity market, and electricity is needed for CO_2 and hydrogen transport via pipeline.
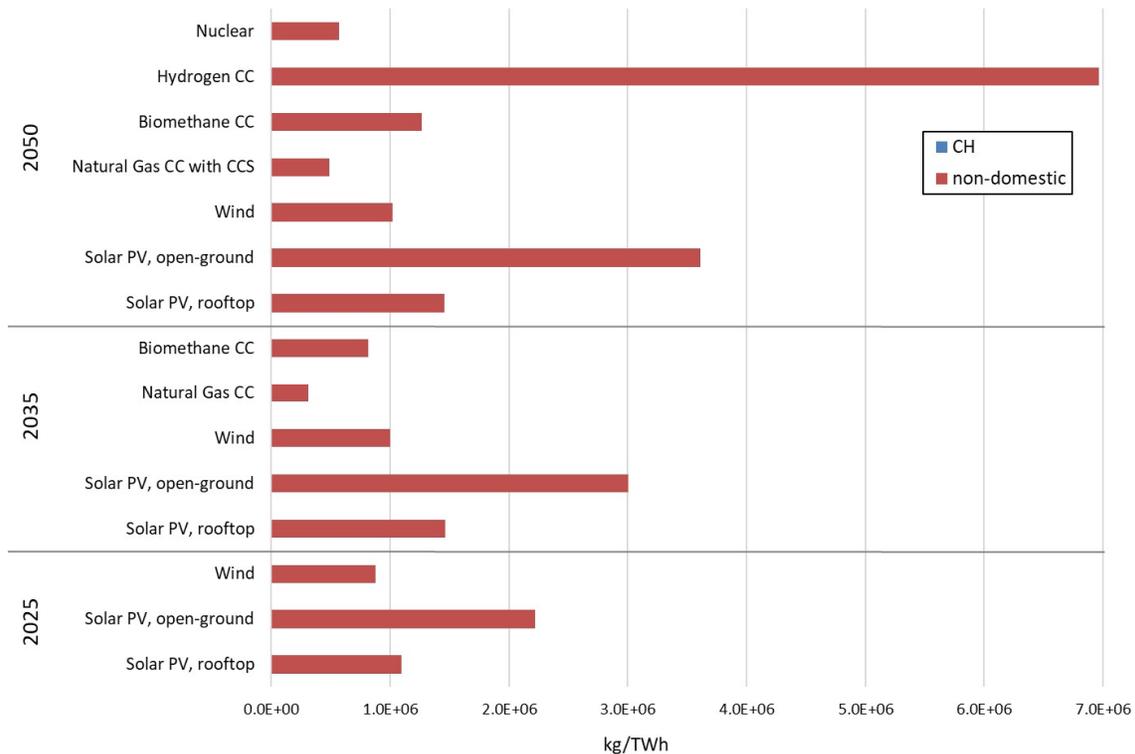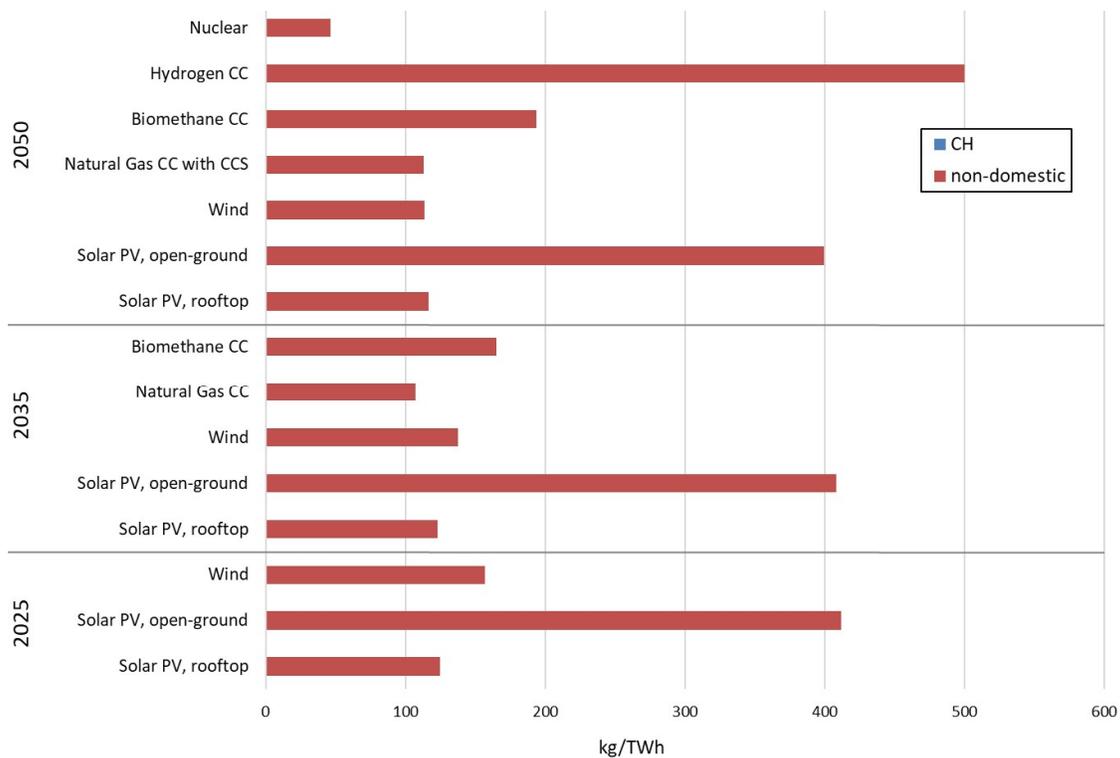

Figure 6.11: Cobalt demand per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.
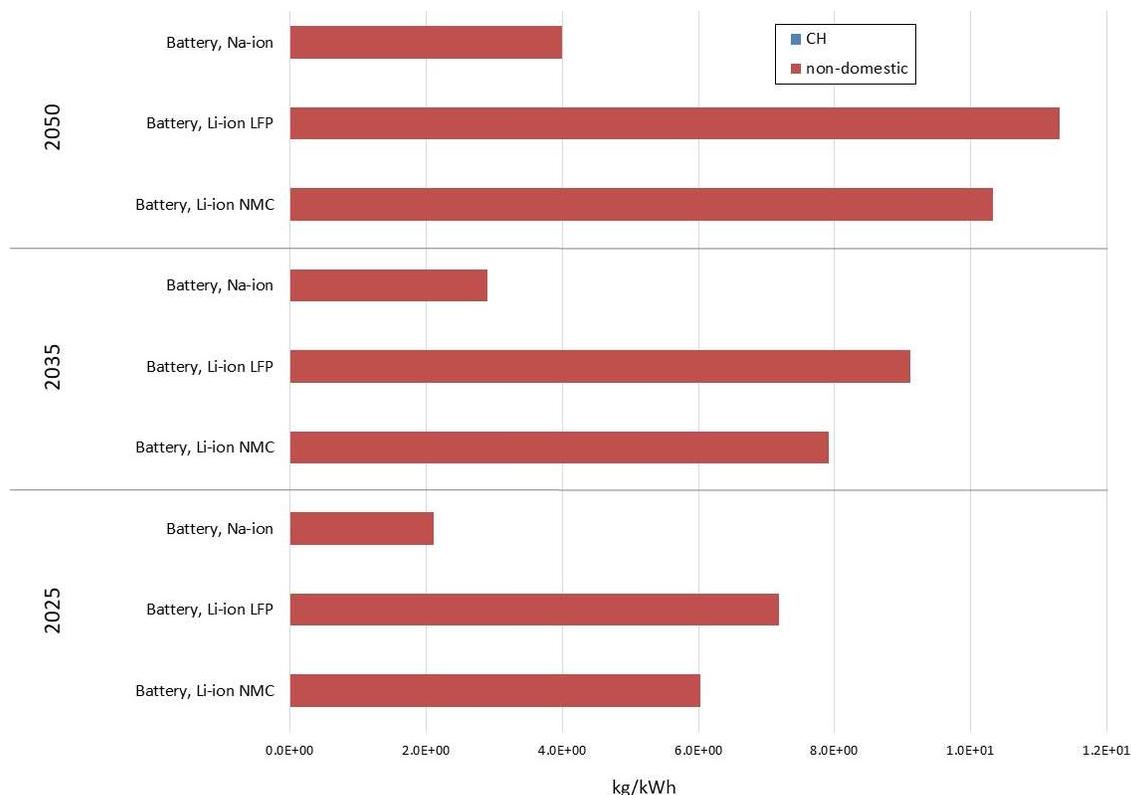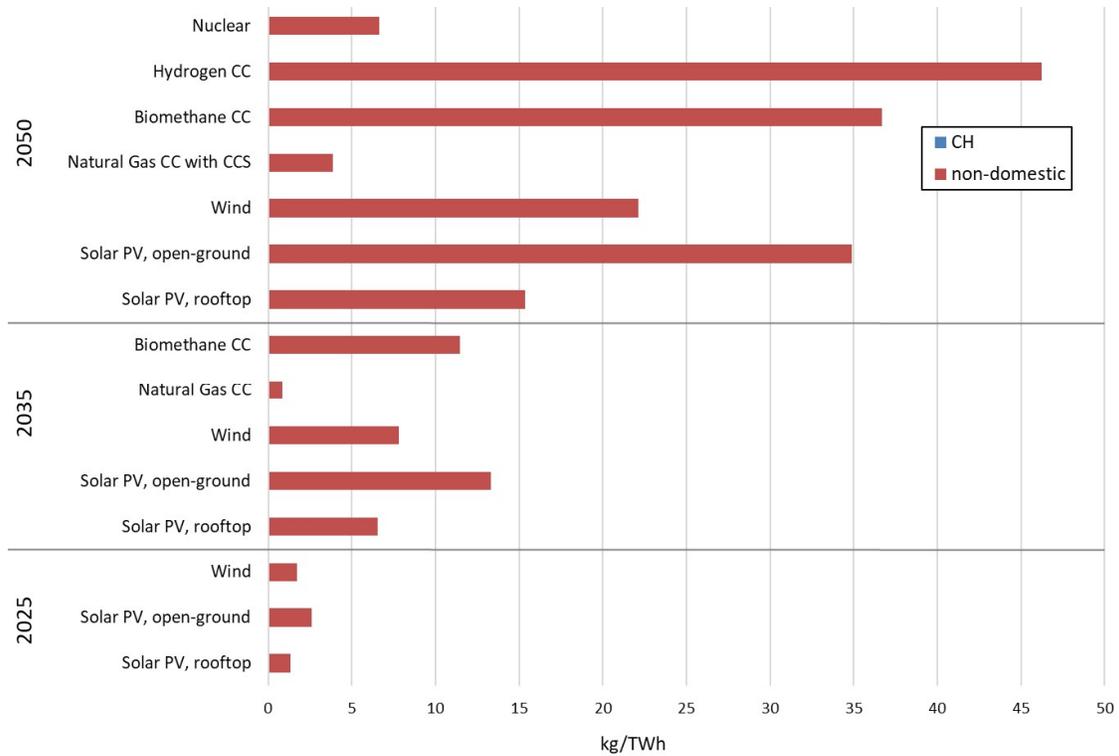
Figure 6.12: Lithium demand per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.
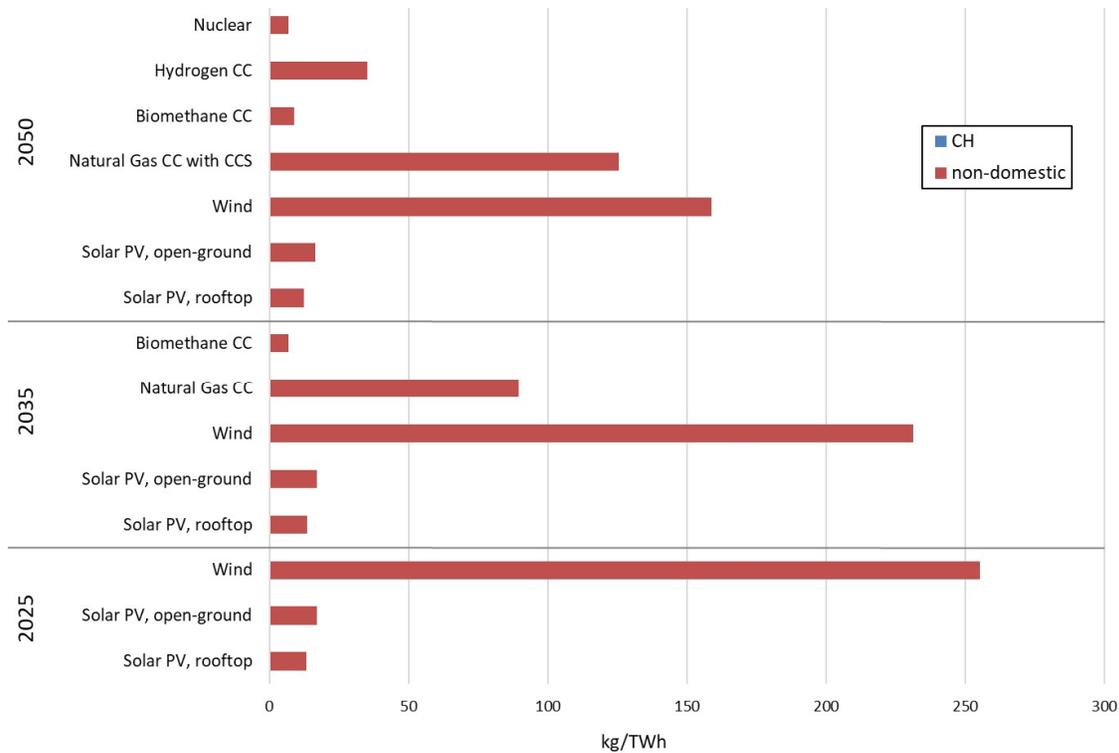
Figure 6.13: Neodymium demand per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.
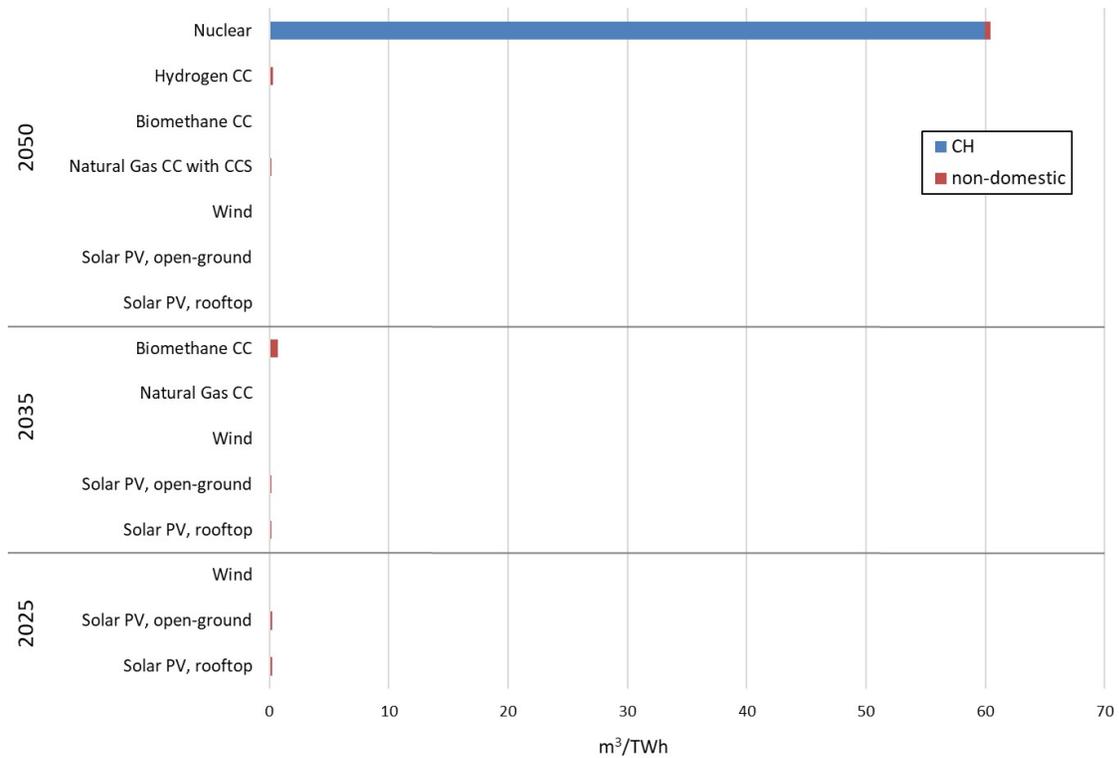
20
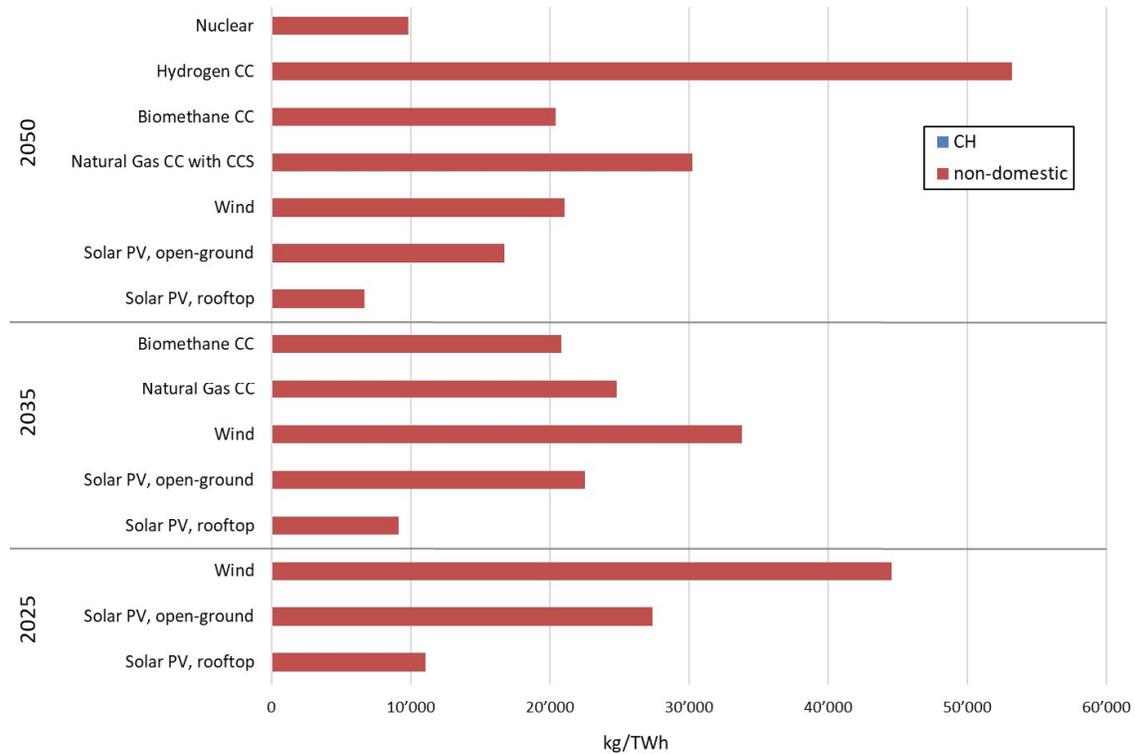
Figure 6.14: Nickel demand per TWh of electricity for different power generation technologies in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad. CC: Combined Cycle; CCS: Carbon Capture and Storage; PV: Photovoltaics.

Figure 6.15 to Figure 6.18 show the metal demand of the different battery technologies in 2025, 2035, and 2050. Cobalt demand is by far highest for the NMC battery; Lithium demand is highest for both Li-ion batteries; Nickel is highest for the Li-ion NMC and the Na-ion battery; and Neodymium, with demand in general about three orders of magnitude lower, is at a similar level across all three battery technologies. The results for cobalt, lithium, and nickel are mostly driven by direct metal demand for battery electrodes.
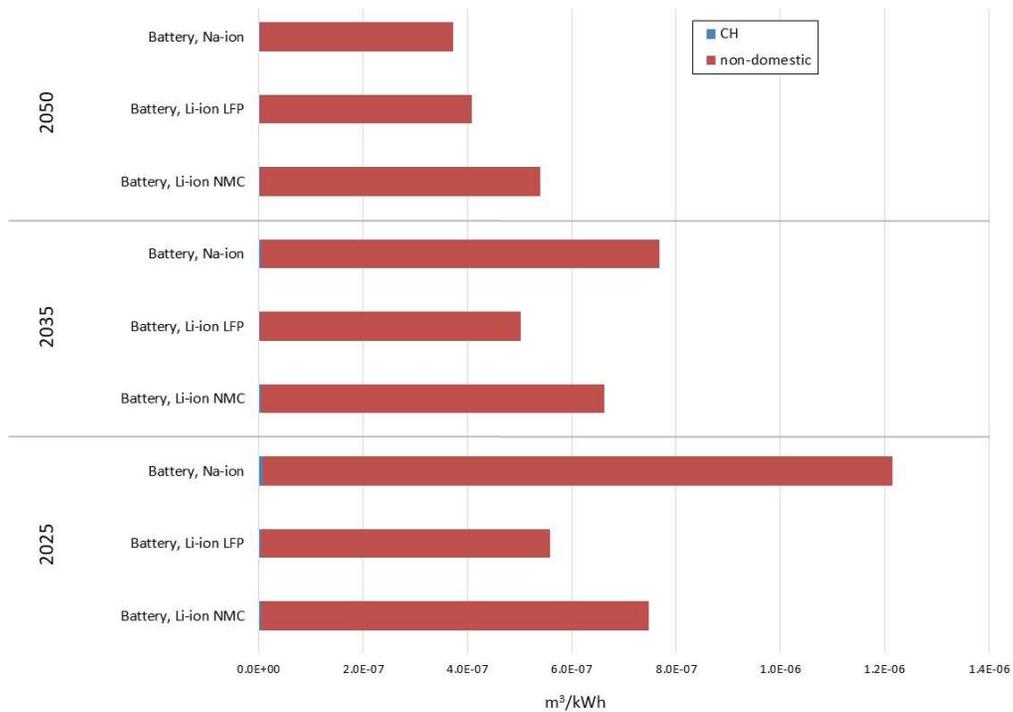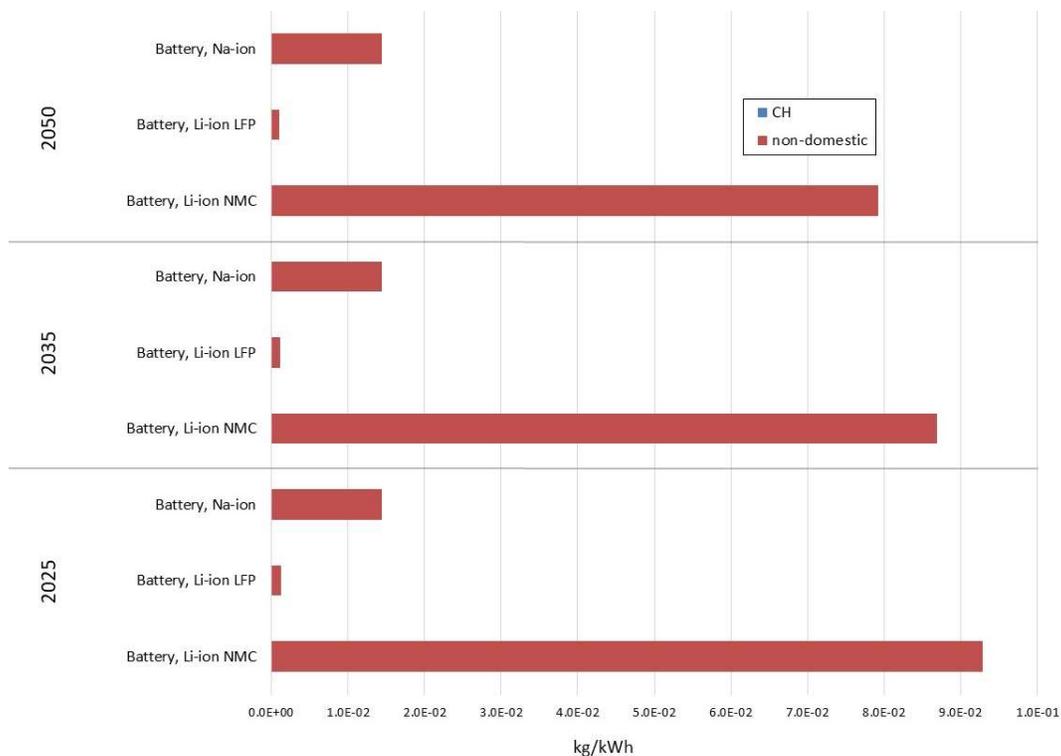
Figure 6.15: Cobalt demand per kWh of electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad.
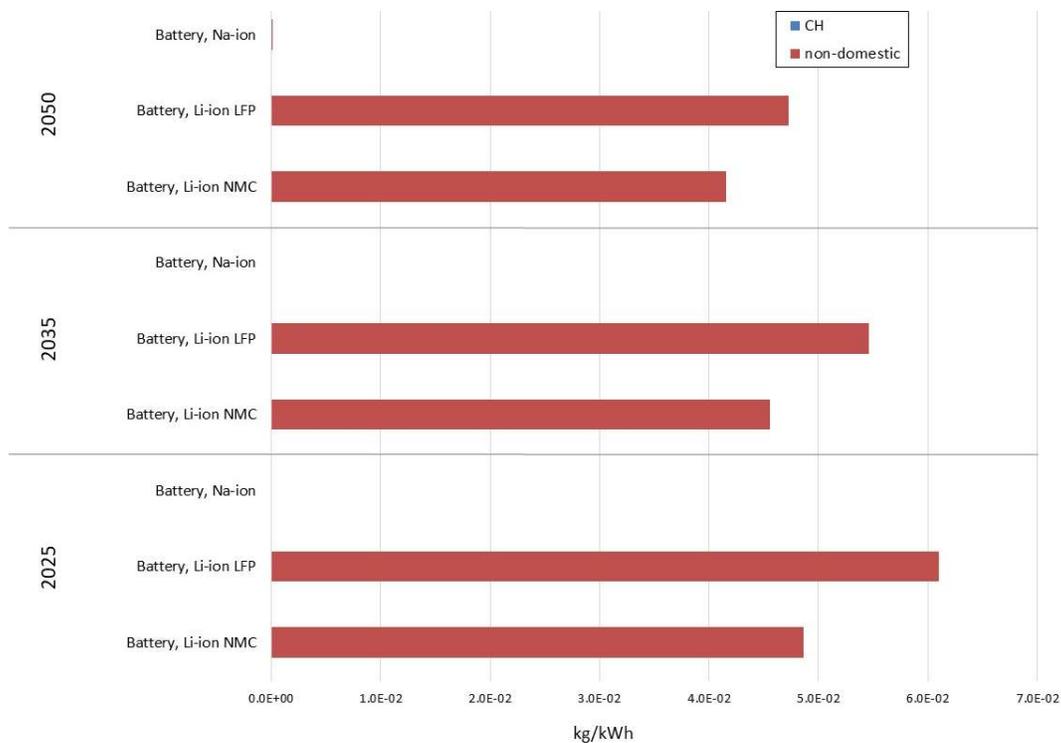
Figure 6.16: Lithium demand per kWh of electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad.
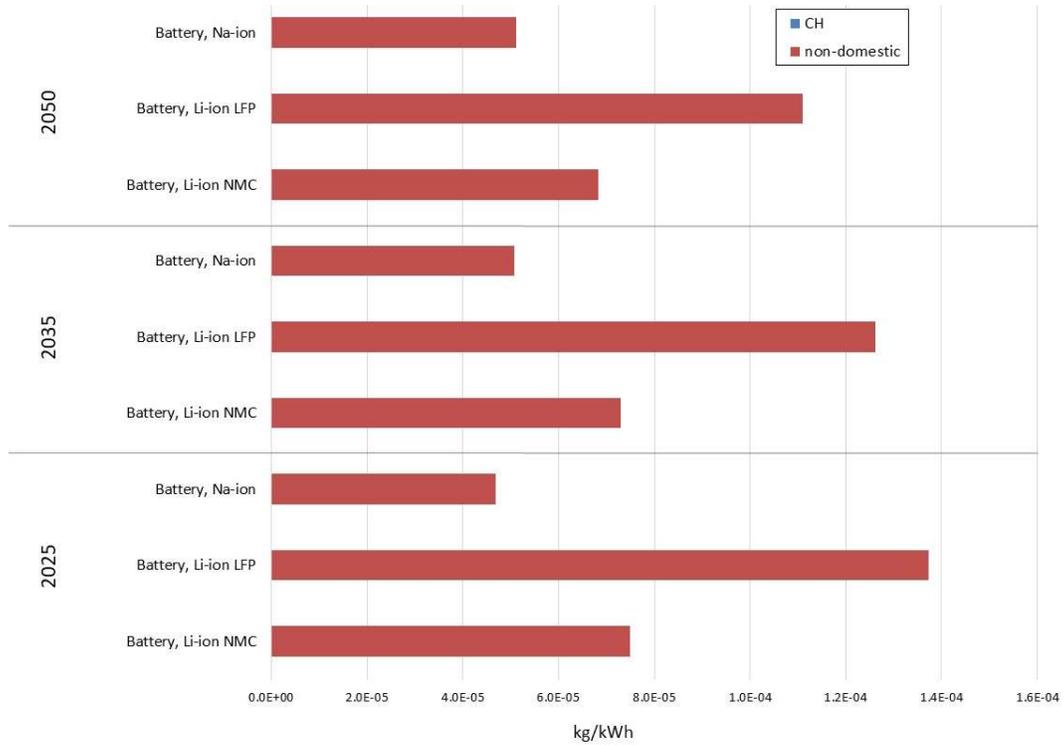
Figure 6.17: Neodymium demand per kWh of electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad.
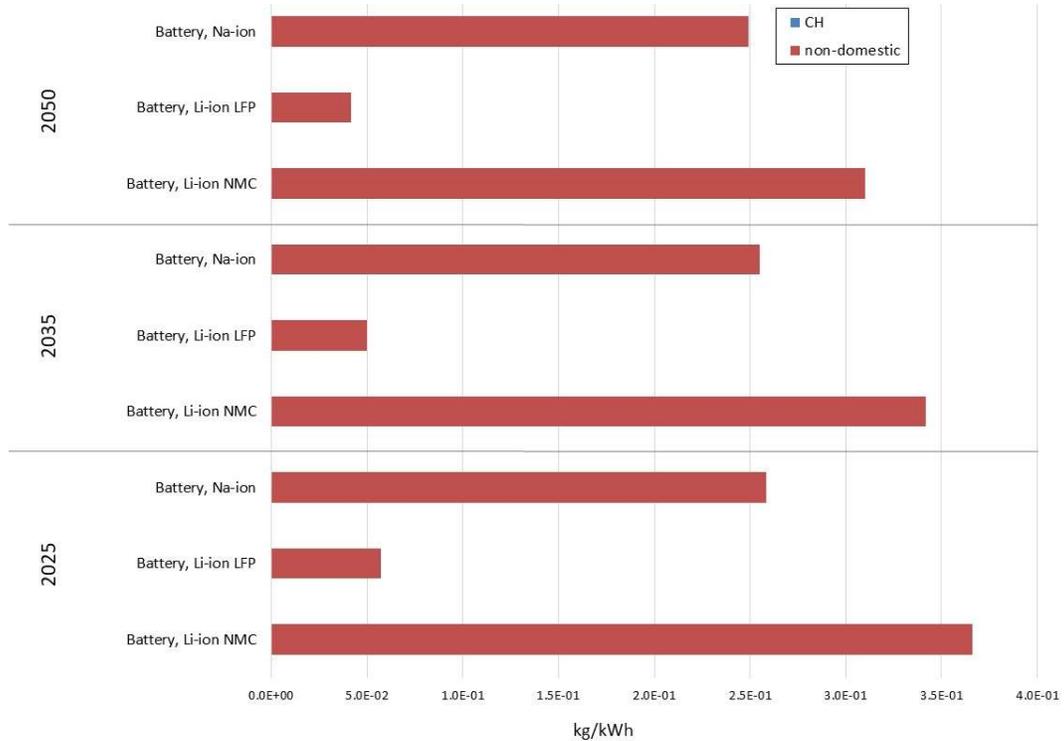
Figure 6.18: Nickel demand per kWh of electricity storage capacity of different batteries in 2025, 2035, and 2050. The blue segments of the stacked bars represent demand within Switzerland, the red segments represent demand along value chains abroad.

Neodymium is not directly needed for the batteries, but is indirectly caused by electricity consumption along the value chains.

6.7 Impact of natural gas supply on LCIA results

The origin of natural gas determines supply chain-related environmental impacts due to, e.g., supply pathway-specific methane leakage of gas extraction and transport, energy consumption for natural gas conversion and transport, etc., and natural gas flaring vs. venting at the extraction site. This impact is shown for two exemplary cases here: natural gas import to Germany[18], from Norway (NO) via pipeline, and from the US as Liquefied Natural Gas (LNG). We refrain from showing metal demand for those two cases, as this seems less relevant than the other environmental indicators.

Table 6.1 shows these results, per m^3 and per kWh, respectively, of natural gas. Environmental burdens and impacts are substantially higher for natural gas imported from the US.

Table 6.1: Environmental performance indicators for natural gas, imported to Germany, from Norway via pipeline, and from the US, as LNG.

		natural gas, high pressure, import from NO		natural gas, high pressure, import from US	
climate impacts	kg CO₂eq	0.12	per m³	0.902	per m³
		0.012	per kWh	0.090	per kWh
land occupation	m²a	1.90E-04	per m³	1.80E-03	per m³
		1.90E-05	per kWh	1.80E-04	per kWh
ecosystem damages	species*a	4.65E-10	per m³	3.88E-09	per m³
		4.65E-11	per kWh	3.88E-10	per kWh
radioactive waste	m³	1.30E-11	per m³	2.73E-10	per m³
		1.30E-12	per kWh	2.73E-11	per kWh
hazardous waste	kg	0.00363	per m³	0.0295	per m³
		0.000363	per kWh	0.00295	per kWh

---

[18] Specific LCA datasets for Switzerland are not available; thus, "import to Germany". Environmental impacts can be assumed to be representative of natural gas imports to Switzerland, as both imports from Norway and the US often occur via Germany.

7 Discussion and conclusions

The results of this comparison of the environmental performance of power generation technologies and battery production are aimed at providing support for decision-making in a Swiss context. However, this analysis does not aim at answering the question of "What is the best technology (from an environmental perspective)?", as answering such a question always requires weighing various criteria or indicators against each other and thus subjective choices and value judgements. In addition, an informed decision-making process should consider additional environmental indicators as well as economic and social aspects.

7.1 Power generation technologies

In general, the results of this analysis are consistent with previous studies on the LCA-based environmental performance of power generation technologies (Bauer et al., 2010, 2017; Gibon et al., 2022; Treyer et al., 2014; Treyer & Bauer, 2016; X. Zhang & Bauer, 2018).

Considering the results for the range of environmental performance indicators evaluated here, a few general conclusions can be drawn from the present analysis:

- Wind turbines, rooftop PV, and biomethane-fueled gas power plants exhibit low scores across all quantified environmental burdens, i.e., show the best environmental performance.
- Except for radioactive waste, nuclear power also performs consistently well.
- If reducing climate change impacts, i.e., greenhouse gas emissions, is the main concern, open-ground PV plants also represent a viable option. However, these come with environmental trade-offs, primarily regarding metal demand and land use. Since the land use-related indicator quantified here represents only the quantity of land occupied without further consideration of whether occupying this land actually represents a concern from the environmental perspective, case-specific assessments are needed for open-ground PV. LCA does not represent the method of choice for such site-specific assessments.
- Natural gas power plants cause by far the highest greenhouse gas emissions. Applying CCS can only reduce those GHG emissions by around 60%, and the remaining emissions are still much higher than those of renewable and nuclear options. Other environmental burdens from natural gas-based power generation without CCS are low; CCS increases them due to higher natural gas demand, CO_2 transport and storage infrastructure, and associated energy demand. The origin of natural gas has a substantial impact on the environmental performance of electricity from natural gas-fired power plants; importing it over short distances via pipeline is, in general, the preferred option compared to LNG imports.
- The question of whether using hydrogen as a fuel for gas power plants is an environmentally sound option cannot be conclusively answered. This evaluation shows that the environmental performance of this option depends heavily on the hydrogen source and supply pathway. Producing it in Spain via water electrolysis with PV electricity and importing that hydrogen via pipeline to Switzerland seems to be an environmentally sound option, especially in the future with a decarbonized European electricity system.
- Critical raw material demand, in general, tends to be higher for comparatively small-scale, decentralized wind and solar PV power generation than for large-scale power plants such as nuclear reactors and gas combined cycle plants. However, due to the limited number of CRM analyzed here, a comprehensive picture cannot be provided. Supply risk analysis regarding very specific elements throughout all life cycles of power generation technologies would be needed.
- Overall, the environmental burdens of power generation will most likely go down in the future – due to improving technology, e.g., wind turbines being able to harvest more wind or more efficient PV modules, but also due to an expected reduction of the overall environmental

footprint of our economy, thanks to more and more widespread use of clean technologies worldwide.

When interpreting these results, it must be noted that they reflect product systems with specific specifications and assumptions. Changing those could lead to very different outcomes – most notably for gas power plants using hydrogen and biomethane. The environmental burdens of these are largely determined by the production route and origin of hydrogen and biomethane, respectively. Water electrolysis powered by low-carbon electricity for hydrogen production and biomethane production using residual biomass, respectively, represent the most environmentally sound options.

7.2 Batteries

Among the batteries evaluated here, Na-Ion batteries perform better than Li-Ion batteries throughout almost all the environmental burdens quantified. Mainly because Na-Ion batteries contain less critical raw materials, which has dual benefits as the extraction and refining of such materials is most often associated with substantial environmental burdens, and at the same time, with supply risks (European Commission, 2023).[19] Expected improvements in technology performance, which seem to be more pronounced for Li-ion batteries than for Na-ion batteries, as well as more environmentally sound material extraction and refining in the future, are, however, likely to reduce this environmental advantage of Na-ion batteries.

7.3 Limitations and uncertainties

First, it must be acknowledged that this assessment of power generation technologies and batteries is not comprehensive: neither in terms of technology options nor in terms of quantified environmental burdens. This analysis could be extended by adding technologies, such as geothermal or hydro power, and by evaluating a broader range of environmental burdens, including impacts on biodiversity[20] and water scarcity. However, most relevant technologies within a Swiss context are included, and the selection of environmental performance indicators aims at representativeness. In the context of the environmental performance indicators quantified here, it must be kept in mind that some of them – land occupation, radioactive and non-radioactive waste – do not actually have damaging impacts on human health or ecosystem quality; these indicators only represent quantities of potentially problematic issues, not only from an environmental but maybe even more from a social perspective.

Regarding uncertainties related to life cycle inventories, these are most likely highest when it comes to critical raw material (CRM) demand. This CRM demand is a relatively new area of concern, and LCI for power generation and associated value chains might not always be precise regarding the quantification of these CRM, as they are most often needed in very small quantities.

Next, these power generation technologies, in reality, do not operate in isolation. The electricity supply system represents a complex interplay between a range of generation technologies with different characteristics, including the option to import electricity from neighboring countries. Which technology combination best serves its purpose of securing the supply and the associated environmental impacts it has can only be determined with system models, which consider daily and seasonal production profiles of the power generation technologies. Thus, an evaluation of the environmental burdens per unit of electricity produced cannot be considered as a conclusive answer to the question of which technologies are preferred from an environmental perspective.

Such systemic aspects are even more important for batteries, which were only assessed from a "cradle-to-grave" perspective in this study. Batteries, if integrated into an electricity system, not only

---

[19] These supply risks are, however, out of scope of this analysis.
[20] There is some overlap between "damages to ecosystems" and "biodiversity impacts". The LCA community is currently developing more comprehensive indicators to quantify biodiversity impacts, also in a more regionalized way throughout all unit processes of product systems, as these biodiversity impacts crucially depend on locations of emissions and other burdens. Such more advanced methodology is, however, not yet fully operational.

cause supply- and manufacturing-chain-related environmental burdens but can also help cope with intermittent renewable power generation and thereby reduce the overall electricity supply's environmental footprint. Quantifying production-related environmental burdens, as performed in this analysis, can be considered only a first step towards a more comprehensive assessment. Moreover, battery recycling is considered here only in a generic sense, without integrating potential future closed-loop recycling options; also, the use of used batteries from battery electric vehicles for second-life stationary applications is not included in this analysis.

Performing prospective analysis for future reference years involves its own challenges and uncertainties. First, these relate to projected technology development and characteristics, such as solar PV module types and efficiencies, or the specific energies of batteries. We estimate future developments based on the available literature. Second, these challenges and uncertainties are related to the overall development of the global economy, as reflected in our background inventories. We build upon specific scenarios from established energy system and integrated assessment models to reflect ambitious climate policies. If the development pathway were different and climate policies were less ambitious, fewer renewables might be installed, and higher amounts of fossil fuels might be used both in Switzerland and worldwide, which would have a potentially substantial impact on the environmental burdens quantified for 2035 and 2050.

Finally, environmental impacts can be location-specific, i.e., dependent on the location-specific environmental burdens that are released or caused. Within the present analysis, this mainly applies to ecosystem damages. For example, ecosystem damages due to land use and pollutant emissions depend on site-specific boundary conditions – which type of land is occupied, which pollutants are emitted at which locations, etc. To address this in a meaningful way, the so-called regionalized Life Cycle Impact Assessment (LCIA) needs to be applied (Sacchi et al., 2025). However, such a regionalized LCIA was out of scope of this analysis.

8 Literature

ams - automotive manufacturing solutions. (2024, July 24). *Powering the future: Top 5 EV battery chemistries and formats across the world*. Https://Www.Automotivemanufacturingsolutions.Com/Electrification/Powering-the-Future-Top-5-Ev-Battery-Chemistries-and-Formats-across-the-World/542508#:~:Text=Common%20types%3A,For%20their%20lower%2Dend%20models.

Bareiß, K., de la Rua, C., Möckl, M., & Hamacher, T. (2019). Life cycle assessment of hydrogen from proton exchange membrane water electrolysis in future energy systems. *Applied Energy*, *237*, 862–872. https://doi.org/10.1016/j.apenergy.2019.01.001

Bauer, C., Desai, H., Heck, T., Sacchi, R., Schneider, S., Terlouw, T., Treyer, K., & Zhang, X. (2022). *Stromspeicherung und Wasserstoff – Technologien , Kosten und Auswirkungen auf das Klima Einschliesslich Aufdatierung der Kosten und Potenziale von Photovoltaik und Windenergie ; Bericht auf Englisch mit Zusammenfassung auf Deutsch und Französisch*. https://www.psi.ch/de/media/72878/download?attachment

Bauer, C., Hirschberg, S., Bäuerle, Y., Biollaz, S., Calbry-Muzyka, B. C., Heck, T., Lehnert, M., Meier, A., Prasser, H.-M., Schenler, W., Treyer, K., Vogel, F., Wieckert, H. C., Zhang, X., Zimmermann, M., Burg, V., Bowman, G., Erni, M., Saar, M., & Tran, M. Q. (2017). *Potentials, costs and environmental assessment of electricity generation technologies*.

Bauer, C., Schenler, W., & Roth, S. (2010). A comparative sustainability assessment of combined heat and electricity supply by cogeneration and heat pump systems for Switzerland. *Proceedings of the 23rd International Conference on Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems, ECOS 2010*, *1*.

Dai, Q., Dunn, J., Kelly, J. C., & Elgowainy, A. (2017). *Update of Life Cycle Analysis of Lithium-ion Batteries in the GREET Model*. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://greet.anl.gov/files/Li_battery_update_2017&ved=2ahUKEwiizdKMwICRAxVVzwIHHQGjG5kQFnoECAwQAQ&usg=AOvVaw3Xh6s5NsIWKl4Ekq_3Mtos

Dai, Q., Kelly, J. C., Dunn, J., & Benavides, P. T. (2018). *Update of Bill-of-materials and Cathode Materials Production for Lithium-ion Batteries in the GREET Model*. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://greet.anl.gov/files/update_bom_cm&ved=2ahUKEwjdjpK0vICRAxU06gIHHcTpLuwQFnoECAwQAQ&usg=AOvVaw3SDRrcQJqcZm_FGY5hhQHr

European Commission. (2021). Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. *Official Journal of the European Union*, *64*(20/01/2014), 1–28. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2014:015:FULL&from=EN

European Commission. (2023). *Study on the Critical Raw Materials for the EU 2023 – Final Report*. https://op.europa.eu/en/publication-detail/-/publication/57318397-fdd4-11ed-a05c-01aa75ed71a1

Gibon, T., Hahn, Á., & Guiton, M. (2022). *Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources*. https://unece.org/sites/default/files/2022-04/LCA_3_FINAL March 2022.pdf

Gibon, T., & Menacho, A. H. (2023). Parametric Life Cycle Assessment of Nuclear Power for Simplified Models. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.3c03190

Hahn Menacho, A. J., Sacchi, R., Bauer, C., Moretti, C., Panos, E., McKenna, R., & Burgherr, P. (2025). The global environmental footprint of Switzerland's net-zero energy system uncovers impacts abroad. *Communications Earth and Environment*, *6*(1). https://doi.org/10.1038/s43247-025-02220-5

Hahn Menacho, A. J., Sacchi, R., Bauer, C., Panos, E., McKenna, R., & Burgherr, P. (2025). The material-energy nexus in net-zero transition scenarios: exploring environmental trade-offs and uncertainties. *Resources, Conservation and Recycling*, *218*, 108251. https://doi.org/10.1016/j.resconrec.2025.108251

Hasselwander, S., Meyer, M., & Österle, I. (2023). Techno-Economic Analysis of Different Battery Cell Chemistries for the Passenger Vehicle Market. *Batteries*, *9*(7). https://doi.org/10.3390/batteries9070379

Hauschild, M. Z., Rosenbaum, R., & Irving Olsen, S. (2018). Life cycle assessment. In *Life Cycle Assessment - Theory and practice*. Springer. https://doi.org/10.17654/JPHMTFeb2015_029_042

International Energy Agency. (2025). *Global Critical Minerals Outlook 2025*. www.iea.org

ISO. (2006a). *ISO 14040. Environmental management - life cycle assessment - prinicples and framework*. https://www.iso.org/standard/37456.html

ISO. (2006b). *ISO 14044: Life cycle assessment — Requirements and guidelines* (Vol. 14044). https://www.iso.org/standard/38498.html

McKinsey. (2024, December 17). *The battery chemistries powering the future of electric vehicles*. Https://Www.Mckinsey.Com/Industries/Automotive-and-Assembly/Our-Insights/the-Battery-Chemistries-Powering-the-Future-of-Electric-Vehicles.

Nichols, D. (2025, September 30). *Green Cars - Different Types of EV Batteries*. Https://Www.Greencars.Com/Greencars-101/Different-Types-of-Ev-Batteries#:~:Text=Common%20Battery%20Types%20in%20EVs,Safe%2C%20and%20long%2Dlasting.

Panos, E., Stelios Tsiaras, Kostas Fragkiadakis, Leonidas Paroussos, Jalomi Maayan Tardif, Isabelle Stadelmann-Steffen, Alexander Fuchs, Turhan Demiray, Giacomo Catenazzi, Martin Jakob, Giacomo Rubino, Nik Zielonka, & Evelina Trutnevyte. (2024). *Revised scenario protocol capturing new energy sector developments translating into re-defined pathway and shock scenarios*. https://sweet-sure.ch/wp-content/uploads/2025/04/D2.2-SWEET_Call1-2020_SURE_DeliverableD2.2_clean-_20241210_v2.pdf

Sacchi, R., & Hahn Menacho, A. (2024, December 12). *SWEET-SURE. SPS1 and SPS4 Data Repository*. Https://Github.Com/Premise-Community-Scenarios/Sweet_sure-2050-Switzerland.

Sacchi, R., Menacho, A. H., Seitfudem, G., Agez, M., Schlesinger-Martinat, J., Koyamparambath, A., Saldivar, J. S., Loubet, P., & Bauer, C. (2025). Contextual LCIA without the overhead: an exchange-based framework for flexible impact assessment. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-025-02551-7

Sacchi, R., Terlouw, T., Siala, K., Dirnaichner, A., Bauer, C., Cox, B., Mutel, C., Daioglou, V., & Luderer, G. (2022). PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. *Renewable and Sustainable Energy Reviews*, *160*, 112311. https://doi.org/10.1016/j.rser.2022.112311

Sand, M., Skeie, R. B., Sandstad, M., Krishnan, S., Myhre, G., Bryant, H., Derwent, R., Hauglustaine, D., Paulot, F., Prather, M., & Stevenson, D. (2023). A multi-model assessment of the Global Warming

Potential of hydrogen. *Communications Earth & Environment*, *4*(1), 203. https://doi.org/10.1038/s43247-023-00857-8

Simons, A., & Bauer, C. (2012). Life cycle assessment of the European pressurized reactor and the influence of different fuel cycle strategies. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *226*(3). https://doi.org/10.1177/0957650912440549

Treyer, K., & Bauer, C. (2016). Life cycle inventories of electricity generation and power supply in version 3 of the ecoinvent database---part I: electricity generation. *The International Journal of Life Cycle Assessment*, *21*(9), 1236–1254. https://doi.org/10.1007/s11367-013-0665-2

Treyer, K., Bauer, C., & Simons, A. (2014). Human health impacts in the life cycle of future European electricity generation. *Energy Policy*, *74*(S1). https://doi.org/10.1016/j.enpol.2014.03.034

Volkart, K., Bauer, C., & Boulet, C. (2013). Life cycle assessment of carbon capture and storage in power generation and industry in Europe. *International Journal of Greenhouse Gas Control*, *16*, 91–106. https://doi.org/10.1016/j.ijggc.2013.03.003

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): overview and methodology. *International Journal of Life Cycle Assessment*, *21*(9), 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Zhang, S., Steubing, B., Karlsson Potter, H., Hansson, P. A., & Nordberg, Å. (2024). Future climate impacts of sodium-ion batteries. *Resources, Conservation and Recycling*, *202*. https://doi.org/10.1016/j.resconrec.2023.107362

Zhang, X., & Bauer, C. (2018). *Life Cycle Assessment (LCA) of Nuclear Power in Switzerland*. https://www.psi.ch/sites/default/files/2019-05/PSI_LCA-Nuclear_CH_Final-Formatted.pdf %0A

9 Appendix

Table 9.1 shows the complete set of numerical results, including those for the power plant infrastructure (scaled to 1 MW electric net generation capacity).

Table 9.1: Numerical results.

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2025	2.63E+07	Solar PV, rooftop	6.50E+05	2.57E+07	GHG emissions	kg CO2e	TWh electricity generated
2025	2.53E+06	Solar PV, rooftop	3.81E+04	2.49E+06	land occupation	m2-year	TWh electricity generated
2025	1.47E-01	Solar PV, rooftop	2.45E-03	1.44E-01	ecosystem damage	species loss-year	TWh electricity generated
2025	2.03E-01	Solar PV, rooftop	1.48E-03	2.02E-01	radioactive waste	m3	TWh electricity generated
2025	1.10E+06	Solar PV, rooftop	3.70E+00	1.10E+06	toxic waste	kg	TWh electricity generated
2025	1.25E+02	Solar PV, rooftop	1.21E-04	1.25E+02	Cobalt	kg	TWh electricity generated
2025	1.35E+00	Solar PV, rooftop	0.00E+00	1.35E+00	Lithium	kg	TWh electricity generated
2025	1.33E+01	Solar PV, rooftop	0.00E+00	1.33E+01	Neodymium	kg	TWh electricity generated
2025	1.11E+04	Solar PV, rooftop	0.00E+00	1.11E+04	Nickel	kg	TWh electricity generated
2025	3.50E+07	Solar PV, open-ground	1.86E+06	3.32E+07	GHG emissions	kg CO2e	TWh electricity generated
2025	2.51E+07	Solar PV, open-ground	2.12E+07	3.88E+06	land occupation	m2-year	TWh electricity generated
2025	3.80E-01	Solar PV, open-ground	1.47E-01	2.33E-01	ecosystem damage	species loss-year	TWh electricity generated
2025	2.25E-01	Solar PV, open-ground	1.62E-03	2.24E-01	radioactive waste	m3	TWh electricity generated
2025	2.22E+06	Solar PV, open-ground	4.06E+00	2.22E+06	toxic waste	kg	TWh electricity generated
2025	4.12E+02	Solar PV, open-ground	1.20E-03	4.12E+02	Cobalt	kg	TWh electricity generated
2025	2.60E+00	Solar PV, open-ground	0.00E+00	2.60E+00	Lithium	kg	TWh electricity generated
2025	1.69E+01	Solar PV, open-ground	0.00E+00	1.69E+01	Neodymium	kg	TWh electricity generated
2025	2.74E+04	Solar PV, open-ground	0.00E+00	2.74E+04	Nickel	kg	TWh electricity generated
2025	1.18E+07	Wind	1.37E+05	1.17E+07	GHG emissions	kg CO2e	TWh electricity generated
2025	1.69E+06	Wind	1.37E+04	1.67E+06	land occupation	m2-year	TWh electricity generated
2025	7.32E-02	Wind	5.56E-04	7.26E-02	ecosystem damage	species loss-year	TWh electricity generated
2025	9.38E-02	Wind	7.27E-04	9.30E-02	radioactive waste	m3	TWh electricity generated
2025	8.75E+05	Wind	1.82E+00	8.75E+05	toxic waste	kg	TWh electricity generated
2025	1.57E+02	Wind	1.41E-04	1.57E+02	Cobalt	kg	TWh electricity generated
2025	1.70E+00	Wind	0.00E+00	1.70E+00	Lithium	kg	TWh electricity generated
2025	2.55E+02	Wind	0.00E+00	2.55E+02	Neodymium	kg	TWh electricity generated
2025	4.46E+04	Wind	0.00E+00	4.46E+04	Nickel	kg	TWh electricity generated
2025	7.20E+10	Battery, Li-ion NMC	5.46E+07	7.20E+10	GHG emissions	kg CO2e	TWh storage capacity
2025	6.01E+09	Battery, Li-ion NMC	8.27E+07	5.93E+09	land occupation	m2-year	TWh storage capacity
2025	5.27E+02	Battery, Li-ion NMC	5.10E-01	5.26E+02	ecosystem damage	species loss-year	TWh storage capacity
2025	7.48E+02	Battery, Li-ion NMC	4.43E+00	7.44E+02	radioactive waste	m3	TWh storage capacity
2025	6.04E+09	Battery, Li-ion NMC	1.11E+04	6.04E+09	toxic waste	kg	TWh storage capacity
2025	9.29E+07	Battery, Li-ion NMC	5.60E-01	9.29E+07	Cobalt	kg	TWh storage capacity
2025	4.86E+07	Battery, Li-ion NMC	0.00E+00	4.86E+07	Lithium	kg	TWh storage capacity
2025	7.50E+04	Battery, Li-ion NMC	0.00E+00	7.50E+04	Neodymium	kg	TWh storage capacity
2025	3.66E+08	Battery, Li-ion NMC	0.00E+00	3.66E+08	Nickel	kg	TWh storage capacity
2025	9.46E+10	Battery, Li-ion LFP	7.96E+07	9.45E+10	GHG emissions	kg CO2e	TWh storage capacity

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2025	8.05E+09	Battery, Li-ion LFP	9.18E+07	7.96E+09	land occupation	m2-year	TWh storage capacity
2025	7.37E+02	Battery, Li-ion LFP	6.11E-01	7.37E+02	ecosystem damage	species loss-year	TWh storage capacity
2025	5.58E+02	Battery, Li-ion LFP	3.97E+00	5.54E+02	radioactive waste	m3	TWh storage capacity
2025	7.18E+09	Battery, Li-ion LFP	9.93E+03	7.18E+09	toxic waste	kg	TWh storage capacity
2025	1.32E+06	Battery, Li-ion LFP	5.13E-01	1.32E+06	Cobalt	kg	TWh storage capacity
2025	6.10E+07	Battery, Li-ion LFP	0.00E+00	6.10E+07	Lithium	kg	TWh storage capacity
2025	1.37E+05	Battery, Li-ion LFP	0.00E+00	1.37E+05	Neodymium	kg	TWh storage capacity
2025	5.71E+07	Battery, Li-ion LFP	0.00E+00	5.71E+07	Nickel	kg	TWh storage capacity
2025	4.44E+10	Battery, Na-ion	9.53E+08	4.35E+10	GHG emissions	kg CO2e	TWh storage capacity
2025	3.65E+09	Battery, Na-ion	1.86E+08	3.46E+09	land occupation	m2-year	TWh storage capacity
2025	3.02E+02	Battery, Na-ion	3.47E+00	2.98E+02	ecosystem damage	species loss-year	TWh storage capacity
2025	1.22E+03	Battery, Na-ion	8.38E+00	1.21E+03	radioactive waste	m3	TWh storage capacity
2025	2.11E+09	Battery, Na-ion	2.09E+04	2.11E+09	toxic waste	kg	TWh storage capacity
2025	1.44E+07	Battery, Na-ion	3.46E-01	1.44E+07	Cobalt	kg	TWh storage capacity
2025	7.51E+03	Battery, Na-ion	0.00E+00	7.51E+03	Lithium	kg	TWh storage capacity
2025	4.68E+04	Battery, Na-ion	0.00E+00	4.68E+04	Neodymium	kg	TWh storage capacity
2025	2.59E+08	Battery, Na-ion	0.00E+00	2.59E+08	Nickel	kg	TWh storage capacity
2025	7.50E+08	Solar PV plant, rooftop, 1 MW	1.85E+07	7.32E+08	GHG emissions	kg CO2e	MW installed
2025	7.21E+07	Solar PV plant, rooftop, 1 MW	1.09E+06	7.10E+07	land occupation	m2-year	MW installed
2025	4.19E+00	Solar PV plant, rooftop, 1 MW	6.97E-02	4.12E+00	ecosystem damage	species loss-year	MW installed
2025	5.80E+00	Solar PV plant, rooftop, 1 MW	4.22E-02	5.76E+00	radioactive waste	m3	MW installed
2025	3.12E+07	Solar PV plant, rooftop, 1 MW	1.05E+02	3.12E+07	toxic waste	kg	MW installed
2025	3.55E+03	Solar PV plant, rooftop, 1 MW	3.46E-03	3.55E+03	Cobalt	kg	MW installed
2025	3.84E+01	Solar PV plant, rooftop, 1 MW	0.00E+00	3.84E+01	Lithium	kg	MW installed
2025	3.78E+02	Solar PV plant, rooftop, 1 MW	0.00E+00	3.78E+02	Neodymium	kg	MW installed
2025	3.15E+05	Solar PV plant, rooftop, 1 MW	0.00E+00	3.15E+05	Nickel	kg	MW installed
2025	1.05E+09	Solar PV, open-ground plant, 1 MW	5.57E+07	9.95E+08	GHG emissions	kg CO2e	MW installed
2025	7.53E+08	Solar PV, open-ground plant, 1 MW	6.36E+08	1.17E+08	land occupation	m2-year	MW installed
2025	1.14E+01	Solar PV, open-ground plant, 1 MW	4.40E+00	7.00E+00	ecosystem damage	species loss-year	MW installed
2025	6.75E+00	Solar PV, open-ground plant, 1 MW	4.87E-02	6.70E+00	radioactive waste	m3	MW installed
2025	6.65E+07	Solar PV, open-ground plant, 1 MW	1.22E+02	6.65E+07	toxic waste	kg	MW installed
2025	1.23E+04	Solar PV, open-ground plant, 1 MW	3.59E-02	1.23E+04	Cobalt	kg	MW installed
2025	7.79E+01	Solar PV, open-ground plant, 1 MW	0.00E+00	7.79E+01	Lithium	kg	MW installed
2025	5.07E+02	Solar PV, open-ground plant, 1 MW	0.00E+00	5.07E+02	Neodymium	kg	MW installed
2025	8.22E+05	Solar PV, open-ground plant, 1 MW	0.00E+00	8.22E+05	Nickel	kg	MW installed
2025	5.57E+08	Wind plant, 1 MW	1.47E+06	5.55E+08	GHG emissions	kg CO2e	MW installed
2025	6.86E+07	Wind plant, 1 MW	6.46E+05	6.79E+07	land occupation	m2-year	MW installed
2025	3.35E+00	Wind plant, 1 MW	1.19E-02	3.34E+00	ecosystem damage	species loss-year	MW installed
2025	4.48E+00	Wind plant, 1 MW	3.47E-02	4.44E+00	radioactive waste	m3	MW installed
2025	4.16E+07	Wind plant, 1 MW	8.68E+01	4.16E+07	toxic waste	kg	MW installed
2025	7.38E+03	Wind plant, 1 MW	6.66E-03	7.38E+03	Cobalt	kg	MW installed
2025	8.08E+01	Wind plant, 1 MW	0.00E+00	8.08E+01	Lithium	kg	MW installed
2025	1.23E+04	Wind plant, 1 MW	0.00E+00	1.23E+04	Neodymium	kg	MW installed

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2025	2.14E+06	Wind plant, 1 MW	0.00E+00	2.14E+06	Nickel	kg	MW installed
2035	1.50E+07	Solar PV, rooftop	6.13E+05	1.44E+07	GHG emissions	kg CO2e	TWh electricity generated
2035	2.20E+06	Solar PV, rooftop	1.91E+04	2.18E+06	land occupation	m2-year	TWh electricity generated
2035	9.99E-02	Solar PV, rooftop	2.25E-03	9.77E-02	ecosystem damage	species loss-year	TWh electricity generated
2035	1.58E-01	Solar PV, rooftop	1.14E-03	1.56E-01	radioactive waste	m3	TWh electricity generated
2035	1.46E+06	Solar PV, rooftop	2.84E+00	1.46E+06	toxic waste	kg	TWh electricity generated
2035	1.23E+02	Solar PV, rooftop	9.00E-05	1.23E+02	Cobalt	kg	TWh electricity generated
2035	6.55E+00	Solar PV, rooftop	0.00E+00	6.55E+00	Lithium	kg	TWh electricity generated
2035	1.35E+01	Solar PV, rooftop	0.00E+00	1.35E+01	Neodymium	kg	TWh electricity generated
2035	9.12E+03	Solar PV, rooftop	0.00E+00	9.12E+03	Nickel	kg	TWh electricity generated
2035	2.24E+07	Solar PV, open-ground	1.80E+06	2.06E+07	GHG emissions	kg CO2e	TWh electricity generated
2035	2.30E+07	Solar PV, open-ground	1.96E+07	3.47E+06	land occupation	m2-year	TWh electricity generated
2035	3.15E-01	Solar PV, open-ground	1.36E-01	1.79E-01	ecosystem damage	species loss-year	TWh electricity generated
2035	1.72E-01	Solar PV, open-ground	1.23E-03	1.71E-01	radioactive waste	m3	TWh electricity generated
2035	3.00E+06	Solar PV, open-ground	3.07E+00	3.00E+06	toxic waste	kg	TWh electricity generated
2035	4.08E+02	Solar PV, open-ground	9.29E-04	4.08E+02	Cobalt	kg	TWh electricity generated
2035	1.33E+01	Solar PV, open-ground	0.00E+00	1.33E+01	Lithium	kg	TWh electricity generated
2035	1.71E+01	Solar PV, open-ground	0.00E+00	1.71E+01	Neodymium	kg	TWh electricity generated
2035	2.25E+04	Solar PV, open-ground	0.00E+00	2.25E+04	Nickel	kg	TWh electricity generated
2035	8.29E+06	Wind	1.31E+05	8.15E+06	GHG emissions	kg CO2e	TWh electricity generated
2035	1.42E+06	Wind	8.90E+03	1.41E+06	land occupation	m2-year	TWh electricity generated
2035	5.54E-02	Wind	5.16E-04	5.49E-02	ecosystem damage	species loss-year	TWh electricity generated
2035	7.92E-02	Wind	6.09E-04	7.86E-02	radioactive waste	m3	TWh electricity generated
2035	9.97E+05	Wind	1.52E+00	9.97E+05	toxic waste	kg	TWh electricity generated
2035	1.38E+02	Wind	1.08E-04	1.38E+02	Cobalt	kg	TWh electricity generated
2035	7.79E+00	Wind	0.00E+00	7.79E+00	Lithium	kg	TWh electricity generated
2035	2.31E+02	Wind	0.00E+00	2.31E+02	Neodymium	kg	TWh electricity generated
2035	3.38E+04	Wind	0.00E+00	3.38E+04	Nickel	kg	TWh electricity generated
2035	3.97E+08	Natural Gas CC	3.25E+08	7.24E+07	GHG emissions	kg CO2e	TWh electricity generated
2035	8.02E+05	Natural Gas CC	4.54E+04	7.57E+05	land occupation	m2-year	TWh electricity generated
2035	1.24E+00	Natural Gas CC	9.64E-01	2.77E-01	ecosystem damage	species loss-year	TWh electricity generated
2035	8.76E-02	Natural Gas CC	6.42E-04	8.69E-02	radioactive waste	m3	TWh electricity generated
2035	3.10E+05	Natural Gas CC	1.60E+00	3.10E+05	toxic waste	kg	TWh electricity generated
2035	1.07E+02	Natural Gas CC	1.05E-04	1.07E+02	Cobalt	kg	TWh electricity generated
2035	8.36E-01	Natural Gas CC	0.00E+00	8.36E-01	Lithium	kg	TWh electricity generated
2035	8.96E+01	Natural Gas CC	0.00E+00	8.96E+01	Neodymium	kg	TWh electricity generated
2035	2.48E+04	Natural Gas CC	0.00E+00	2.48E+04	Nickel	kg	TWh electricity generated
2035	2.39E+07	Biomethane CC	2.98E+06	2.09E+07	GHG emissions	kg CO2e	TWh electricity generated
2035	8.12E+06	Biomethane CC	3.56E+06	4.56E+06	land occupation	m2-year	TWh electricity generated
2035	2.36E-01	Biomethane CC	1.34E-01	1.02E-01	ecosystem damage	species loss-year	TWh electricity generated
2035	7.34E-01	Biomethane CC	5.55E-03	7.29E-01	radioactive waste	m3	TWh electricity generated
2035	8.16E+05	Biomethane CC	1.39E+01	8.16E+05	toxic waste	kg	TWh electricity generated
2035	1.65E+02	Biomethane CC	7.32E-04	1.65E+02	Cobalt	kg	TWh electricity generated

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2035	1.15E+01	Biomethane CC	0.00E+00	1.15E+01	Lithium	kg	TWh electricity generated
2035	6.78E+00	Biomethane CC	0.00E+00	6.78E+00	Neodymium	kg	TWh electricity generated
2035	2.08E+04	Biomethane CC	0.00E+00	2.08E+04	Nickel	kg	TWh electricity generated
2035	4.14E+10	Battery, Li-ion NMC	6.48E+07	4.14E+10	GHG emissions	kg CO2e	TWh storage capacity
2035	4.96E+09	Battery, Li-ion NMC	4.86E+07	4.92E+09	land occupation	m2-year	TWh storage capacity
2035	3.84E+02	Battery, Li-ion NMC	4.42E-01	3.83E+02	ecosystem damage	species loss-year	TWh storage capacity
2035	6.62E+02	Battery, Li-ion NMC	3.79E+00	6.58E+02	radioactive waste	m3	TWh storage capacity
2035	7.92E+09	Battery, Li-ion NMC	9.48E+03	7.92E+09	toxic waste	kg	TWh storage capacity
2035	8.69E+07	Battery, Li-ion NMC	4.11E-01	8.69E+07	Cobalt	kg	TWh storage capacity
2035	4.55E+07	Battery, Li-ion NMC	0.00E+00	4.55E+07	Lithium	kg	TWh storage capacity
2035	7.30E+04	Battery, Li-ion NMC	0.00E+00	7.30E+04	Neodymium	kg	TWh storage capacity
2035	3.42E+08	Battery, Li-ion NMC	0.00E+00	3.42E+08	Nickel	kg	TWh storage capacity
2035	5.07E+10	Battery, Li-ion LFP	8.91E+07	5.06E+10	GHG emissions	kg CO2e	TWh storage capacity
2035	6.48E+09	Battery, Li-ion LFP	5.84E+07	6.42E+09	land occupation	m2-year	TWh storage capacity
2035	5.21E+02	Battery, Li-ion LFP	5.40E-01	5.21E+02	ecosystem damage	species loss-year	TWh storage capacity
2035	5.03E+02	Battery, Li-ion LFP	3.52E+00	4.99E+02	radioactive waste	m3	TWh storage capacity
2035	9.11E+09	Battery, Li-ion LFP	8.80E+03	9.11E+09	toxic waste	kg	TWh storage capacity
2035	1.21E+06	Battery, Li-ion LFP	3.51E-01	1.21E+06	Cobalt	kg	TWh storage capacity
2035	5.46E+07	Battery, Li-ion LFP	0.00E+00	5.46E+07	Lithium	kg	TWh storage capacity
2035	1.26E+05	Battery, Li-ion LFP	0.00E+00	1.26E+05	Neodymium	kg	TWh storage capacity
2035	5.00E+07	Battery, Li-ion LFP	0.00E+00	5.00E+07	Nickel	kg	TWh storage capacity
2035	2.86E+10	Battery, Na-ion	9.61E+08	2.77E+10	GHG emissions	kg CO2e	TWh storage capacity
2035	2.91E+09	Battery, Na-ion	6.26E+07	2.85E+09	land occupation	m2-year	TWh storage capacity
2035	2.35E+02	Battery, Na-ion	3.16E+00	2.32E+02	ecosystem damage	species loss-year	TWh storage capacity
2035	7.69E+02	Battery, Na-ion	5.03E+00	7.63E+02	radioactive waste	m3	TWh storage capacity
2035	2.90E+09	Battery, Na-ion	1.26E+04	2.90E+09	toxic waste	kg	TWh storage capacity
2035	1.45E+07	Battery, Na-ion	2.65E-01	1.45E+07	Cobalt	kg	TWh storage capacity
2035	4.04E+04	Battery, Na-ion	0.00E+00	4.04E+04	Lithium	kg	TWh storage capacity
2035	5.08E+04	Battery, Na-ion	0.00E+00	5.08E+04	Neodymium	kg	TWh storage capacity
2035	2.55E+08	Battery, Na-ion	0.00E+00	2.55E+08	Nickel	kg	TWh storage capacity
2035	4.27E+08	Solar PV plant, rooftop, 1 MW	1.75E+07	4.10E+08	GHG emissions	kg CO2e	MW installed
2035	6.27E+07	Solar PV plant, rooftop, 1 MW	5.43E+05	6.21E+07	land occupation	m2-year	MW installed
2035	2.85E+00	Solar PV plant, rooftop, 1 MW	6.42E-02	2.78E+00	ecosystem damage	species loss-year	MW installed
2035	4.49E+00	Solar PV plant, rooftop, 1 MW	3.24E-02	4.46E+00	radioactive waste	m3	MW installed
2035	4.16E+07	Solar PV plant, rooftop, 1 MW	8.10E+01	4.16E+07	toxic waste	kg	MW installed
2035	3.50E+03	Solar PV plant, rooftop, 1 MW	2.56E-03	3.50E+03	Cobalt	kg	MW installed
2035	1.87E+02	Solar PV plant, rooftop, 1 MW	0.00E+00	1.87E+02	Lithium	kg	MW installed
2035	3.84E+02	Solar PV plant, rooftop, 1 MW	0.00E+00	3.84E+02	Neodymium	kg	MW installed
2035	2.60E+05	Solar PV plant, rooftop, 1 MW	0.00E+00	2.60E+05	Nickel	kg	MW installed
2035	6.73E+08	Solar PV, open-ground plant, 1 MW	5.40E+07	6.19E+08	GHG emissions	kg CO2e	MW installed
2035	6.91E+08	Solar PV, open-ground plant, 1 MW	5.87E+08	1.04E+08	land occupation	m2-year	MW installed
2035	9.44E+00	Solar PV, open-ground plant, 1 MW	4.08E+00	5.36E+00	ecosystem damage	species loss-year	MW installed
2035	5.16E+00	Solar PV, open-ground plant, 1 MW	3.68E-02	5.12E+00	radioactive waste	m3	MW installed

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2035	9.01E+07	Solar PV, open-ground plant, 1 MW	9.21E+01	9.01E+07	toxic waste	kg	MW installed
2035	1.22E+04	Solar PV, open-ground plant, 1 MW	2.79E-02	1.22E+04	Cobalt	kg	MW installed
2035	3.99E+02	Solar PV, open-ground plant, 1 MW	0.00E+00	3.99E+02	Lithium	kg	MW installed
2035	5.14E+02	Solar PV, open-ground plant, 1 MW	0.00E+00	5.14E+02	Neodymium	kg	MW installed
2035	6.76E+05	Solar PV, open-ground plant, 1 MW	0.00E+00	6.76E+05	Nickel	kg	MW installed
2035	4.28E+08	Wind plant, 1 MW	1.35E+06	4.26E+08	GHG emissions	kg CO2e	MW installed
2035	6.23E+07	Wind plant, 1 MW	4.61E+05	6.18E+07	land occupation	m2-year	MW installed
2035	2.77E+00	Wind plant, 1 MW	1.11E-02	2.76E+00	ecosystem damage	species loss-year	MW installed
2035	4.18E+00	Wind plant, 1 MW	3.22E-02	4.15E+00	radioactive waste	m3	MW installed
2035	5.22E+07	Wind plant, 1 MW	8.04E+01	5.22E+07	toxic waste	kg	MW installed
2035	7.16E+03	Wind plant, 1 MW	5.65E-03	7.16E+03	Cobalt	kg	MW installed
2035	4.09E+02	Wind plant, 1 MW	0.00E+00	4.09E+02	Lithium	kg	MW installed
2035	1.23E+04	Wind plant, 1 MW	0.00E+00	1.23E+04	Neodymium	kg	MW installed
2035	1.79E+06	Wind plant, 1 MW	0.00E+00	1.79E+06	Nickel	kg	MW installed
2035	1.30E+08	Natural Gas Turbine without CCS plant, 1 MW	1.68E+05	1.30E+08	GHG emissions	kg CO2e	MW installed
2035	1.65E+07	Natural Gas Turbine without CCS plant, 1 MW	4.49E+05	1.61E+07	land occupation	m2-year	MW installed
2035	9.29E-01	Natural Gas Turbine without CCS plant, 1 MW	2.36E-03	9.27E-01	ecosystem damage	species loss-year	MW installed
2035	5.55E-01	Natural Gas Turbine without CCS plant, 1 MW	3.92E-03	5.51E-01	radioactive waste	m3	MW installed
2035	1.47E+07	Natural Gas Turbine without CCS plant, 1 MW	9.80E+00	1.47E+07	toxic waste	kg	MW installed
2035	4.77E+03	Natural Gas Turbine without CCS plant, 1 MW	5.90E-03	4.77E+03	Cobalt	kg	MW installed
2035	9.53E+00	Natural Gas Turbine without CCS plant, 1 MW	0.00E+00	9.53E+00	Lithium	kg	MW installed
2035	2.98E+01	Natural Gas Turbine without CCS plant, 1 MW	0.00E+00	2.98E+01	Neodymium	kg	MW installed
2035	8.22E+05	Natural Gas Turbine without CCS plant, 1 MW	0.00E+00	8.22E+05	Nickel	kg	MW installed
2035	1.30E+08	Biomethane Turbine without CCS plant, 1 MW	1.68E+05	1.30E+08	GHG emissions	kg CO2e	MW installed
2035	1.65E+07	Biomethane Turbine without CCS plant, 1 MW	4.49E+05	1.61E+07	land occupation	m2-year	MW installed
2035	9.29E-01	Biomethane Turbine without CCS plant, 1 MW	2.36E-03	9.27E-01	ecosystem damage	species loss-year	MW installed
2035	5.55E-01	Biomethane Turbine without CCS plant, 1 MW	3.92E-03	5.51E-01	radioactive waste	m3	MW installed
2035	1.47E+07	Biomethane Turbine without CCS plant, 1 MW	9.80E+00	1.47E+07	toxic waste	kg	MW installed
2035	4.77E+03	Biomethane Turbine without CCS plant, 1 MW	5.90E-03	4.77E+03	Cobalt	kg	MW installed
2035	9.53E+00	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	9.53E+00	Lithium	kg	MW installed
2035	2.98E+01	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	2.98E+01	Neodymium	kg	MW installed
2035	8.22E+05	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	8.22E+05	Nickel	kg	MW installed

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2050	8.58E+06	Solar PV, rooftop	5.60E+05	8.02E+06	GHG emissions	kg CO2e	TWh electricity generated
2050	2.16E+06	Solar PV, rooftop	3.26E+04	2.12E+06	land occupation	m2-year	TWh electricity generated
2050	7.23E-02	Solar PV, rooftop	2.10E-03	7.02E-02	ecosystem damage	species loss-year	TWh electricity generated
2050	1.09E-01	Solar PV, rooftop	7.76E-04	1.08E-01	radioactive waste	m3	TWh electricity generated
2050	1.46E+06	Solar PV, rooftop	1.94E+00	1.46E+06	toxic waste	kg	TWh electricity generated
2050	1.16E+02	Solar PV, rooftop	4.16E-05	1.16E+02	Cobalt	kg	TWh electricity generated
2050	1.54E+01	Solar PV, rooftop	0.00E+00	1.54E+01	Lithium	kg	TWh electricity generated
2050	1.25E+01	Solar PV, rooftop	0.00E+00	1.25E+01	Neodymium	kg	TWh electricity generated
2050	6.69E+03	Solar PV, rooftop	0.00E+00	6.69E+03	Nickel	kg	TWh electricity generated
2050	1.39E+07	Solar PV, open-ground	1.71E+06	1.21E+07	GHG emissions	kg CO2e	TWh electricity generated
2050	2.14E+07	Solar PV, open-ground	1.76E+07	3.81E+06	land occupation	m2-year	TWh electricity generated
2050	2.69E-01	Solar PV, open-ground	1.23E-01	1.46E-01	ecosystem damage	species loss-year	TWh electricity generated
2050	1.16E-01	Solar PV, open-ground	8.11E-04	1.15E-01	radioactive waste	m3	TWh electricity generated
2050	3.61E+06	Solar PV, open-ground	2.03E+00	3.61E+06	toxic waste	kg	TWh electricity generated
2050	3.99E+02	Solar PV, open-ground	4.54E-04	3.99E+02	Cobalt	kg	TWh electricity generated
2050	3.49E+01	Solar PV, open-ground	0.00E+00	3.49E+01	Lithium	kg	TWh electricity generated
2050	1.65E+01	Solar PV, open-ground	0.00E+00	1.65E+01	Neodymium	kg	TWh electricity generated
2050	1.68E+04	Solar PV, open-ground	0.00E+00	1.68E+04	Nickel	kg	TWh electricity generated
2050	4.99E+06	Wind	1.28E+05	4.86E+06	GHG emissions	kg CO2e	TWh electricity generated
2050	1.29E+06	Wind	1.67E+04	1.27E+06	land occupation	m2-year	TWh electricity generated
2050	4.01E-02	Wind	5.11E-04	3.95E-02	ecosystem damage	species loss-year	TWh electricity generated
2050	5.97E-02	Wind	4.37E-04	5.92E-02	radioactive waste	m3	TWh electricity generated
2050	1.02E+06	Wind	1.09E+00	1.02E+06	toxic waste	kg	TWh electricity generated
2050	1.14E+02	Wind	5.46E-05	1.14E+02	Cobalt	kg	TWh electricity generated
2050	2.21E+01	Wind	0.00E+00	2.21E+01	Lithium	kg	TWh electricity generated
2050	1.59E+02	Wind	0.00E+00	1.59E+02	Neodymium	kg	TWh electricity generated
2050	2.10E+04	Wind	0.00E+00	2.10E+04	Nickel	kg	TWh electricity generated
2050	1.54E+08	Natural Gas CC with CCS	5.30E+07	1.01E+08	GHG emissions	kg CO2e	TWh electricity generated
2050	1.37E+06	Natural Gas CC with CCS	7.23E+04	1.30E+06	land occupation	m2-year	TWh electricity generated
2050	5.75E-01	Natural Gas CC with CCS	1.67E-01	4.09E-01	ecosystem damage	species loss-year	TWh electricity generated
2050	1.28E-01	Natural Gas CC with CCS	9.20E-04	1.27E-01	radioactive waste	m3	TWh electricity generated
2050	4.90E+05	Natural Gas CC with CCS	2.30E+00	4.90E+05	toxic waste	kg	TWh electricity generated
2050	1.13E+02	Natural Gas CC with CCS	8.56E-05	1.13E+02	Cobalt	kg	TWh electricity generated
2050	3.84E+00	Natural Gas CC with CCS	0.00E+00	3.84E+00	Lithium	kg	TWh electricity generated
2050	1.26E+02	Natural Gas CC with CCS	0.00E+00	1.26E+02	Neodymium	kg	TWh electricity generated
2050	3.03E+04	Natural Gas CC with CCS	0.00E+00	3.03E+04	Nickel	kg	TWh electricity generated
2050	1.71E+07	Biomethane CC	2.35E+06	1.48E+07	GHG emissions	kg CO2e	TWh electricity generated
2050	8.66E+06	Biomethane CC	3.35E+06	5.32E+06	land occupation	m2-year	TWh electricity generated
2050	2.06E-01	Biomethane CC	1.18E-01	8.71E-02	ecosystem damage	species loss-year	TWh electricity generated
2050	3.89E-02	Biomethane CC	2.67E-04	3.86E-02	radioactive waste	m3	TWh electricity generated
2050	1.26E+06	Biomethane CC	6.67E-01	1.26E+06	toxic waste	kg	TWh electricity generated
2050	1.93E+02	Biomethane CC	6.64E-03	1.93E+02	Cobalt	kg	TWh electricity generated
2050	3.67E+01	Biomethane CC	0.00E+00	3.67E+01	Lithium	kg	TWh electricity generated

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2050	8.91E+00	Biomethane CC	0.00E+00	8.91E+00	Neodymium	kg	TWh electricity generated
2050	2.04E+04	Biomethane CC	0.00E+00	2.04E+04	Nickel	kg	TWh electricity generated
2050	2.42E+07	Hydrogen CC	1.32E+06	2.29E+07	GHG emissions	kg CO2e	TWh electricity generated
2050	4.07E+07	Hydrogen CC	1.21E+05	4.06E+07	land occupation	m2-year	TWh electricity generated
2050	5.26E-01	Hydrogen CC	4.25E-02	4.83E-01	ecosystem damage	species loss-year	TWh electricity generated
2050	3.13E-01	Hydrogen CC	2.23E-03	3.10E-01	radioactive waste	m3	TWh electricity generated
2050	6.97E+06	Hydrogen CC	5.57E+00	6.97E+06	toxic waste	kg	TWh electricity generated
2050	5.00E+02	Hydrogen CC	2.38E-04	5.00E+02	Cobalt	kg	TWh electricity generated
2050	4.63E+01	Hydrogen CC	0.00E+00	4.63E+01	Lithium	kg	TWh electricity generated
2050	3.52E+01	Hydrogen CC	0.00E+00	3.52E+01	Neodymium	kg	TWh electricity generated
2050	5.32E+04	Hydrogen CC	0.00E+00	5.32E+04	Nickel	kg	TWh electricity generated
2050	2.05E+06	Nuclear	8.73E+04	1.96E+06	GHG emissions	kg CO2e	TWh electricity generated
2050	5.46E+05	Nuclear	5.86E+04	4.87E+05	land occupation	m2-year	TWh electricity generated
2050	6.41E-02	Nuclear	4.06E-02	2.34E-02	ecosystem damage	species loss-year	TWh electricity generated
2050	6.04E+01	Nuclear	6.00E+01	4.51E-01	radioactive waste	m3	TWh electricity generated
2050	5.71E+05	Nuclear	1.13E+03	5.70E+05	toxic waste	kg	TWh electricity generated
2050	4.62E+01	Nuclear	2.85E-04	4.62E+01	Cobalt	kg	TWh electricity generated
2050	6.64E+00	Nuclear	0.00E+00	6.64E+00	Lithium	kg	TWh electricity generated
2050	6.76E+00	Nuclear	0.00E+00	6.76E+00	Neodymium	kg	TWh electricity generated
2050	9.83E+03	Nuclear	0.00E+00	9.83E+03	Nickel	kg	TWh electricity generated
2050	2.17E+10	Battery, Li-ion NMC	6.45E+07	2.16E+10	GHG emissions	kg CO2e	TWh storage capacity
2050	4.48E+09	Battery, Li-ion NMC	6.73E+07	4.41E+09	land occupation	m2-year	TWh storage capacity
2050	2.88E+02	Battery, Li-ion NMC	4.84E-01	2.87E+02	ecosystem damage	species loss-year	TWh storage capacity
2050	5.39E+02	Battery, Li-ion NMC	2.97E+00	5.36E+02	radioactive waste	m3	TWh storage capacity
2050	1.03E+10	Battery, Li-ion NMC	7.41E+03	1.03E+10	toxic waste	kg	TWh storage capacity
2050	7.92E+07	Battery, Li-ion NMC	1.95E-01	7.92E+07	Cobalt	kg	TWh storage capacity
2050	4.16E+07	Battery, Li-ion NMC	0.00E+00	4.16E+07	Lithium	kg	TWh storage capacity
2050	6.83E+04	Battery, Li-ion NMC	0.00E+00	6.83E+04	Neodymium	kg	TWh storage capacity
2050	3.10E+08	Battery, Li-ion NMC	0.00E+00	3.10E+08	Nickel	kg	TWh storage capacity
2050	2.50E+10	Battery, Li-ion LFP	8.31E+07	2.49E+10	GHG emissions	kg CO2e	TWh storage capacity
2050	5.46E+09	Battery, Li-ion LFP	7.07E+07	5.39E+09	land occupation	m2-year	TWh storage capacity
2050	3.77E+02	Battery, Li-ion LFP	5.43E-01	3.76E+02	ecosystem damage	species loss-year	TWh storage capacity
2050	4.08E+02	Battery, Li-ion LFP	2.83E+00	4.05E+02	radioactive waste	m3	TWh storage capacity
2050	1.13E+10	Battery, Li-ion LFP	7.08E+03	1.13E+10	toxic waste	kg	TWh storage capacity
2050	1.08E+06	Battery, Li-ion LFP	1.55E-01	1.08E+06	Cobalt	kg	TWh storage capacity
2050	4.73E+07	Battery, Li-ion LFP	0.00E+00	4.73E+07	Lithium	kg	TWh storage capacity
2050	1.11E+05	Battery, Li-ion LFP	0.00E+00	1.11E+05	Neodymium	kg	TWh storage capacity
2050	4.18E+07	Battery, Li-ion LFP	0.00E+00	4.18E+07	Nickel	kg	TWh storage capacity
2050	2.10E+10	Battery, Na-ion	9.64E+08	2.00E+10	GHG emissions	kg CO2e	TWh storage capacity
2050	2.92E+09	Battery, Na-ion	7.00E+07	2.85E+09	land occupation	m2-year	TWh storage capacity
2050	2.05E+02	Battery, Na-ion	3.18E+00	2.02E+02	ecosystem damage	species loss-year	TWh storage capacity
2050	3.72E+02	Battery, Na-ion	2.07E+00	3.70E+02	radioactive waste	m3	TWh storage capacity
2050	3.99E+09	Battery, Na-ion	5.18E+03	3.99E+09	toxic waste	kg	TWh storage capacity

year	total score	technology	CH	non-domestic	environmental burden	unit	per
2050	1.45E+07	Battery, Na-ion	1.40E-01	1.45E+07	Cobalt	kg	TWh storage capacity
2050	1.06E+05	Battery, Na-ion	0.00E+00	1.06E+05	Lithium	kg	TWh storage capacity
2050	5.12E+04	Battery, Na-ion	0.00E+00	5.12E+04	Neodymium	kg	TWh storage capacity
2050	2.49E+08	Battery, Na-ion	0.00E+00	2.49E+08	Nickel	kg	TWh storage capacity
2050	2.44E+08	Solar PV plant, rooftop, 1 MW	1.59E+07	2.29E+08	GHG emissions	kg CO2e	MW installed
2050	6.14E+07	Solar PV plant, rooftop, 1 MW	9.29E+05	6.05E+07	land occupation	m2-year	MW installed
2050	2.06E+00	Solar PV plant, rooftop, 1 MW	5.98E-02	2.00E+00	ecosystem damage	species loss-year	MW installed
2050	3.11E+00	Solar PV plant, rooftop, 1 MW	2.21E-02	3.08E+00	radioactive waste	m3	MW installed
2050	4.15E+07	Solar PV plant, rooftop, 1 MW	5.53E+01	4.15E+07	toxic waste	kg	MW installed
2050	3.32E+03	Solar PV plant, rooftop, 1 MW	1.18E-03	3.32E+03	Cobalt	kg	MW installed
2050	4.38E+02	Solar PV plant, rooftop, 1 MW	0.00E+00	4.38E+02	Lithium	kg	MW installed
2050	3.56E+02	Solar PV plant, rooftop, 1 MW	0.00E+00	3.56E+02	Neodymium	kg	MW installed
2050	1.91E+05	Solar PV plant, rooftop, 1 MW	0.00E+00	1.91E+05	Nickel	kg	MW installed
2050	4.16E+08	Solar PV, open-ground plant, 1 MW	5.12E+07	3.64E+08	GHG emissions	kg CO2e	MW installed
2050	6.43E+08	Solar PV, open-ground plant, 1 MW	5.28E+08	1.14E+08	land occupation	m2-year	MW installed
2050	8.07E+00	Solar PV, open-ground plant, 1 MW	3.68E+00	4.39E+00	ecosystem damage	species loss-year	MW installed
2050	3.47E+00	Solar PV, open-ground plant, 1 MW	2.43E-02	3.45E+00	radioactive waste	m3	MW installed
2050	1.08E+08	Solar PV, open-ground plant, 1 MW	6.08E+01	1.08E+08	toxic waste	kg	MW installed
2050	1.20E+04	Solar PV, open-ground plant, 1 MW	1.36E-02	1.20E+04	Cobalt	kg	MW installed
2050	1.05E+03	Solar PV, open-ground plant, 1 MW	0.00E+00	1.05E+03	Lithium	kg	MW installed
2050	4.95E+02	Solar PV, open-ground plant, 1 MW	0.00E+00	4.95E+02	Neodymium	kg	MW installed
2050	5.03E+05	Solar PV, open-ground plant, 1 MW	0.00E+00	5.03E+05	Nickel	kg	MW installed
2050	2.95E+08	Wind plant, 1 MW	1.34E+06	2.94E+08	GHG emissions	kg CO2e	MW installed
2050	6.43E+07	Wind plant, 1 MW	8.96E+05	6.34E+07	land occupation	m2-year	MW installed
2050	2.28E+00	Wind plant, 1 MW	1.22E-02	2.27E+00	ecosystem damage	species loss-year	MW installed
2050	3.66E+00	Wind plant, 1 MW	2.68E-02	3.64E+00	radioactive waste	m3	MW installed
2050	6.17E+07	Wind plant, 1 MW	6.71E+01	6.17E+07	toxic waste	kg	MW installed
2050	6.85E+03	Wind plant, 1 MW	3.30E-03	6.85E+03	Cobalt	kg	MW installed
2050	1.35E+03	Wind plant, 1 MW	0.00E+00	1.35E+03	Lithium	kg	MW installed
2050	9.78E+03	Wind plant, 1 MW	0.00E+00	9.78E+03	Neodymium	kg	MW installed
2050	1.29E+06	Wind plant, 1 MW	0.00E+00	1.29E+06	Nickel	kg	MW installed
2050	1.30E+08	Natural Gas Turbine with CCS plant, 1 MW	1.68E+05	1.30E+08	GHG emissions	kg CO2e	MW installed
2050	1.65E+07	Natural Gas Turbine with CCS plant, 1 MW	4.49E+05	1.61E+07	land occupation	m2-year	MW installed
2050	9.29E-01	Natural Gas Turbine with CCS plant, 1 MW	2.36E-03	9.27E-01	ecosystem damage	species loss-year	MW installed
2050	5.55E-01	Natural Gas Turbine with CCS plant, 1 MW	3.92E-03	5.51E-01	radioactive waste	m3	MW installed
2050	1.47E+07	Natural Gas Turbine with CCS plant, 1 MW	9.80E+00	1.47E+07	toxic waste	kg	MW installed
2050	4.77E+03	Natural Gas Turbine with CCS plant, 1 MW	5.90E-03	4.77E+03	Cobalt	kg	MW installed
2050	9.53E+00	Natural Gas Turbine with CCS plant, 1 MW	0.00E+00	9.53E+00	Lithium	kg	MW installed
2050	2.98E+01	Natural Gas Turbine with CCS plant,	0.00E+00	2.98E+01	Neodymium	kg	MW installed

year	total score	technology	CH	non-domestic	environmental burden	unit	per
		1 MW					
2050	8.22E+05	Natural Gas Turbine with CCS plant, 1 MW	0.00E+00	8.22E+05	Nickel	kg	MW installed
2050	1.30E+08	Biomethane Turbine without CCS plant, 1 MW	1.68E+05	1.30E+08	GHG emissions	kg CO2e	MW installed
2050	1.65E+07	Biomethane Turbine without CCS plant, 1 MW	4.49E+05	1.61E+07	land occupation	m2-year	MW installed
2050	9.29E-01	Biomethane Turbine without CCS plant, 1 MW	2.36E-03	9.27E-01	ecosystem damage	species loss-year	MW installed
2050	5.55E-01	Biomethane Turbine without CCS plant, 1 MW	3.92E-03	5.51E-01	radioactive waste	m3	MW installed
2050	1.47E+07	Biomethane Turbine without CCS plant, 1 MW	9.80E+00	1.47E+07	toxic waste	kg	MW installed
2050	4.77E+03	Biomethane Turbine without CCS plant, 1 MW	5.90E-03	4.77E+03	Cobalt	kg	MW installed
2050	9.53E+00	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	9.53E+00	Lithium	kg	MW installed
2050	2.98E+01	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	2.98E+01	Neodymium	kg	MW installed
2050	8.22E+05	Biomethane Turbine without CCS plant, 1 MW	0.00E+00	8.22E+05	Nickel	kg	MW installed
2050	7.15E+07	Hydrogen Turbine plant, 1 MW	1.41E+05	7.13E+07	GHG emissions	kg CO2e	MW installed
2050	1.42E+07	Hydrogen Turbine plant, 1 MW	5.02E+05	1.37E+07	land occupation	m2-year	MW installed
2050	6.74E-01	Hydrogen Turbine plant, 1 MW	2.45E-03	6.71E-01	ecosystem damage	species loss-year	MW installed
2050	3.80E-01	Hydrogen Turbine plant, 1 MW	2.36E-03	3.77E-01	radioactive waste	m3	MW installed
2050	2.78E+07	Hydrogen Turbine plant, 1 MW	5.90E+00	2.78E+07	toxic waste	kg	MW installed
2050	4.85E+03	Hydrogen Turbine plant, 1 MW	3.05E-03	4.85E+03	Cobalt	kg	MW installed
2050	1.61E+02	Hydrogen Turbine plant, 1 MW	0.00E+00	1.61E+02	Lithium	kg	MW installed
2050	3.97E+01	Hydrogen Turbine plant, 1 MW	0.00E+00	3.97E+01	Neodymium	kg	MW installed
2050	7.58E+05	Hydrogen Turbine plant, 1 MW	0.00E+00	7.58E+05	Nickel	kg	MW installed
2050	1.35E+08	Nuclear plant, 1 MW	1.51E+07	1.20E+08	GHG emissions	kg CO2e	MW installed
2050	6.01E+07	Nuclear plant, 1 MW	1.10E+07	4.91E+07	land occupation	m2-year	MW installed
2050	1.31E+00	Nuclear plant, 1 MW	1.45E-01	1.16E+00	ecosystem damage	species loss-year	MW installed
2050	5.79E-01	Nuclear plant, 1 MW	3.66E-03	5.75E-01	radioactive waste	m3	MW installed
2050	3.94E+07	Nuclear plant, 1 MW	9.15E+00	3.94E+07	toxic waste	kg	MW installed
2050	3.67E+03	Nuclear plant, 1 MW	3.99E-02	3.67E+03	Cobalt	kg	MW installed
2050	5.16E+02	Nuclear plant, 1 MW	0.00E+00	5.16E+02	Lithium	kg	MW installed
2050	1.18E+02	Nuclear plant, 1 MW	0.00E+00	1.18E+02	Neodymium	kg	MW installed
2050	8.68E+05	Nuclear plant, 1 MW	0.00E+00	8.68E+05	Nickel	kg	MW installed