Health Impact Assessment
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DEBUNKING THE VALUE-ADDED MYTH IN NICKEL DOWNSTREAM INDUSTRY

ECONOMIC & HEALTH IMPACT OF NICKEL INDUSTRY IN CENTRAL SULAWESI, SOUTHEAST SULAWESI, AND NORTH MALUKU

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Debunking the value-added myth in nickel downstream industry – Economic and health impact of nickel industry in Central Sulawesi, Southeast Sulawesi, and North Maluku

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Debunking the value-added myth in nickel downstream industry

Economic and health impact of nickel industry in Central Sulawesi, Southeast Sulawesi, and North Maluku

This study quantifies the impact of Indonesia's fast-expanding nickel industry on the country's economy, public health and environment, with a special focus on Central Sulawesi, Southeast Sulawesi, and North Maluku where most nickel processing centres are located.

Key findings

Economic impacts

- While the nickel industry contributes significantly to the country's exports, it is crucial to understand its economic burden, especially as it depends on captive coal plants that have long-term impacts on the community.
- As per models, the continued growth in a business-as-usual (BAU) scenario in nickel smelting operations in Central Sulawesi, Southeast Sulawesi and North Maluku would generate positive GDP by USD 4 billion (IDR 62.8 trillion) in the 5th year of the construction phase. Post that, the industry's impact on the region's environment and public health will begin to negatively affect the region's overall economic output.
- Environmental degradation results in a gradual decrease in economic benefits, notably apparent post the 8th year, with negative indicators surfacing by the 9th year. These projections also hold true at both national and regional levels with the BAU scenario.
- While nickel smelting activities demonstrate minimal impact on reducing equality, negative repercussions from mining and excavations contribute to escalating inequality over time.
- The nickel industry in the BAU scenario proves to have a more negative economic and labour absorption outcome compared to the renewable energy (RE) and installation of Air Pollution Control (APC) scenario.
- Despite the implementation of measures such as renewable energy (RE) to replace coal-fired power plants (CFPP) and air pollution control (APC) to mitigate adverse

effects, our analysis indicates that the impacts of ecological depletion and the health cost that affect workers and local communities are unlikely to be fully mitigated.

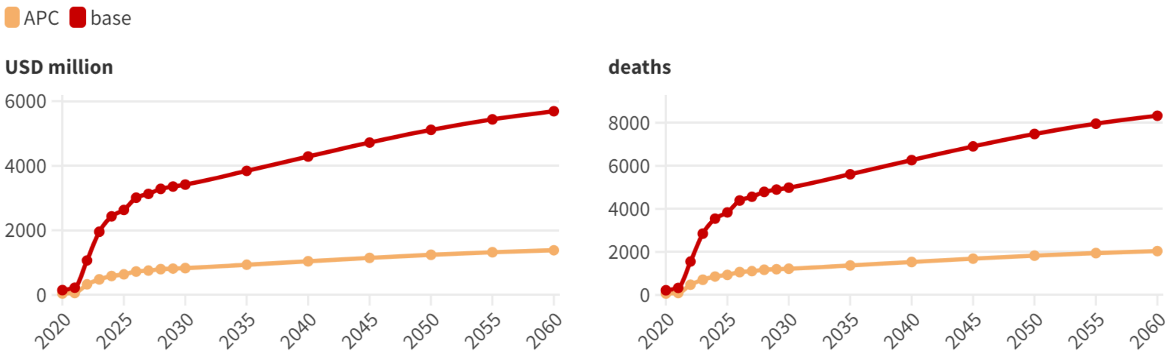
- The total accumulated wages of workers in various sectors generated over 15 years amounted to USD 14.71 billion (IDR 228 trillion). However, the BAU scenario regarding the projection of workers' wages in the long term tends to decline because the income of workers in the agricultural and fisheries sectors is quite affected by the activities of the nickel processing industry. Workers who face reduced productivity due to air pollution also affect the income they receive.
- The implications of nickel mining on the agriculture and fisheries sectors in the three provinces tend to be negative under the BAU scenario. The nickel industry can generate economic value-added losses of more than USD 387.10 million (IDR 6 trillion) in 15 years.
- The scenario of the existing operation of the nickel industry can cause farmers and fishermen to lose USD 234.84 million (IDR 3.64 trillion) in income in the next 15 years.

Air pollution-related health and environmental impacts

- The distribution of emissions from the metal industry in Indonesia dramatically changed since nickel downstreaming began - marked by the banning of nickel ore export in 2020. As a result of coal-based processing and captive CFPP, the islands of Sulawesi and Maluku became major hotspots of emissions.
- Nearly 80% of the total emissions in the three provinces evaluated for this study — Central Sulawesi, Southeast Sulawesi, and North Maluku – were from nickel refining and processing. The remaining were from captive power, operated to supply electricity to the smelters.
- The rapid rise of the nickel industry - if left unregulated - would lead to more than 3,800 deaths in 2025 and nearly 5,000 cases in 2030.
- Emissions from smelters and captive power in the three provinces studied are expected to leave an annual economic burden of USD 2.63 billion (IDR 40.7 trillion) in 2025. Without meaningful interventions to mitigate emissions, this burden is expected to increase by more than 30% – or USD 3.42 billion (IDR 53 trillion) – in 2030.
- Citizens living in Southeast Sulawesi, North Maluku, Southeast Sulawesi, and Central Sulawesi would bear the brunt of both economic damages and health impacts as a result of prolonged exposure to toxic air.
- Obsidian Stainless Steel, with an annual production capacity of 2.2 million tons ferronickel and 3 million tons of stainless steel, is estimated to be responsible for more than a thousand deaths annually and takes the top spot. Other companies that made the top five list are Indonesia Tsingshan Stainless Steel, Alchemist Metal Industry, Virtue Dragon Nickel Industry, and Gunbuster Nickel Industry are estimated to cause between 300 and 500 deaths annually.
- Without proper installation and operation of APC technologies, as many as 1.2 million citizens would be exposed to maximum daily exceedance of NO_2 and SO_2, and 7 million people to $PM_{2.5}$ maximum daily exceedance. All three are well-recognized as major health-harming air pollutants.
- Besides mitigating emissions from CFPPs, APC measures are crucial in metal processing flue gas, which contains high concentrations of toxic air pollutants. With the use of APC technologies, over 3,500 deaths linked to emissions from processing and 250 deaths linked to emissions from captive coal power can be avoided in 2030.

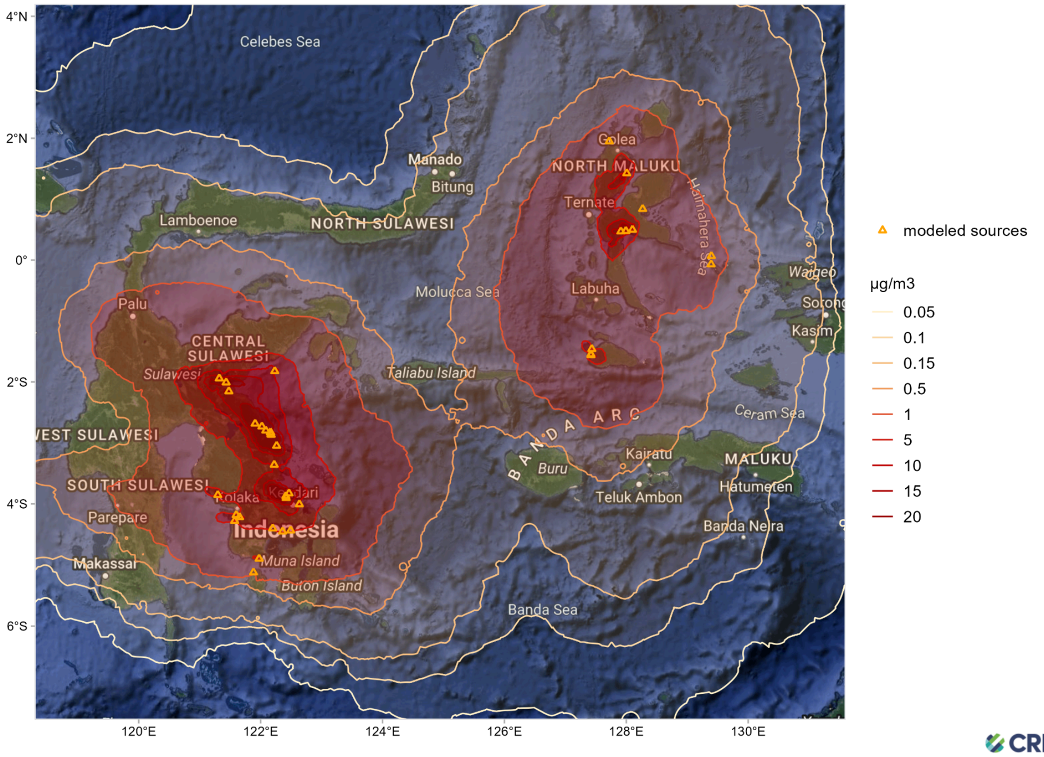
- Up to 55,600 deaths and USD 38.2 billion (IDR 592 trillion) in losses could be avoided by 2060 if all processing centres in Central Sulawesi, Southeast Sulawesi, and North Maluku enforced stringent air quality standards.
- The lack of pollution control measures in captive coal plants increases the risk of mercury and toxic particles being deposited in the local ecology. The analysis shows that mercury deposition rates may reach 2.5 times the safe threshold of 125 mg/ha/year, with high potential of contamination reaching water bodies. Toxic particle deposition may be as high as 80 kg/ha/year near processing centres, indicating high risks of negative ecological and biological impacts.
- Indonesia's diverse marine and forests, particularly those in Sulawesi and Maluku Islands, are under threat of being contaminated with heavy metal-laden particles that are generated from captive coal plants and processing centres. Aketajawe Lolobata National Park, Murhum/Nipa-Nipa Grand Forest Park, Tokobae Island Marine Park, and Lasolo Bay Marine Park, are those among many protected areas most affected.

Air pollution-related costs and deaths linked to smelters and captive power by scenario; without intervention, base vs. with stringent standards, APC



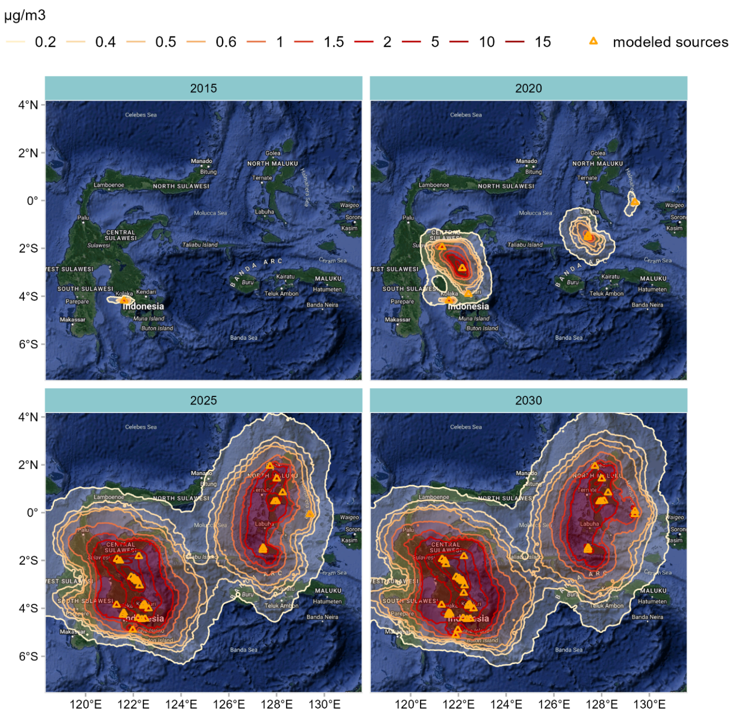
Source: CREA analysis. • Current valuation in 2024.

Annual mean PM2.5 concentration from all smelters and captive power plants



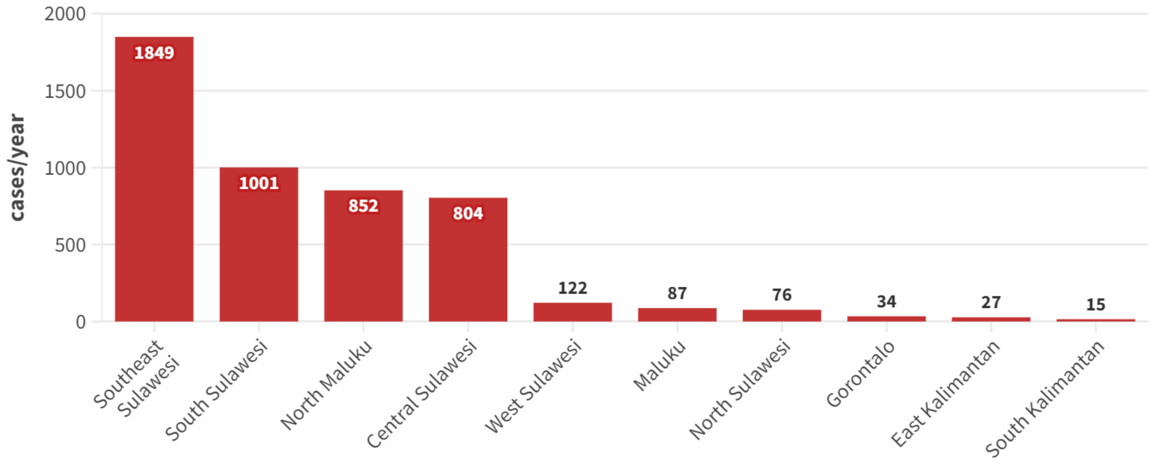
Annual mean PM2.5 concentration

attributed to smelters and associated captive power plants, by year



Air pollution-related deaths linked to smelters and captive power in 2030

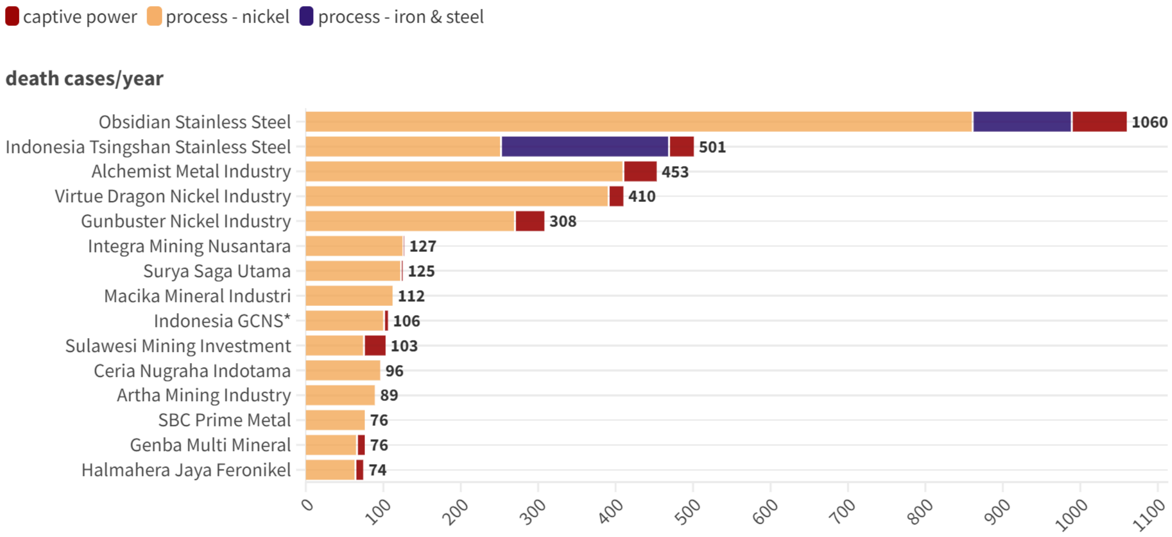
by affected province, due to emissions from the three studied provinces



Source: CREA analysis.

Smelter companies with the largest projected health impact

Annual air pollution-related deaths linked to smelters and captive power in 2030



Source: CREA analysis. •
*Indonesia GCNS, Indonesia Guang Ching Nickel And Stainless Steel Industry

Contents

Abbreviations

%Co	Percent of cobalt content
%Ni	Percent of nickel content
APC	Air Pollution Control
BAU	Business-As-Usual
BF	Blast Furnace
CELIOS	Center of Economic and Law Studies
CFPP	Coal-fired Power Plant
CI	Confidence Interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COD	Commercial Operation Date
Conc.	Concentration
EEA	European Environment Agency
EIA	Environmental Impact Assessment
FGC	Flue Gas Concentration
GCPT	Global Coal Plant Tracker
GDP	Gross Domestic Product
GRDP	Gross Regional Domestic Product
GEM	Global Energy Monitor
GW	Gigawatt
$GtCO_2$-eq	Gigatonnes of carbon dioxide equivalent
ha	Hectare
Hg	Mercury
HPAL	High Pressure Acid Leaching
IDR	Indonesian Rupiah
IEA	International Energy Agency
IESR	Institute for Essential Services Reform
IHME	Institute for Health Metrics and Evaluation
int. USD	International Dollar, equivalent to the purchasing power of 1 USD
JETP	Just Energy Transition Partnership
LHV	Lower Heating Value
MEMR	Ministry of Energy and Mineral Resources

$\mu g/Nm^3$	Microgram per normal cubic metre (at 101.325 kPa, 273.15 K)
mg/Nm^3	Milligram per normal cubic metre (at 101.325 kPa, 273.15 K)
$MtCO_2$-eq	Million tonnes of carbon dioxide equivalent
MW	Megawatt
Nm^3/GJ	Normal cubic metre per GigaJoule (at 101.325 kPa, 273.15 K)
Nm^3/MWh	Normal cubic metre per Megawatt-hour (at 101.325 kPa, 273.15 K)
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
O_2	Oxygen
O_3	Ozone, ground-level
PLN	*Perusahaan Listrik Negara*, Indonesia's State-owned Electricity Provider
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter with particles that are 2.5 microns or less in diameter
PM_{10}	Particulate Matter with particles that are 10 microns or less in diameter
RKEF	Rotary Kiln Electric Furnace
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxides
tpa	Metric ton per annum
UNEP	United Nations Environment Programme
USD	United States Dollar
WRF	Weather Research Forecasting

Background

Nickel boom and Indonesia’s downstreaming strategy

Having abundant geological and mineral resources, Indonesia holds a significant share in the global mining trades. The country’s reserves for nickel and tin are known to be the largest in the world. In addition, Indonesia holds the sixth-highest potential for coal and bauxite and the seventh for copper (MEMR, 2021). Downstreaming of natural resources has become one of the Government’s national agendas to facilitate and sustain economic growth, which is crucial in realising Golden Indonesia 2045 Vision. Marking 100 years of independence, Indonesia has firmly set strategic national plans to become a developed country by 2045 and escape the middle-income trap (Kominfo, 2023).

Nickel, in particular, has been in the spotlight in recent years for the sharp growth in export volume. Global demand for nickel has significantly increased in the past five years at about 10% annual growth, from 2.44 million tons in 2019 to 3.61 million tons in 2023 (Statista, 2022). Parallel to this growth, Indonesia has steadily increased its national annual nickel production from 0.2 million tons in 2016 to 0.76 million tons in 2020, equivalent to 30% of global volume (MEMR, 2021).

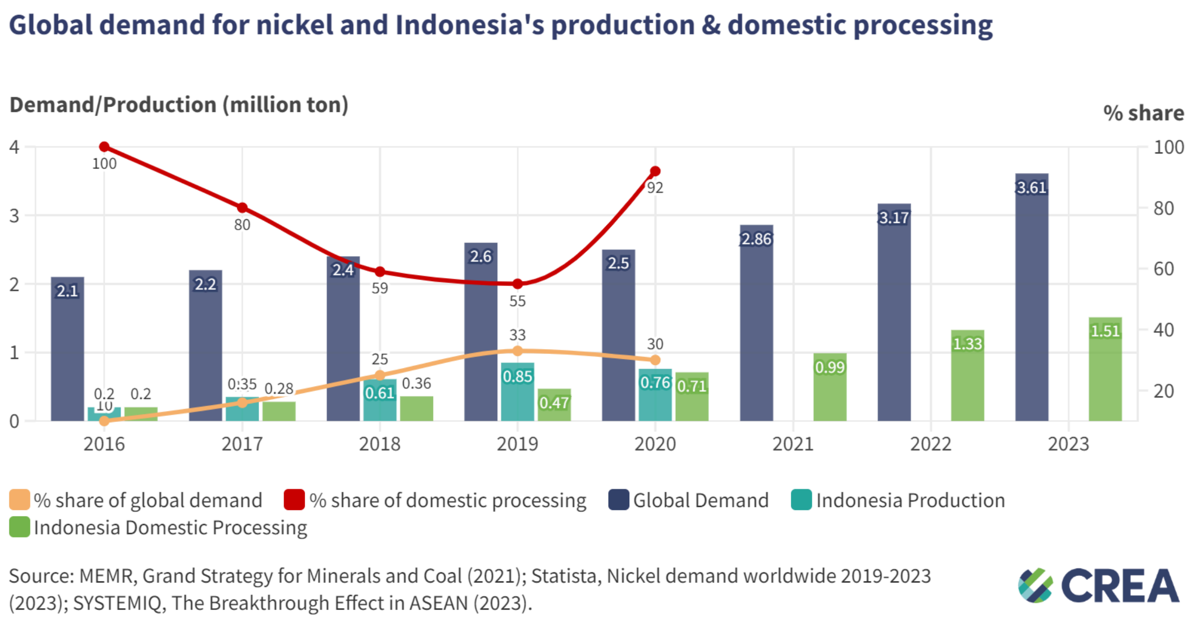


Figure 1. Indonesia’s nickel dynamics against the global demand between 2016 and 2023

Despite such growth, domestic processing of raw nickel ores significantly dropped from about 100% in 2016 to 55% in 2019, as shown in Figure 1 above (MEMR, 2021). To close the gap, the Government banned the export of nickel ore with a grade below 1.7% as of January 1, 2020.[1] This strategy has increased the export of nickel products by 8.5-fold, rising from USD 4 billion in 2017 to USD 34 billion in 2022 (Kominfo, 2023).

Figure 2 shows provinces with significant reserves, along with the locations of companies engaged in nickel smelting and refining across Sulawesi, Malukus, and Papua.

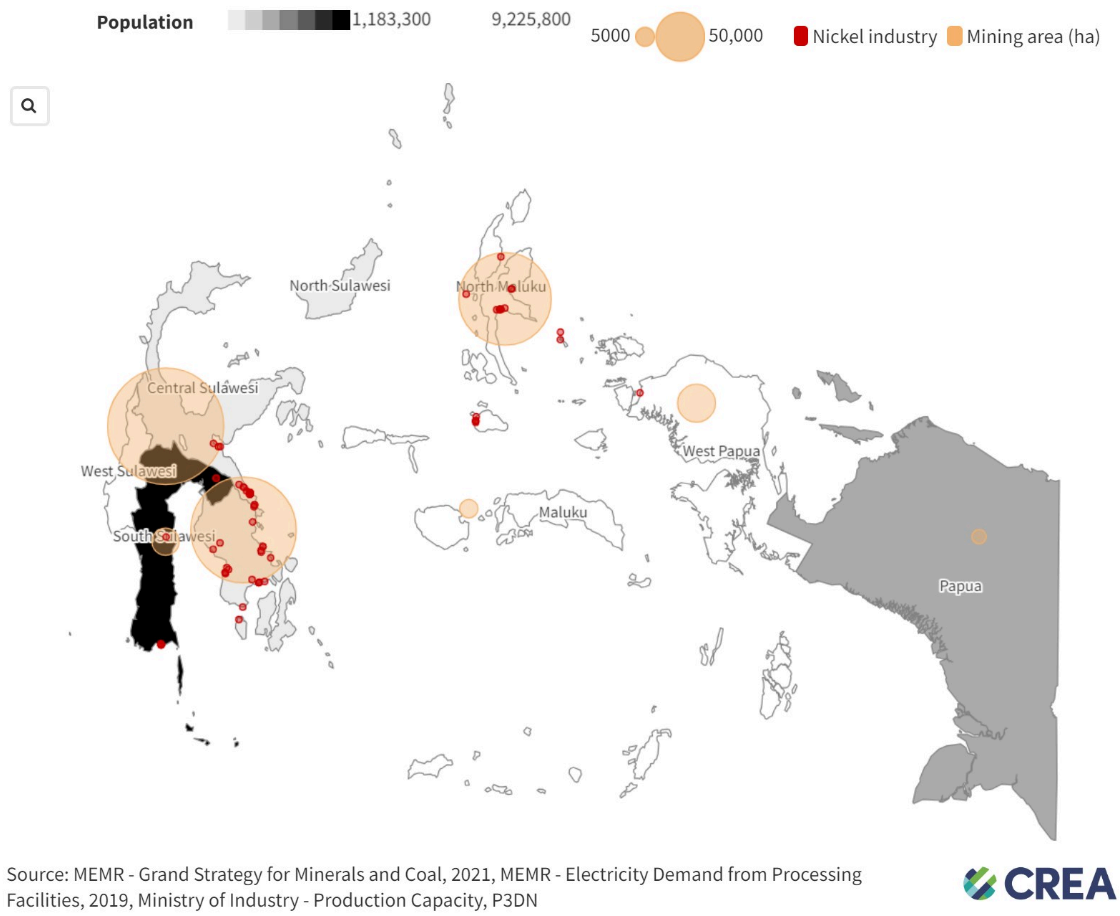


Figure 2. Distribution map of Indonesia's current nickel industry across Eastern Indonesia

The largest nickel reserves are located in the Eastern part of Indonesia, with total nickel ore and metal estimated at 143 million tons and 49 million tons, respectively. As of June 2021, the Government has granted 338 active permits to nickel mining companies (MEMR, 2021). The rise of nickel smelting and refining industries has been very rapid, particularly in

[1] Ministerial Regulation No. 11 Year 2019 (MEMR-JDIH, 2019)

Southeast Sulawesi, Central Sulawesi, and North Maluku. Significant additions are expected up to 2025, and further rise may continue until 2030.

Figure 3 below summarises available nickel production capacities, collected in this study, across Indonesia by commodity types and province.

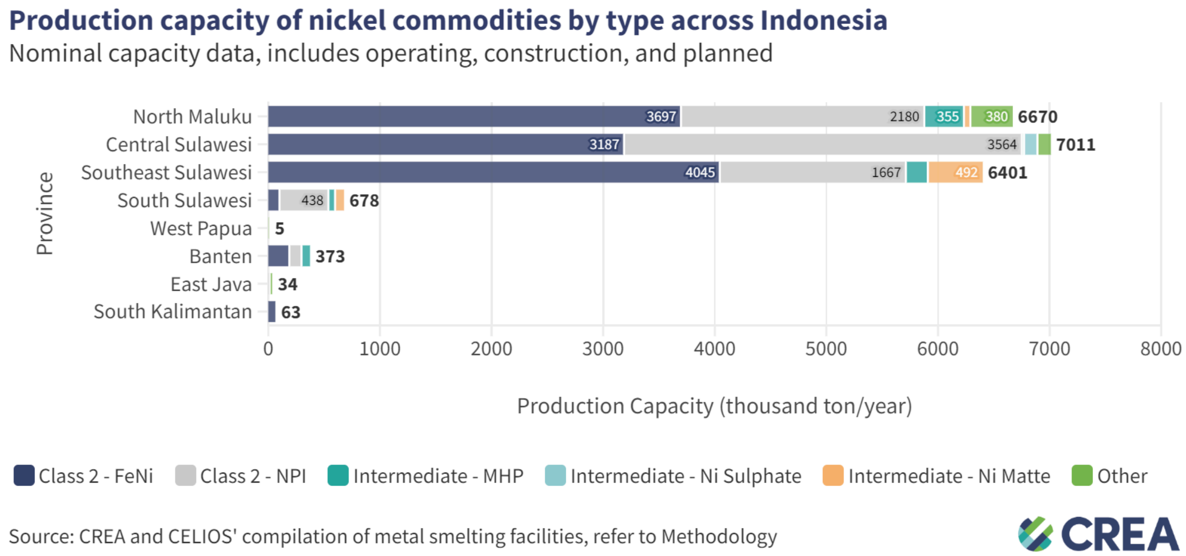


Figure 3. Distribution of nominal production capacity of the different nickel commodities by commodity types and status (operating and noted as in construction or planned)

The majority of Indonesian nickel ore reserves are in the form of **laterite ores**, split into two types — **limonite ores** (0.8-1.5%Ni, iron-rich) and **saprolite ores** (1.5-3%Ni, with 0.1-0.2%Co extractable through chemical process) (Anderson, 2023). Under the current utilisation of the available reserves, MEMR's Geological Agency estimates total lifespans of 34 years for limonites and 15 years for saprolites (Handayani, 2023).

Historically, Indonesia has only focused on **Class 2 Nickel** commodities — **Ferronickel (FeNi)** and **Nickel Pig Iron (NPI)**, which are primarily used in stainless steel production. FeNi and NPI are generally produced from **saprolite ores**, which are processed through the pyrometallurgy process using **Blast Furnace (BF)** and **Rotary Kiln Electric Furnace (RKEF)** smelters. By banning the export of nickel ore, the Government placed the main focus on downstreaming to boost the domestic value added. As the result of this strategy, the use of Class 2 Nickel products in domestic stainless steel production and for conversion to **high-purity Class 1 Nickel products and intermediates**[2] to be used in the production

[2] Mixed Hydroxide/Sulphate Precipitate (MHP/MSP), nickel sulphate, nickel matte, and high-purity nickel

of electric vehicle (EV) battery cells, renewable technologies, and superalloys have increased (MEMR, 2021; Huber, 2021).

Limonite ores are used as feed materials in hydrometallurgy process, namely **High-Pressure Acid Leach (HPAL)**, yielding **Mixed Hydroxide Precipitate (MHP) and Mixed Sulphide Precipitate (MSP)**, nickel and cobalt intermediates. Subsequent conversion processes can be used to extract **Nickel Sulphate** (21%Ni) and **Nickel Hydroxide** (40%Ni) from **MHP or MSP**. Meanwhile, **Nickel Matte** (80%Ni) can be obtained from **FeNi or NPI** through **RKEF**. All three are used in battery cell production.

With the International Energy Agency (IEA) noting Indonesia as 'the world's largest nickel mining and refining centre', the country plays a key role in meeting the growing global demand for **FeNi**, **NPI**, **MHP/MSP**, **Nickel Sulphate**, **Nickel Hydroxide**, and **Nickel Matte** used in the production of stainless steel and battery supply chain (IEA, 2023; Melvin, 2023). During the Asia-Pacific Economic Cooperation Summit held in November 2023, President Joko Widodo announced that Indonesia will start production of EVs in 2024, with an aim to reach 600,000 units by 2030. He also reiterated the country's commitment to renewable resources and developing a 30,000-hectare green industrial park (Setkab, 2030).

Opportunities and challenges

Extractive industries are energy and emission-intensive, which brings out the first crucial issue — **reliance and high proportion of coal use** in Indonesia's downstream industries. Over three-fourths, or 8.2 GW out of 10.8 GW, of the total operating capacity of all captive coal power in Indonesia is dedicated to metal processing (CREA, 2023). Furthermore, captive coal remains unaddressed in the national energy planning and climate roadmap.

The Just Energy Transition Partnership (JETP) Comprehensive Investment and Policy Plan (CIPP), finalised in November 2023, states that off-grid captive coal power plants are outside of the current scope. Peak power sector emissions at 290 $MTCO_2$ by 2030 would be 'extremely difficult to achieve' based on what is known about the captive power landscape (JETP Secretariat, 2023). Decarbonising Indonesia's metal industry is seen as challenging due to a trilemma of competing national economic strategies, lack of cost-effective energy alternatives, and unreliable power grid systems (Zhu et al., 2023).

China is the largest investor in captive coal power in Indonesia, with more than 70% ownership held by 14 private and state-owned metals processing and mining companies. International investors can play a key role in the country's decarbonisation efforts by

aligning their emission standards with international guidelines or China's stricter standards (Zhu et al., 2022; Wang, 2022).[3]

Notwithstanding the existing regulatory framework for emissions from the mining sector, the rapid growth of nickel mining and processing has led to **a rise in incidences of air, soil, and water pollution** in the past few years. Some of these include effluent discharge off the coast of Obi Island turning seawater red, heavy metals contamination in Halmahera's Weda Bay and Buli Bay, submarine wastewater disposal from the Indonesia Morowali Industrial Park, post-mining land degradation in North Konawe, and flue release from coal power plants and coal transport affecting the health of the local communities living near the Konawe Industrial Park — all attributed to nickel mining and processing (Mongabay Environmental News, 2022; Kompas, 2023; Ginting & Moore, 2021; Barus et al, 2022).

Coral Triangle - home to 76% of the world's shallow-water coral species - is at great risk with Indonesia's rapid growth in nickel mining and processing centres. (CTI-CFF, 2009). There have been concerns from environmental groups as well as members of the House of Representatives of the Republic of Indonesia that rapid expansion may create pressure to relax or even lift regulations on deep-sea tailings disposal or increase risks of illegal disposals. In response, the Coordinating Minister for Maritime Affairs and Investment, Luhut Binsar Pandjaitan, stated in July 2023 that Indonesia currently only allows waste disposal in special waste disposal containers or dams, dry stacking, or a combination of both (Setiawan, 2023).

Deforestation and biodiversity loss in the islands of Sulawesi and North Maluku has increased significantly since the nickel industry expanded. Over 500 thousand hectares of forest have been lost in Central Sulawesi and Southeast Sulawesi, not just through legal concessions but reportedly also through illegitimate practices (Hidayat & Hermawan, 2022). Total land concessions from the government to the mining industry exceeded one million hectares in 2022, of which over 75% is forest area, according to The Indonesian Forum for the Environment (WALHI) (Wicaksono, 2023).

Concerns about social and governance aspects, including worker rights and protection in the nickel industry, have also been raised. Between 2019 and 2023, 32 people from the local communities have been prosecuted for conflicts with nickel mining

[3] 2022 Guidelines for Ecological and Environmental Protection of Foreign Investment Cooperation and Construction Projects, issued by the Ministry of Environment and Ecology and Ministry of Commerce of China

companies.[4] Of these, two were arrested, while 14 reported having experienced abuse from authorities (Bhawono, 2023). Several activists and community leaders have criticised the revision of Article 162 of Law No. 3 Year 2020 concerning the Revision of the Mining and Coal Law as an instrument to silence advocates (Constitutional Court of Indonesia, 2022).[5]

On December 24, 2023, 21 workers died in a smelter explosion at a facility owned by PT Indonesia Tsingshan Stainless Steel and PT Gunbuster Nickel Industry (Tenggara Strategics, 2024). This was not an isolated incident. Between 2015 and 2022, 53 workers have been killed in smelter fires and explosions, according to Trend Asia. Some 65 incidents were reported between 2015 and 2023, indicating widespread gross negligence in maintaining safety standards in the sector (Handayani, 2024).

Repeated occurrences of smelter fires and explosions have been recorded in multiple facilities, with 65 incident counts from 2015 to 2023 (Handayani, 2024). This may imply issues in occupational health and safety management, caused by auditing negligence and compromised standards. Trend Asia highlighted that there have been 53 fatalities (40 Indonesians and 13 Chinese nationals) between 2015 to 2022. This number does not include the recent accident on 24 December 2023, where smelters owned by PT Indonesia Tsingshan Stainless Steel and PT Gunbuster Nickel Industry exploded, causing 21 fatalities (13 Indonesians and 8 Chinese nationals) (Tenggara Stategics, 2024).

Indonesia is faced with the urgent task of reforming the domestic metal industry, which requires all stakeholders in the nickel supply chain to play a proactive role in ensuring worker safety and protecting the environment. For a just and sustainable transition, the sourcing of critical minerals must be done responsibly with careful consideration for environmental and social impacts.

[4] Due to negative impacts on the livelihoods of the local communities, land disputes concerning indigenous peoples rights, and migration into mining communities.
[5] Violation of this rule can be punished with imprisonment of up to one year or a fine of up to IDR 100 million.

Methodology

Economic modelling

Interregional Input-Output (IRIO) was used to analyse and calculate the economic impact of nickel downstream activities in Central Sulawesi, Southeast Sulawesi and North Maluku. While IRIO and Input-Output (I-O) methods are similar in most ways, the former is more capable of detailed analysis of inter- and intra-regional effects, which include spillover effect and feedback impact.

With IRIO, we can see the impact of investment policies in one region on other regions. The IRIO table consists of input-output tables from various regions that are connected through inter-regional trade transactions. This table reflects the flow of goods between regions and can be considered interregional trade.

In general, IRIO analysis is explained in Table 1, where there is a process of input of economic transactions to produce an output. In producing output, the primary production sector will produce input to the primary production sector itself and other sectors (secondary and tertiary), and is added to the final demand in each province.

Table 1. IRIO Methodology

Province	Sector	Region D			Region J			Others		
		1	...	16	1	...	16	1	...	16
Region D	1	Z_{11}^{DD}	...	Z_{116}^{DD}	Z_{11}^{DJ}	...	Z_{116}^{DJ}	Z_{11}^{DL}	...	Z_{116}^{DL}
	¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
	16	Z_{161}^{DD}	...	Z_{1616}^{DD}	Z_{161}^{DJ}	...	Z_{1616}^{DJ}	Z_{161}^{DL}	...	Z_{1616}^{DL}
Region J	1	Z_{11}^{JD}	...	Z_{116}^{JD}	Z_{11}^{JJ}	...	Z_{116}^{JJ}	Z_{11}^{JL}	...	Z_{116}^{JL}
	¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
	16	Z_{161}^{JD}	...	Z_{1616}^{JD}	Z_{161}^{JJ}	...	Z_{1616}^{JJ}	Z_{161}^{JL}	...	Z_{1616}^{JL}
Others	1	Z_{11}^{LD}	...	Z_{116}^{LD}	Z_{11}^{LJ}	...	Z_{116}^{LJ}	Z_{11}^{LL}	...	Z_{116}^{LL}
	¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
	16	Z_{161}^{LD}	...	Z_{1616}^{LD}	Z_{161}^{LJ}	...	Z_{1616}^{LJ}	Z_{161}^{LL}	...	Z_{1616}^{LL}

The diagonal matrix of Z is a transaction matrix between sectors in the same area. For example, ZDD is a transaction matrix between sectors in Region D. Meanwhile, the off-diagonal matrix of Z is a matrix of inter-sector transactions between one region and another. For example, the ZJD matrix is a transaction matrix between Region D and Region J sectors, where Central Sulawesi is a producer, and North Maluku is a consumer. As an additional note, this off-diagonal matrix does not have to be a square matrix as it is possible that the number of sectors in one area is different from another.

Apart from analysing linkages, the impact of policies on output and labour absorption are also part of this study. The impact of this policy refers to changes in value in parts of final demand, such as household consumption (C), government consumption (G), investment (I), changes in stocks (I), and exports (E). This approach has similarities to the Keynesian multiplier framework, where changes in exogenous variables in final demand can affect output increases in all sectors. For example, economic policies such as investment can be allocated to all or specific sectors. Despite the same numbers, the impacts will vary as the strengths and relationships of each sector are different. This study calculates impact on economic output and labour absorption.

CELIOS uses two scenarios: the first scenario assumes nickel smelter facilities continue their BAU (Business-as-Usual) approach, including the use of coal-fired power plants. The RE and APC scenario assumes the use of APC (Air Pollution Control)[6] and a higher share of renewable energy in the nickel smelter.

To measure the impact on first scenario (BAU) of downstream nickel in three regions, this study makes the following assumptions:

1) Based on the data that CELIOS gather from company and Ministry of Investment, the study assumes an total investment of IDR 292 trillion (USD 18.8 billion)[7]. The development is divided into eight phases: Phase one and two includes a 5% fee for land acquisition, and phases three and four include 20% of the total costs to be used for the construction of factories. Phases five and six cost 15% for development, while seven and eight cost 10% for operations.
2) Considering the availability of nickel ore supply and assuming there are no new smelter permits issued, the estimated time in the model calculation is assumed to be 15 years.

[6] Renewable energy and air pollution control (RE and APC)
[7] Compilation of total investment in nickel processing industry 2023 in Central Sulawesi, Southeast Sulawesi and North Maluku. Investment including factory facility, and captive power plant.

3) Central Sulawesi, Southeast Sulawesi and North Maluku were chosen for this study as they have the most number of nickel downstream processing units.
4) Operational costs in the nickel downstream process are included in the modelling based on additional production[8].
5) An increase in production in the mining industry will reduce agricultural production by up to 2.69% based on sensitivity between sectors.
6) In the fisheries sector, increased nickel mining reduced fisheries activities by 0.17%.
7) The increase in health costs due to smelter activities reduces consumption by 0.75%.

For the RE and APC scenario, the assumptions are as follows:

1) The investment of IDR 292 T (USD 18,8 billion) to develop nickel downstream area is divided into eight stages: First and second stages: 5% (land acquisition stage), third and fourth stages: 20% (physical development stage 1), fifth and sixth stages: 15% (physical development stage 2), seventh and eighth stages: 10% (operational stage).
2) Operational costs in the nickel downstream process are included in the modelling based on additional production.
3) An increase in production in the mining industry will reduce agricultural production by up to 2.69% based on sensitivity between sectors.
4) An environmental benefit that we take from Pirmana, et al (2021)[9] that degradation cost from the iron and steel industry is IDR 35.85 trillion (USD 2,3 billion). We used this calculation for the benefit for development of nickel downstream with green technology.
5) Use of APC (Air Pollution Control) for Capital, Operations, and Health Benefits.

[8] Quantity of the function of the total production cost. Total Production Cost=f(quantity). The output production in this model includes the price of the commodity.
[9] Pirmana, V., Alisjahbana, A. S., Yusuf, A. A., Hoekstra, R., & Tukker, A. (2021). Environmental costs assessment for improved environmental-economic account for Indonesia. Journal of Cleaner Production, 280, 124521. https://doi.org/10.1016/j.jclepro.2020.124521

Air pollution modelling

The atmospheric modelling developed for this study quantifies the impacts of air pollutant emissions from coal power generation and metals processing done in three key Indonesian provinces where centres of nickel reserves and processing industries are located. These are Central Sulawesi, Southeast Sulawesi, and North Maluku.

This study uses the most common approach to study the environmental, economic and health impacts of air pollution by following the chain of causation of emissions, its atmospheric dispersion and chemical transformation, and population exposure. Impacts are quantified for a list of industrial facilities located in clusters or designated industrial parks. Historical, current, and future impacts correspond to the progression of Indonesia's nickel downstreaming strategy over the years.

The analysis carried out in this study is done by:

1) developing an exhaustive list of metal industries that are and will be based in Indonesia, particularly Central Sulawesi, Southeast Sulawesi, and North Maluku, to establish plant- and/or cluster-level inventory of emissions;
2) estimating pollution dispersion from coal power generation and metals processing through atmospheric modelling;
3) quantifying air pollution-related health and environmental impacts resulting from changes in ambient concentration; and
4) valuing impacts and total risks in monetary terms using a cost-of-illness method.

The analysis was carried out in a spatial grid with a 5x5 km resolution, with health impacts calculated for each grid cell. All datasets were aggregated or interpolated to this resolution as required.

1) Emissions inventory

CREA compiled a plant- and cluster-level emissions inventory of **all operational captive power generation dedicated to power the relevant nickel industries processing and metal processing done in industrial facilities located in the three evaluated provinces** to be used as inputs to the air quality modelling.

The inventory developed for **captive coal-fired power plants** includes plant-specific information on combustion and generation technologies, power generation capacity and plant location, and pollutant flue gas concentrations. It also includes stack information: height and diameter, flue gas release velocity, and temperature. The stack characteristics

are used to model plume release height and the thermal rise of pollutants. The first compilation on existing, under construction, and planned captive CFPPs was taken from the Global Energy Monitor (GEM) Global Coal Plant Tracker (GCPT) July 2023 release (GEM, 2023). Basic information includes plant coordinates, power generation capacity, start year of operation, and status (operating, in construction, permitted, pre-permit, or announced).

Power supply coming from sources other than captive CFPPs was noted in MEMR Directorate General of Minerals and Coal's December 2019 release titled "Electricity Demand of Metal Processing Facilities" (MEMR, 2019). In addition to captive CFPPs, **diesel generators and gas-fired power plants** were included in the overall captive power generation impacts analysis.

The initial inventory was then cross-verified and complemented with information compiled from local partners. Further data compilation was conducted to obtain available plant-specific emissions data from official reports, Environmental Impact Assessment (EIA) documents, national emissions standards, and other relevant regulations. Available measurement data of flue gas concentrations and volumes from specific plants were directly applied to respective plants. The average of the available measurements was applied to other captive CFPPs, diesel generators, and gas-fired power plants without data.

For all captive power generation, emissions mass rate (E) of the main air pollutants (SO_2, NO_x, PM) were calculated using the following formula:

$$E = CAP \times CF \times FGV \times FGC$$ — if flue gas volume is available

$$E = CAP \times CF \times (HR \times SFGV) \times FGC$$ — if flue gas volume is not available

where CAP is the gross electric generation capacity of the plant unit (MW), EFF is the gross thermal efficiency (on Lower Heating Value (LHV) basis, in MJ/kg), CF is the capacity factor or rate of utilisation (%), HR is the heat rate which corresponds to a thermal efficiency of electricity production (GJ/MWh), FGV is the measured flue gas volume (Nm^3/GJ), SFGV is the specific flue gas volume (Nm^3/GJ), and FGC is the flue gas concentration of the pollutant (mg/Nm^3).

Mercury releases from coal combustion of the captive CFPPs were calculated as follows:

$$E = \frac{CAP \times CF}{EFF} \times \frac{1}{CAL} \times C_{Hg} \times (1 - CE)$$

where CAL is the calorific value of the coal, C_{Hg} is the mercury content in coal, and CE is the mercury control efficiency.

Additional assumptions applied to the captive power emissions inventory are listed below.

- Captive coal power plants are assumed to operate at 80% utilisation. An exception is applied to diesel generators used in facilities that also have other types of captive power and/or that have PLN grid connections. In such cases, these diesel generators are assumed to operate as backup generators with 15% utilisation.
- Emissions from gas power plants connected with integrated steel plants were quantified in this study as part of the steelmaking emissions, given that they use the byproduct gases from the process.
- For captive coal power plants, heat rate values estimated in GEM's GCPT based on plant size, type, and age were assigned. Similar assumptions used in the GCPT were applied for plants not included in the tracker.
- For diesel generators, the heat rate was set at 10.29 GJ/MWh for diesel generators, corresponding to a thermal efficiency of 35%.
- SFGV of 379 Nm^3/GJ (corrected at 7% oxygen) was used for captive CFPPs, calculated as the average of Indonesian coal samples in the USGS World Coal Quality Inventory (USGS, 2019).
- SFGV of 315 Nm^3/GJ was used for captive diesel generators, as recommended in EURELECTRIC and VGB for emission calculations (EURELECTRIC and VGB, 2010).
- Information on FGC collected in CREA & IESR's 2023 study, "Health Benefits of Just Energy Transition and Coal Phase-out in Indonesia", applied to the captive coal fleet was used as inputs, in addition to data available from EIA documents. The available information was generalised to relevant power plants, creating separate categories for small plants (<100MW), new plants (commissioned since 2015), and plants equipped with emission control devices for SO_2 and NO_x.
- Data on mercury content in coal used as fuel sources in 47 CFPPs in Indonesia was obtained from a survey on national mercury emissions from CFPPs in Indonesia (BCRC-SEA, 2017). Mercury control efficiency was based on values specific to coal type and air pollutant control technology in the UNEP (2017) Mercury Toolkit.

The inventory developed for individual facilities and/or clusters of metal industries as **point sources where metal processings occur** includes information on metal commodity

products, which are grouped by type, content, grade, input and output processing capacities, and processing technology. Their year of operation, current or dated construction progress, location, and power capacity by source is also included. Stack information - height and diameter, flue gas release velocity, and temperature, was also collected to model plume release height and the thermal rise of pollutants.

In the effort to compile an exhaustive list of all relevant facilities to be evaluated in this study, CREA and CELIOS referred to various relevant sources which include compilation of information from local partners, public announcements and media releases, and official reports from relevant government agencies and respective companies.

Among a collection of other valuable sources, large portions of basic information of existing, under construction, and planned metal processing facilities were obtained from the following references:

- MEMR Directorate General of Minerals and Coal's December 2019 release titled "Electricity Demand of Metal Processing Facilities" (MEMR, 2019);
- MEMR's 2021 release titled "Grand Strategy for Minerals and Coal, Upstream and Downstream Development Directions Main Minerals and Coal Towards Advanced Indonesia" (MEMR, 2021);
- production capacity and commodity types of companies, published in the Ministry of Industry's database of the Inventory List of Domestically produced Goods/Services established under the Domestic Product Use Improvement Program (*Peningkatan Penggunaan Produksi Dalam Negeri*, P3DN);
- a list of nickel smelter projects in Indonesia published in an article titled "The Current Face of the Nickel Industry" released in September 2022 (Wicaksono, 2022).

The inventory was then cross-verified and complemented with emissions data collected from relevant official reports, Environmental Impact Assessment (EIA) documents, national emissions standards, and other relevant regulations and media publications. Detailed monitoring data was available from the Report on the Implementation of Environmental Management and Monitoring Plans (*Laporan Pelaksanaan Rencana Pengelolaan dan Pemantauan Lingkungan*, RPL-RKL), covering the period of January to June 2021 for PT Trimegah Bangun Persada located in Obi Island, North Maluku, and the period of July to December 2021 for PT Indonesia Morowali Industrial Park and its tenants located in Morowali, Central Sulawesi.

To quantify emissions released from facilities producing nickel and iron & steel commodities, CREA referred to the available emissions measurements, which were then used as a proxy to calculate the total flue gas volume per tonne of production capacity and

the average pollutant concentration in flue gases weighted by flue gas flow. This was applied to all other facilities where measurement data is not available. Flue gas flow is likely underestimated, as the measurements cover only the main release points.

Emissions mass rate (E) of the main air pollutants (SO_2, NO_x, PM) from the processing were calculated using the following formula:

$$E = C \times FGV \times FGC$$

where C is the production capacity (ton), FGV is the measured or averaged flue gas volume of the metal processing (Nm^3/GJ), and FGC is the measured or averaged flue gas concentration of the pollutant (mg/Nm^3).

Additional assumptions applied to metal processing emissions inventory are listed below;

- Since flue gas concentration measurements were only available for total PM, the apportioned PM_{10} and $PM_{2.5}$ were done using the ratio of emission factors published in these following sources:
  - EMEP/EEA 2019 Air Pollutant Emission Inventory Guidebook published by the European Environment Agency (EEA) and the European Monitoring and Evaluation Programme (EMEP),
  - The United States Environmental Protection Agency (EPA) AP-42: Compilation of Air Emissions Factors, Fifth Edition, Volume I Chapter 11: Mineral Products Industry, 11.19.2 Crushed Stone Processing and Pulverized Mineral Processing, Measurement of PM_{10} and $PM_{2.5}$ Emission Factors at a Stone Crushing Plant (EPA, 2003),
  - Environment Australia's Emission Estimation Technique Manual for Nickel Concentrating, Smelting and Refining, for fugitive PM_{10} emissions from the handling and grinding of ores and products (Environment Australia, 1999).
- For facilities producing metals other than nickel and iron & steel, the default EMEP/EEA emission factors per tonne of output were assigned. References are listed as follows:
  - EMEP/EEA 2019 Air Pollutant Emission Inventory Guidebook published by the European Environment Agency (EEA) and the European Monitoring and Evaluation Programme (EMEP),
    - 2.C.3 Aluminium production, primary aluminium production (EMEP/EEA, 2019a),
    - 2.C.2 Ferroalloys production (EMEP/EEA, 2019b),

        - 1.A.1.a Public electricity and heat production, Public power - Gas turbines, Gaseous fuels (EMEP/EEA, 2019c),
        - 1.A.1.a Public electricity and heat production, Public power - Gas turbines, Gas oil (EMEP/EEA, 2019d).
    - An exception was applied to facilities that operate with gas-fired power generation, for which mercury emission factor from UNEP's Toolkit for Identification and Quantification of Mercury Releases, default input factors for mercury in various natural gas qualities, was applied (UNEP, 2023).
- For facilities producing metals for which $PM_{2.5}$ emission factors were unavailable, the value assigned was the EMEP/EEA median ratio of $PM_{2.5}$ to the total PM emission factors available for metals with differentiated emission factors.
- Commodities identified in the inventory include nickel, namely Nickel Matte (Ni Matte, ≥ 70% Ni), Nickel(II) oxide (NiO, ≥ 70% Ni), Mixed Hydroxide Precipitate (MHP, ≥ 25% Ni), Ferronickel (FeNi, >10% Ni), Nickel Pig Iron (NPI, ≥ 4% Ni), iron & steel, namely stainless steel slab and stainless steel cold rolled, and aluminium.
- The ratio of processing emissions between nickel commodities, particularly between NPI and FeNi, was assigned based on primary energy consumption and greenhouse gas emissions from nickel smelting products published in Wei et al. (2020) and 2017 European Commission's Joint Research Centre Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries.

Tabulation of all inputs and assumptions applied to build the emissions inventory for this study is provided in Appendix A1.

2) **Atmospheric modelling**

A total of 73 companies were evaluated in this study, covering metal processing facilities and captive power plants. The sites were grouped into 35 clusters.

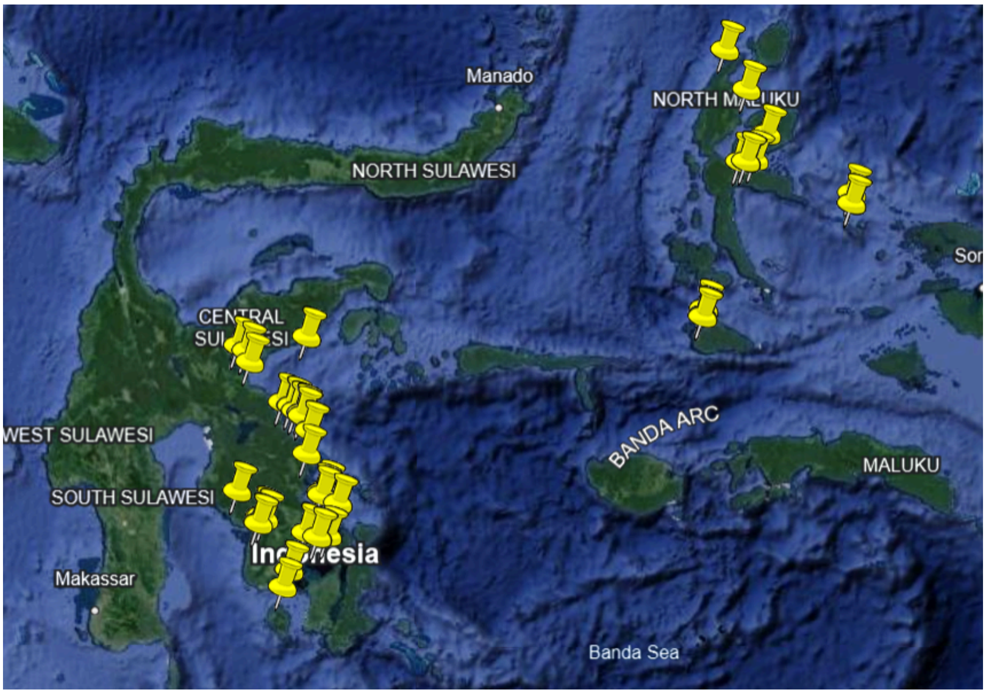


Figure 4. Mapped point location of the evaluated sites across the three provinces

Three release height categories, 30m, 60m, and 120m were defined for the model based on measurements from satellite imagery. The "medium" or 60m release height, which dominates total emissions, was modelled for all clusters. To cover the "low" and "high" releases, CREA modelled releases from these heights from the largest single cluster. We developed a regression model to predict concentrations from the "low" and "high" releases based on simulation results from "medium" height releases and distance from the source. This had a satisfactory goodness-of-fit measure value of R-squared above 90%.

CREA simulated air pollutant concentrations using the CALPUFF air dispersion model, version 7 (Exponent, 2015). CALPUFF is a widely-used industry standard model for long-range air quality impacts of point sources. It is open-sourced and fully documented and has been evaluated extensively by the US Environmental Protection Agency. CALPUFF calculates the atmospheric transport, dispersion, chemical transformation, deposition of the pollutants, and the resulting incremental ground-level concentrations attributed to the

studied emissions sources. Chemical transformations of NO to NO_2 as well as SO_2 and NO_2 to $PM_{2.5}$ are calculated using the ISORROPIA chemistry module in CALPUFF.

Background concentrations of oxidants (ozone, ammonia, hydrogen peroxide) are taken from simulations using the Geos-Chem global atmospheric model with a nested grid for Southeast Asia (Koplitz et al., 2017). Meteorological input data for the year 2021 are generated from the Weather Research Forecasting (WRF) model (Skamarock et al., 2008), version 4.2.2. WRF was set up with 33 vertical levels and two nested grids.

The mother nest has a grid resolution of 60 km and spans approximately 12,000 km in the east-west direction and 4,600 km in the north-south direction. The inner nest has a grid resolution of 12 km, spanning roughly 4,000 km in the east-west and 2,000 km in the north-south direction. Land-use data were obtained from the European Space Agency (2018), and terrain elevation data were obtained from NASA Shuttle Radar Topography Mission (SRTM) high-resolution datasets (Farr et al., 2007).

The mother nest and inner domains use a two-way nesting technique that ensures dynamic interaction between them. WRF simulations use initial and lateral boundary conditions from the National Centers for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) dataset (Saha et al., 2014) of the National Oceanic and Atmospheric Administration (NOAA), producing three-dimensional, hourly meteorological data covering the full calendar year of 2021. Emissions are assumed to be constant throughout the year to assess annual average pollutant concentrations.

3) Health and environmental impact assessment

In this study, CREA uses a detailed and globally implementable health impact assessment framework based on the latest science to estimate the impacts of air pollution on public health. The emphasis is on outcomes for which incidence data are available at the national level from global datasets and outcomes that have high relevance for healthcare costs and labour productivity. These health endpoints were selected and quantified to enable economic valuation, adjusted by levels of economic output and income in different jurisdictions.

For each evaluated health outcome, a concentration-response relationship already used to quantify the health burden of air pollution at the global level in peer-reviewed literature was assigned. The evidence is mature enough to be applied across geographies and exposure levels.

The calculation of health impacts follows a standard epidemiological calculation:

$$\Delta cases = Pop \times \sum_{age} \left[Frac_{age} \times Incidence_{age} \times \frac{RR_{conc,age} - 1}{RR_{conc,age}} \right]$$

where Pop is the total population in the grid location, age is the analysed age group (in the case of age-dependent concentration-response functions, a 5-year age segment; in other cases, the total age range to which the function is applicable), $Frac_{age}$ is the fraction of the population belonging to the analysed age group, $Incidence_{age}$ is the baseline incidence of the analysed health condition, and conc is the pollutant concentration, with $conc_{base}$ referring to the baseline concentration (current ambient concentration). $RR_{(conc,age)}$ is the function giving the risk ratio of the analysed health outcome at the given concentration for the given age group compared with clean air. In the case of a log-linear, non-age-specific concentration-response function, the RR function becomes:

$$RR(c) = [RR_0 \text{ x } c] - [c_0 \text{ x } \Delta c_0], \textit{ when } c > c_0$$

$RR(c) = 1$ otherwise, where RR_0 is the risk ratio found in epidemiological research, Δc_0 is the concentration change that RR_0 refers to, and c_0 is the assumed no-harm concentration (in general, the lowest concentration found in study data).

Data on total population and population age structure were taken from Global Burden of Disease results for 2019 (Global Burden of Disease, 2020), distributed by the Institute for Health Metrics and Evaluation (IHME) (IHME, 2020). The spatial distribution of population within each city and country, as projected for 2020, was based on the Gridded Population of the World v4 from the Center for International Earth Science Information Network (CIESIN) (CIESIN, 2018). Since the 2021 WHO Air Quality Guidelines (WHO, 2021) now recognises health harm from NO_2 at low concentrations, we apply the mortality risk function for NO_2 which include impacts down to 4.5 µg/m^3 (Huangfu and Atkinson, 2020).

Adult deaths were estimated using the risk functions developed by Burnett et al. (2018), as applied by Lelieveld et al. (2019). Deaths of children under the age of five from lower respiratory infections linked to $PM_{2.5}$ pollution were assessed using the Global Burden of Disease risk function for lower respiratory diseases (IHME, 2020). Cause-specific data for all mortality were taken from the 2019 Global Burden of Disease project results (IHME, 2020).

Health impact modelling projects the effects of pollutant exposure during the study year. Some health impacts are immediate, such as exacerbation of asthma symptoms and lost working days, whereas other chronic impacts may have a latency of several years. Concentration-response relationships for emergency room visits for asthma and work

absences were based on studies that evaluated daily variations in pollutant concentrations and health outcomes.

These relationships were applied to changes in annual average concentrations. The annual average baseline concentrations of $PM_{2.5}$ and NO_2 were taken from van Donkelaar et al. (2021) and Larkin et al. (2017), respectively. Since the no-harm concentration for SO_2 is very low and the risk function is linear with respect to the background concentration, there was no need for data on SO_2 background concentrations.

A summary of all air pollution-health parameters and data used in estimating physical impacts is provided in Appendix A2, Table A2a. To understand the health impacts in the future, the study took into account the projected changes in population, population age structure, and mortality by age group, based on the UNDP (2019) World Population Prospects Medium Variant. This factors in the expected reduction in baseline infant mortality and increase in premature deaths from chronic diseases in older adults as a part of the population and epidemiological transitions and improvements in health care.

4) Economic valuation of health impacts

Air pollution increases the risk of developing respiratory and cardiovascular diseases and complications related to these diseases, significantly lowering the quality of life and economic productivity of people affected while increasing healthcare costs. Economic losses as a result of air pollution were calculated using the methods outlined in Myllyvirta (2020). The valuation of deaths was updated to the values derived by Viscusi and Masterman (2017), which are based on labour market data and pay particular attention to applicability in middle- and low-income countries.

The Global Burden of Disease project has quantified the degree of disability caused by each disease into a “disability weight” that can be used to compare the costs of different illnesses. The economic cost of disability and reduced quality of life caused by these diseases and disabilities are assessed based on disability weights, combined with the economic valuation of disability used by the UK environmental regulator Department for Environment Food and Rural Affairs (Birchby et al., 2019), and adjusted by GNI PPP for Indonesia. The deaths of young children are valued at twice the valuation of adult deaths, following OECD’s recommendations (2012).

The valuation of future health impacts is based on the premise that the long-term social discount rate is equal to the long-term GDP growth rate, and the economic loss associated with different health impacts is proportional to the GDP, resulting in a constant present value of health impacts over time. A summary of the input parameters is provided in Appendix A2, Table A2b.

An additional analysis was included to quantify the potential reduction in health impacts achieved through Air Pollution Control (APC) installation. Installation and operating costs for APC were compiled from various sources, summarised in Appendix A3. We use the cross-country estimates of the relative costs of Electrostatic Precipitator (ESP) for dust removal, Flue Gas Desulfurization (FGD) and Selective Catalytic Reduction (SCR) (Ferrari et al., 2019) to calculate the average transferred costs in the current valuation.

This study assumes the inclusion of investment in dust control systems to meet more stringent standards without an increase in operating costs. For future projections, we assumed that the cost escalation of the APC technologies is equal to the long-term average GDP growth rate.

Impacts on national economy

Since the massive investment in the nickel industry in various regions, especially the eastern part of Indonesia, there are often claims that the nickel industry provides significant economic benefits. For example, the Indonesian President correlates the increase in nickel exports, which reached USD 33.8 billion or the equivalent of IDR 510 trillion throughout 2022, as a positive economic achievement.

Often, the investment impacts claims of the nickel industry do not consider various factors. These include the impact on the agricultural and fisheries sectors, health costs and sustainability aspects. CELIOS found using statistical modelling that in a business-as-usual (BAU) scenario, the nickel industry does not always have a positive impact in the long term.

Under the BAU scenario, nickel smelters produce positive outputs concentrated around the 5th year of the project. The construction phase of the smelter may bring jobs involving various tasks. However, CELIOS projects that due to the environmental degradation from smelter activity, including the use of coal power plants, economic benefits are expected to decline, especially after the 8th year as illustrated in Figure 5. The negative trends continue well into the 10th and 15th year of operation.

As illustrated in the analysis for the RE and APC scenario in the following section (Table 3), integrating renewable energy and installing Air Pollution Control devices has the potential to mitigate the nickel industry's adverse impact on the ecology and public health. However, negative externalities such as deforestation, clean water becoming dirty and waste impacting fisherman income would nullify these measures in the later years.

A RE-driven energy mix will reduce the requirement upon coal power plants, hence the lower emission. That being said, the installation of RE should consider the risk of energy sprawl from the implementation of large projects. Designing and implementing APC technology would also lower the risk of poor working conditions and deteriorating air quality surrounding the smelter areas, reducing future public health costs.

Table 2. Summary of national economy impact of nickel industry in Central Sulawesi, Southeast Sulawesi and North Maluku in BAU scenario

Indicators	Unit	Year 1	Year 5	Year 10	Year 15
Total Economic Multiplier	USD Billion	1.22	4.05	-0.023	-0.010
GDP	USD Billion	1.22	4.03	-0.023	-0.010
Business Surplus	USD Billion	0.93	3.01	-0.014	-0.006
Workers Wage	USD Billion	0.276	0.972	-0.008	-0.004
Labour Absorption	Number of People	-1,309	101,752	-7,604	-3,832
Labour Absorption Central Sulawesi	Number of People	-4,429	52,710	-3,121	-1,144
Labour Absorption Southeast Sulawesi	Number of People	-2,733	18,931	-3,556	-2,164
Labour Absorption North Maluku	Number of People	3,205	10,460	-243	-218
Williamson Index		0.74	0.73	0.72	0.72

Table 3. Summary of national economy impact of nickel industry in Central Sulawesi, Southeast Sulawesi, and North Maluku in RE and APC scenario

Indicators	Unit	Year 1	Year 5	Year 10	Year 15
Total Economic Multiplier	USD Billion	2.44	5.72	2.005	0.471
GDP	USD Billion	2.25	5.49	1.79	0.446
Business Surplus	USD Billion	1.72	3.87	1.001	0.322
Workers Wage	USD Billion	0.506	1.55	0.77	0.081
Labour Absorption	Number of People	62,853	249,608	184,056	21,654
Labour Absorption Central Sulawesi	Number of People	19,404	101,599	53,857	8,895
Labour Absorption Southeast Sulawesi	Number of People	14,493	94,314	63,136	1,200
Labour Absorption North Maluku	Number of People	3,205	10,460	-243	-218
Williamson Index		0.74	0.73	0.72	0.72

Gross Domestic Product (GDP)

Nickel smelter activities contributed USD 5.36 billion (IDR 83.17 trillion) to the country's GDP in its construction stage, according to modelling done by CELIOS. At this stage, labour from surrounding regions would be absorbed to support activities in the initial phase of the project.

Figure 5. Indonesia's GDP Impact of Nickel Industry in Central Sulawesi, Southeast Sulawesi and North Maluku with Business-as-Usual (BAU) Scenario

However, the economic benefits are expected to decrease in the operational phase mainly due to the negative impact on the fisheries sector. The factors include coastal pollution from coal-fired power plants that degrades the region's ecology, causing distress to local fishers. Nickel industries begin to negatively impact the country's economy as early as the 7th year of its operation by degrading agricultural lands, forests, and marine ecosystems that support local livelihoods.

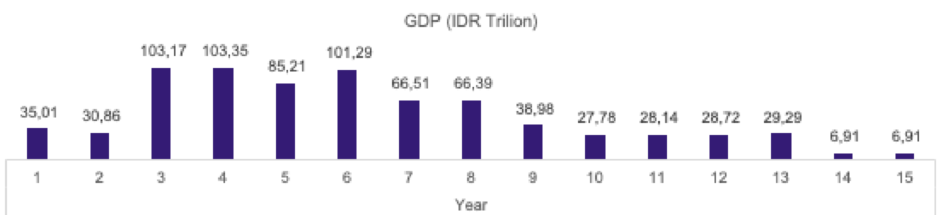


Figure 6. Impact of Nickel Industry in Central Sulawesi, Southeast Sulawesi and North Maluku with Increasing Renewable Energy Capacity and Air Pollution Control on Indonesia's GDP

The use of RE and APC may alleviate the negative impacts of nickel smelters on the surrounding areas. However, the positive GDP resulting from the smelter's activity would predominantly occur within the first nine years, diminishing gradually thereafter. Positive impacts before the 9th year is primarily from labour absorption and activities to support

the smelter constructions. The reduction in GDP impact afterwards would mainly be driven by environmental pressures and declining nickel ore supply.

Despite the potential offsets from RE and APC, this model output suggests the negative output from the nickel industry is closely related to environmental impact and resource depletion. Analysis from mining associations reveals that Indonesia's high-grade nickel ore reserves can only last the next seven to ten years (APNI, 2023). Saprolite consumption is projected to increase to 150 million tonnes in the short term and will increase to 400 million tonnes in 2026.

Central Sulawesi Nickel Industry Local Economy Impact

Central Sulawesi's GDP is congruent with the growth of nickel smelter operations in the region. The region's GDP culminated with the industry's - around 3rd or 4th year of operation, continuing with positive impacts in the first eight years. After this, the industry negatively impacts the region's GDP.

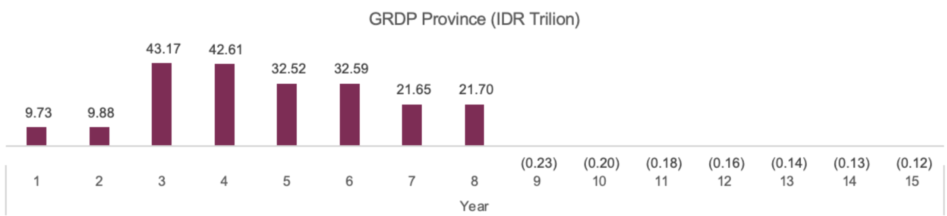


Figure 7. Central Sulawesi Nickel Industry Gross Regional Product Domestic Bruto (GRDP) Impact in BAU Scenario

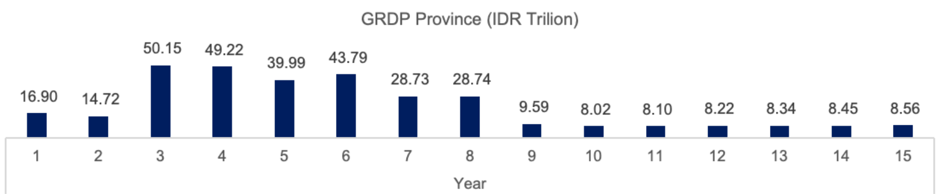


Figure 8. Central Sulawesi Nickel Industry Gross Regional Product Domestic Bruto (GRDP) Impact in RE and APC

Breaking down the overall GDP impact, the trend in the region can be explained by the significant uplift in mining and excavation activities as well as their supporting activities in the first few years of the smelter development and operation. However, a simultaneous reduction in productivity from agriculture, forestry, and fisheries counteract the GDP increment.

Table 4. Sectoral Impact on First Year (Construction Phase) in Central Sulawesi with BAU Scenario and RE and APC Scenario

Economic Sectors	GRDP Added BAU (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-70.7	-67
Mining and excavation	618.7	795.9
Processing industry	2.7	234.4
Procurement of Electricity and Gas	10.4	12.3
Water Supply, Waste Management, Waste and Recycling	1.4	1.7
Construction	8.4	10.2
Wholesale and Retail Trade; Car and Motorcycle Repair	8	15.3
Transportation and Warehousing	9.8	15.2
Provision of accommodation and food and drink	2.1	3.4
Information and Communication	5.3	8.5
Financial Services and Insurance	20.7	27.9
Real Estate	4.8	6.9
Company Services	3.7	8.4
Government Administration, Defense and Mandatory Social Security	1.5	2.3
Education Services	0.4	0.8
Health Services and Social Activities	0.2	13.2
Other Services	0.8	1.4
Total	627.6	1,090.2

By the 9th year, the mining and excavation would substantially slow down but not environmental degradation that severely impacts the economic outputs from agriculture, forestry, and fisheries sector. Consequently, nickel smelters would have a negative impact starting from this period onwards. Worse, since the ecosystem disruption is generally hard to reverse (and in many cases irreversible), the negative output may extend to later periods, even beyond the 15th year.

Table 5. Sectoral Impact on 9th Year in Central Sulawesi with BAU Scenario and RE and APC Scenario

Economic Sectors	GRDP Added (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-14.4	6,928
Mining and excavation	0.4	164,873
Processing industry	0.4	226,048
Procurement of Electricity and Gas	-0.037	5,109
Water Supply, Waste Management, Waste and Recycling	-0.002	0.8
Construction	-0.2	3.6
Wholesale and Retail Trade; Car and Motorcycle Repair	-0.5	18.7
Transportation and Warehousing	-0.1	9.6
Provision of accommodation and food and drink	-0.018	6.5
Information and Communication	-0.045	11.1
Financial Services and Insurance	-0.4	14.7
Real Estate	-0.013	5.2
Company Services	-0.014	18.7
Government Administration, Defense and Mandatory Social Security	-0.005	2.7
Education Services	-14.4	1.8
Health Services and Social Activities	0.4	120.3
Other Services	0.4	1.7
Total	**-0.037**	**618.5**

Southeast Sulawesi Nickel Industry Local Economy Impact

Similar long-term negative impacts of nickel activities is reflected in the model result for the Southeast Sulawesi, from which we could suggest that the positive contribution of nickel, especially under BAU scenarios, would only transpire for eight years.

The region faced an economic decline as the nickel industry had a negative impact on the community's economic centres, particularly agriculture and fisheries. For instance, the nickel industry poses a great risk to the IDR 3.6 trillion (USD 232.26 million) per season/ year pepper farming in Tanamalia, East Luwu as its construction and operation threatens the region's rainforests and lakes (WALHI Sulawesi Selatan, 2023).

This is common in areas affected by mining expansion and extractive industries that damage the environment and eliminate community jobs. The change in people's jobs to daily labourers of nickel mining/industrial companies is also not comparable to their previous jobs as farmers and fishermen. Damage to forest and aquatic ecosystems is detrimental to the community's economy because they have been working side by side and depending on the preservation of the environment.

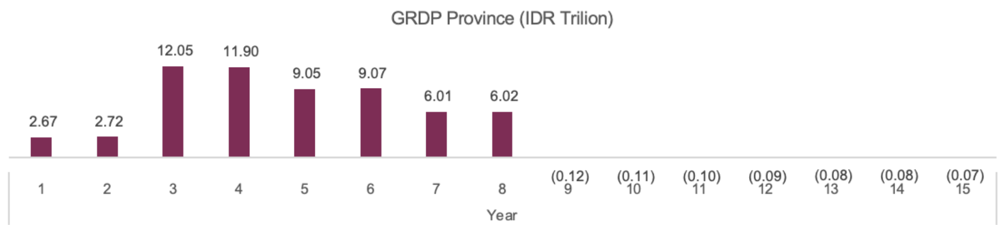


Figure 9. Southeast Sulawesi Nickel Industry GRDP Impact in BAU Scenario

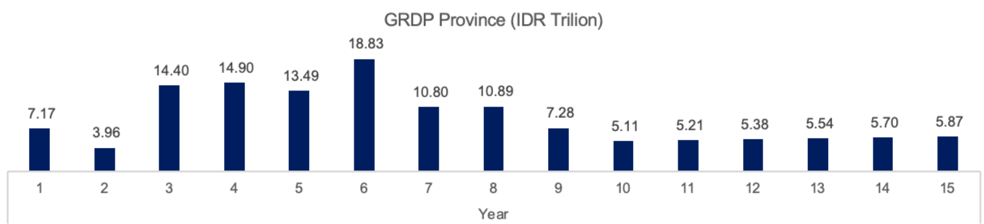


Figure 10. Southeast Sulawesi Nickel Industry GRDP Impact in RE and APC Scenario

Negative relationship between mining-excavation and agriculture-forestry-fisheries in Southeast Sulawesi is estimated to have occurred starting from the first year of the nickel smelter along with its major industrial construction and development activities resulting in

temporary labour absorption and spurs of supporting activities. The adverse impact towards the latter sector starting from the first year mainly emerges from lands and areas seized for the smelter. The loss of farm lands also led to job loss in agriculture starting from the first year.

Anticipation of the destructive impact can be done by implementing the 2nd scenario followed by the implementation of the ESG Report. The ESG Report can help stakeholders manage risks that impact social, environmental and governance aspects. ESG can help the central and local governments in monitoring business activities that can harm the community and the environment. Especially communities around the ore mine, smelter, farmers, and fishermen.

Nickel industry companies are required to implement ESG standards to manage risks and negative externalities that were not previously taken into consideration. Sustainable industrial governance needs to be encouraged and strictly implemented by the government by issuing special regulations on ESG Report obligations so that nickel companies entering Indonesia are included in the category of companies that have a greener standard and traceability.

Table 6. Sectoral Impact on 1st Year (Construction Phase) in Southeast Sulawesi with BAU Scenario and RE and APC Scenario

Economic Sectors	GRDP Added (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-25.4	-25.2
Mining and excavation	195.6	331.9
Processing industry	0.2	142.1
Procurement of Electricity and Gas	0.1	0.9
Water Supply, Waste Management, Waste and Recycling	0.017	0.1
Construction	0.035	0.3
Wholesale and Retail Trade; Car and Motorcycle Repair	0.3	1.9
Transportation and Warehousing	0.7	1.8
Provision of accommodation and food and drink	0.017	0.2

Information and Communication	0.1	0.7
Financial Services and Insurance	0.2	0.8
Real Estate	0.1	0.3
Company Services	0.1	1.3
Government Administration, Defense and Mandatory Social Security	0.02	0.2
Education Services	0.002	0.0
Health Services and Social Activities	0.003	5.0
Other Services	-0.001	0.1
Total	172.0	462.4

Table 7. Sectoral Impact on 9th Year in Southeast Sulawesi with BAU Scenario and RE and APC Scenario

Economic Sectors	GRDP Added (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-7.6	9.3
Mining and excavation	-0.013	74.2
Processing industry	-0.016	91.8
Procurement of Electricity and Gas	-0.006	17.8
Water Supply, Waste Management, Waste and Recycling	-0.003	0.8
Construction	-0.042	2.9
Wholesale and Retail Trade; Car and Motorcycle Repair	-0.1	24.4
Transportation and Warehousing	-0.045	11.7
Provision of accommodation and food and drink	-0.002	5.4
Information and Communication	-0.011	12.3
Financial Services and Insurance	-0.1	10.2
Real Estate	-0.004	4.1
Company Services	-0.007	21.2

Government Administration, Defense and Mandatory Social Security	-7.6	2.2
Education Services	-0.013	0.2
Health Services and Social Activities	-0.016	179.7
Other Services	-0.006	1.8
Total	**-0.003**	**470.0**

General ideas of job opportunity in the nickel industry always follow simple miss-conception, there would be change in occupations of the former farmers to be smelter workers. Thus, changing in occupation will help local labour and increase the median income for the local community. This false pretext results in a complex situation, in fact farmers still work in their land, while local labour coming from other provinces and the smelter existence is a threat for local farmers.

As we see starting from the 9th year, the GDP impact of nickel smelters will drop and even be negative for all sectors especially agriculture, forestry, and fisheries. At this stage, the land and areas seized for the smelters will no longer produce positive outputs due to soil erosion; land, rivers, and marine pollution; and air quality degradation affecting local population. There has been evidence on how rice field contaminations occur due to nickel smelter waste (Arao et al., 2010).

North Maluku Nickel Industry Local Economy Impact

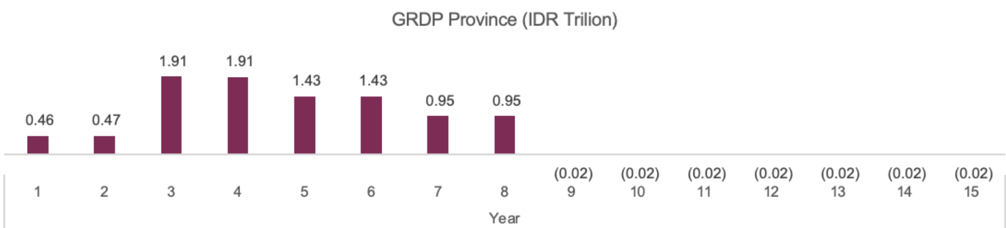


Figure 11. North Maluku Nickel Industry GRDP Impact in BAU Scenario

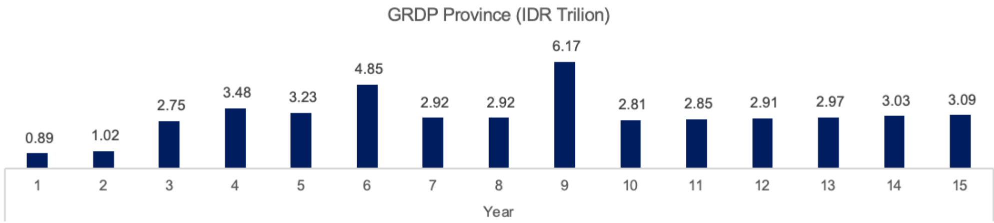


Figure 12. North Maluku Nickel Industry GRDP Impact in RE and APC Scenario

The first scenario of nickel smelter impact for North Maluku also demonstrates the major uplift in the GDP for the region in the first few years then declines afterwards. The drivers behind this output remain consistent with the previous two regions: At the initial stages of the nickel smelter activities, the GDP output is boosted through spurs in activities surrounding the smelter but at the later stage the positive impacts are counter-balanced and even reversed due to the long-term impact of environmental degradation and public health costs.

Regional economic impact under the RE and APC scenario with RE and APC is more positive, which can be demonstrated by North Maluku GRDP model result that shows GDP increment for the 15 years of the smelter activities. However, as previously mentioned, the national aggregate positive impact especially in the 14th and 15th year would begin to deteriorate.

Table 8. Sectoral Impact on First Year (Construction Phase) in North Maluku with BAU and RE and APC Scenario

Economic Sectors	GRDP Added (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-1.0	-0.7
Mining and excavation	25.9	25.9
Processing industry	0.2	20.1
Procurement of Electricity and Gas	0.1	0.3
Water Supply, Waste Management, Waste and Recycling	0.022	0.039
Construction	0.007	0.018
Wholesale and Retail Trade; Car and Motorcycle Repair	2.1	3.0
Transportation and Warehousing	1.5	2.1

Provision of accommodation and food and drink	0.015	0.2
Information and Communication	0.4	0.8
Financial Services and Insurance	0.3	0.6
Real Estate	0.1	0.3
Company Services	0.046	1.2
Government Administration, Defense and Mandatory Social Security	0.3	0.4
Education Services	0.004	0.027
Health Services and Social Activities	-0.1	3.1
Other Services	0.03	0.1
Total	**29.9**	**57.4**

Table 9. Sectoral Impact on 9th Year in North Maluku with BAU and RE and APC Scenario

Economic Sectors	GRDP Province Added (USD Million)	GRDP Added with RE & APC (USD Million)
Agriculture, Forestry and Fisheries	-0.9	5.3
Mining and excavation	-0.001	0.1
Processing industry	-0.005	241.5
Procurement of Electricity and Gas	-0.002	5.1
Water Supply, Waste Management, Waste and Recycling	-0.001	0.4
Construction	-0.001	0.2
Wholesale and Retail Trade; Car and Motorcycle Repair	-0.04	15.8
Transportation and Warehousing	-0.017	11.8
Provision of accommodation and food and drink	-0.001	4.7
Information and Communication	-0.008	7.3

Financial Services and Insurance	-0.016	6.7
Real Estate	-0.002	3.1
Company Services	-0.002	22.2
Government Administration, Defense and Mandatory Social Security	-0.003	2.6
Education Services	-0.001	0.5
Health Services and Social Activities	-0.003	69.4
Other Services	-0.007	1.2
Total	**-1.0**	**397.8**

The sectoral breakdown suggests that under the RE and APC scenario the positive GRDP will be predominantly contributed by mining and excavation, still at the expense of some other sectors especially agriculture, forestry, and fisheries starting from the first year.

In the 9th year, negative output on all sectors under the BAU scenario is presumed to be offsetted by RE and APC with the processing industry to receive the most benefits, likely from the new activities supporting RE and APC establishments and facilities. Moreover, considering the need for additional resources for APC and RE, the real impact on those sectors may be higher than the model estimation.

Commercial profit

Commercial profit in this section is represented by the business surplus estimation. Business surplus is calculated from comparing income with costs resulting from business activities. Interestingly, overall business surplus in the national level BAU scenario is also consistent with the model result for GDP trend. As the mining and excavation activities diminish along with the used up nickel resources, mining and excavation activities would no longer produce additional income and cash flow after the 8th year.

Unfortunately, due to the impact of landscape change and environmental degradation, the business surplus from other sectors especially agriculture, forestry, and fisheries will decline and the commercial profit will diminish and even become negative starting from the 9th year.

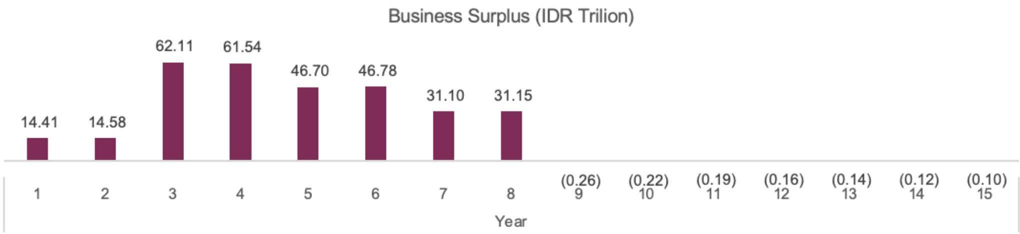


Figure 13. Business Surplus in National Level with BAU Scenario

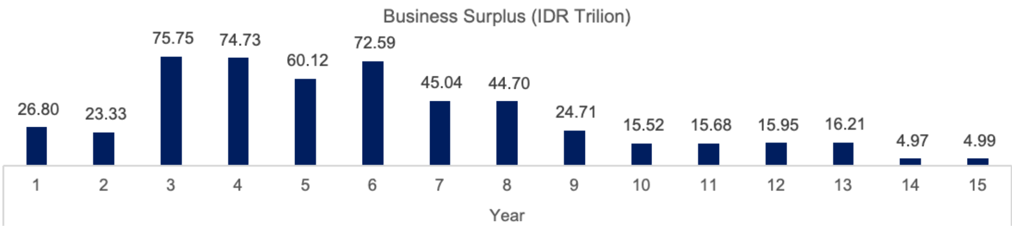


Figure 14. Business Surplus in National Level with RE and APC Scenario

Business surplus with renewable energy (RE) and advanced pollution control (APC) technologies exhibits a more favourable outlook, showing no negative outputs until the 15th year. However, it's possible that beyond this timeframe, unforeseen factors could come into play, such as irreversible ecological depletion. This depletion could render agriculture, forestry, and fisheries inactive, leading to the transpiring health impact on the population residing near smelting facilities, thereby decreasing labour productivity.

Employment and labour

The industry's contribution to employment generation in terms of both employment and wages is an important factor. The nickel industry in the BAU scenario has a more negative outcome compared to the 2nd scenario. In terms of employment, all the provinces show a significant decline in 15 years.

Similar results are also seen in the graph of total wages over 15 years. The total wage of the BAU scenario tends to drop drastically and is smaller than the RE and APC scenario. The total wages of workers generated over 15 years amounted to IDR 228 trillion (USD 14.68 billion). The APC implementation scheme and the increase in RE can increase the number of workers' wages and reduce the significant decline in wages.

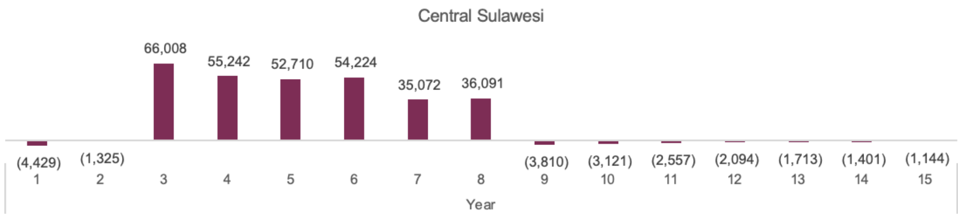


Figure 15. Labour absorption with BAU Scenario in Central Sulawesi, Southeast Sulawesi and North Maluku

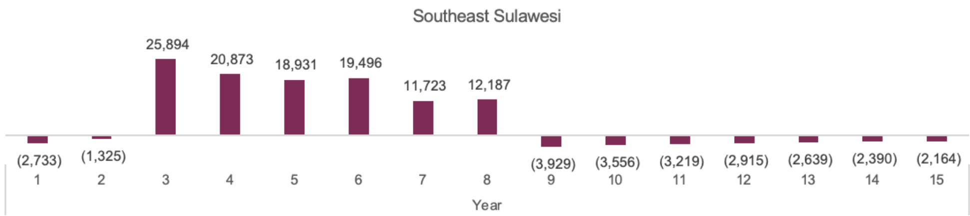


Figure 16. Labor Absorption using the BAU Scenario in Southeast Sulawesi

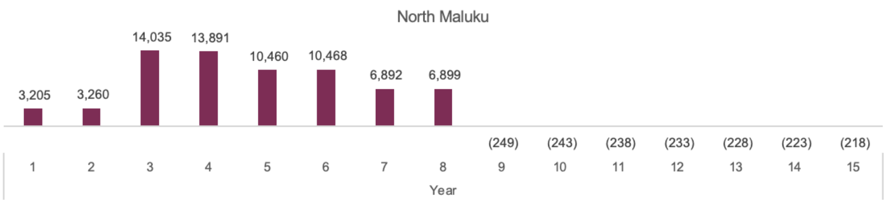


Figure 17. Labor Absorption using the BAU Scenario in North Maluku

The provinces experienced the largest increase in employment in the 3rd year, then dropped drastically starting in year 9th. Central Sulawesi, for example, received the largest employment value of 66,008 people. Then, it continued to decrease by 1,144 people in year 15. The decline occurred from the first two years and began in year 9.

Southeast Sulawesi is not much different. It reached the largest number of 25,894 workers, then dropped to negative 2,164 workers in year 15. This makes this province the worst in total job losses among the provinces. North Maluku in the 3rd year reached 14,035 people of employment. Then, it dropped drastically by decreasing 218 job opportunities.

These trends are consistent with the projection on the diminishing outputs from mining, excavation, and all other sectors as the impact of negative externalities become more evident in the later years.

Worker's Wage

The BAU scenario of worker wages provides an initial increase until it peaks in the 3rd year at IDR 19.95 trillion (USD 1.29 billion) per year. However, in the following years it will continue to experience a significant decline until it only reaches negative IDR 60 billion (USD 3.87 million) per year. This decline is very large because it reaches 333 times the largest income. The remarkable decline is likely to be driven by reduction in demand for labour as the negative externalities begin to reduce the outputs of all economic sectors and declining labour productivity due to health cost burdens.

Figure 18. Workers Wage with BAU Scenario in Central Sulawesi, Southeast Sulawesi and North Maluku

The 2nd scenario provides relatively more positive results compared to the BAU scenario, both in nominal and trend terms. Nominally, this scenario results in larger worker wages from the initial year of implementation, at IDR 7.84 trillion (USD 505.29 million) compared to IDR 4.28 trillion (USD 276.13 million) in the BAU scenario. The largest wage amount also reaches IDR 27.57 trillion (USD 1.78 billion) per year, 31% more than the BAU scenario.

Trend-wise, despite eventually declining as well, the RE and APC scenario is able to generate a larger amount of worker wages each year. In fact, the RE and APC scenario does not give a negative result at all for 15 years. The trend in the RE and APC scenario is likely to be driven by better labour productivity due to mitigated air pollutants. Nevertheless, in the 14th and 15th year the impact will likely decline.

Figure 19. Workers Wage with RE and APC Scenario in Central Sulawesi, Southeast Sulawesi and North Maluku

Farming and fishery impact

The implications of nickel mining on the agriculture and fisheries sectors in the 3 provinces tend to be negative under the BAU scenario, both in terms of economic value added and income of farmers and fishermen. Not only does it cause no added value, but the nickel industry can generate economic value-added losses of more than IDR 6 trillion (USD 387.10 million) in 15 years. Likewise, in the income of farmers and fishermen there is a loss of income of IDR 3.64 trillion (USD 234.84 million) in 15 years.

This contrasts with the RE and APC scenario, which is able to generate positive trends in all provinces, both in terms of added value and income of farmers and fishermen. This positive trend can improve the welfare of farmers and fishermen, as well as improve the economy in the region.

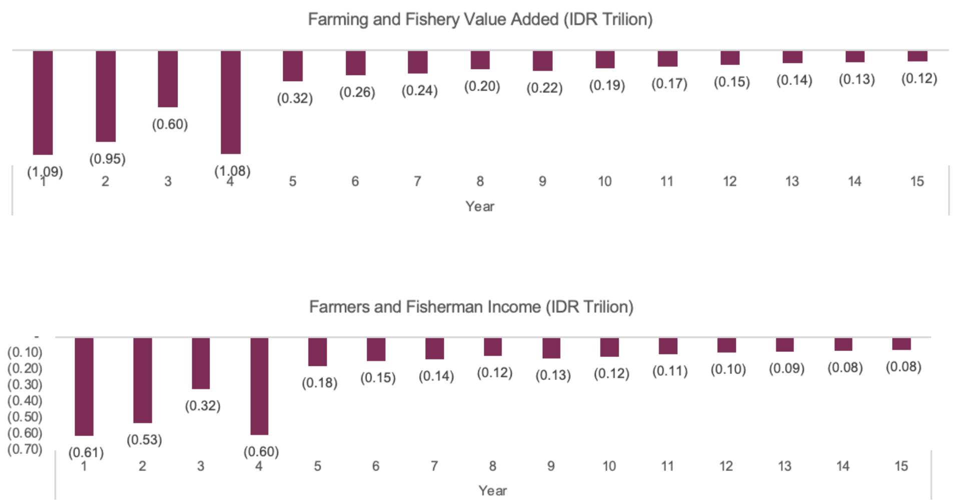


Figure 20. Central Sulawesi Farming and Fishery Impact with BAU Scenario

The impact of the BAU scenario on the value added of Central Sulawesi's agriculture and fisheries sectors includes drought that disrupts agriculture as well as water pollution that poisons fish and damages the fisheries ecosystem. The graph shows that in 15 years the value added generated is always negative. The total value added lost is IDR 5.86 trillion (USD 377.4 million). This trend also occurs in the income of farmers and fishermen, which is always negative. The lost income of farmers and fishermen reached IDR 3.36 trillion (USD 216.77 million) over 15 years.

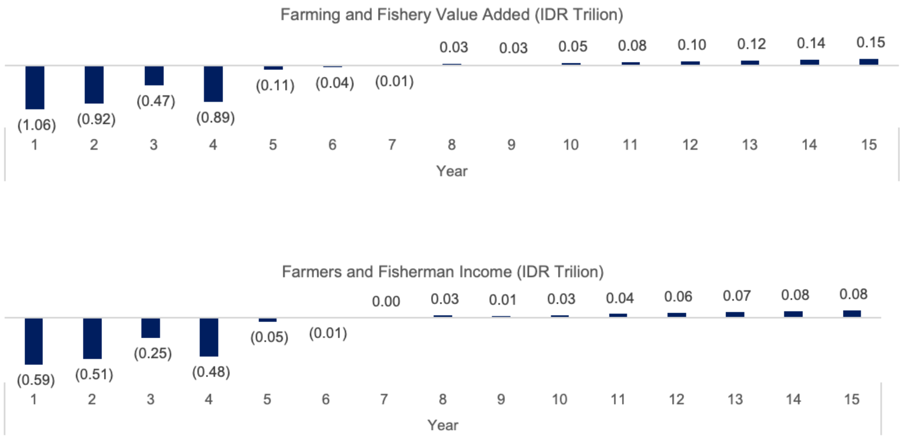


Figure 21. Central Sulawesi Farming and Fishery Impact with RE and APC Scenario

The RE and APC scenario revealed that both value added and income of farmers and fishermen still experienced a continuation of the negative trend in the construction phase. However, later on in year 8 onwards the farmers and fisherman income begin to increase by IDR 80 billion (USD 5.16 million) per year by the 15th year.

Figure 22. Southeast Sulawesi Farming and Fishery Impact with BAU Scenario

The BAU scenario of the nickel industry in Southeast Sulawesi will only provide benefits for local farming during the construction phase, whereas workers need food supplies and drive demand for the agricultural production in Southeast Sulawesi. However, in year 3 and afterwards it will experience a decline until it does not produce added value at all since year 11.

The income of farmers and fishermen occurs similarly because after year 4 there will continue to be a decline until it does not generate income since year 9. This is because the operation of the smelter impacts the water and quality of soil. Therefore, this explains that the profession of farmers and fishermen is highly endangered.

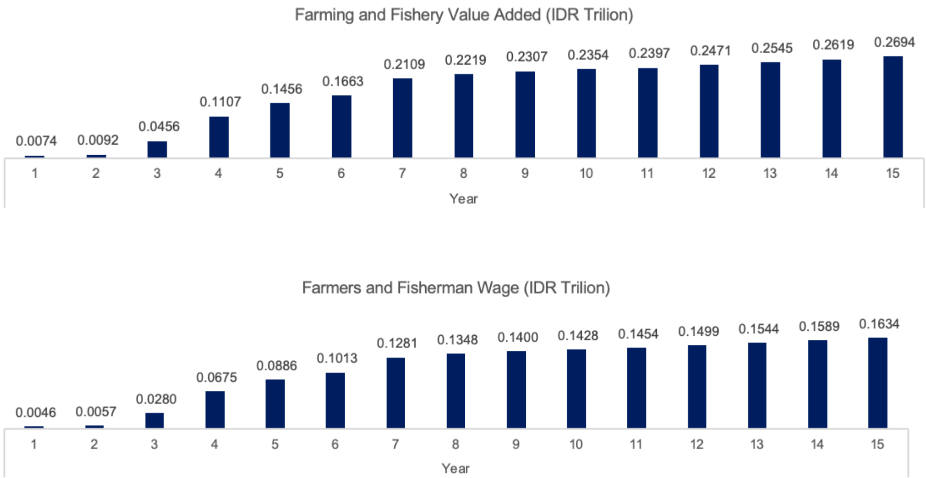


Figure 23. Southeast Sulawesi Farming and Fishery Impact with RE and APC Scenario

In contrast to the BAU scheme, the economic value added under the RE and APC scenario is very positive. The increase in economic value added 36 times from IDR 7.4 billion (USD 477.42 thousand) per year to IDR 269 billion (USD 17.35 million) per year. This is followed by a more than 36-fold increase in the income of farmers and fishermen, from IDR 4.6 billion (USD 296.77 thousand) per year to IDR 163 billion (USD 10.52 million) per year.

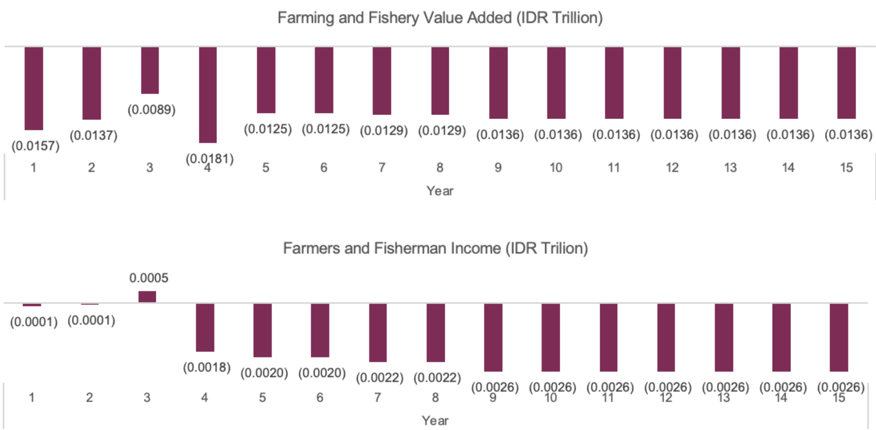


Figure 24. North Maluku Farming and Fishery Impact with BAU Scenario

This scheme shows that the added value of the North Maluku economy has always been negative. For 15 years North Maluku lost an added value of IDR 202 billion (USD 13.03 million). In the income of farmers and fishermen, starting in year 4 there was a negative and resulted in a loss of income of IDR 28.4 billion (USD 1.83 million).

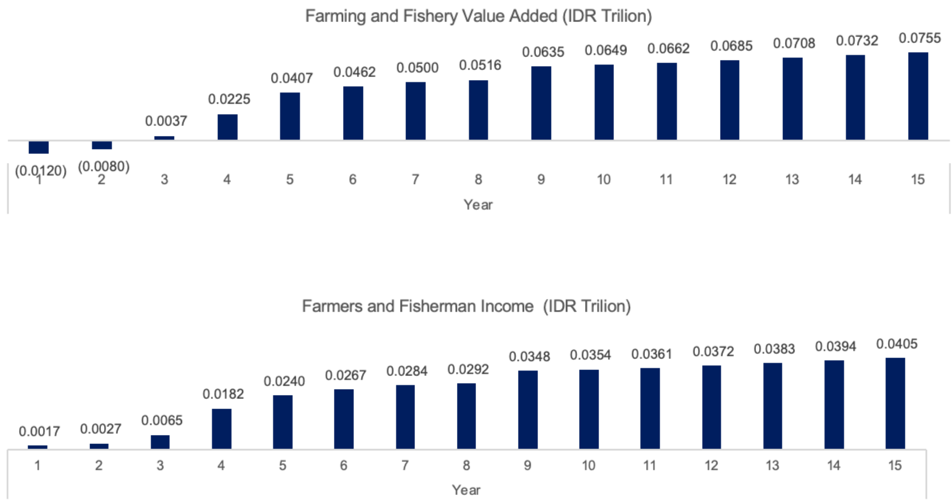


Figure 25. North Maluku Farming and Fishery Impact with RE and APC Scenario

The RE and APC scenario shows results that are trending positively. The added value of the North Maluku economy went from negative IDR 12 billion (USD 774.19 thousand) per year to IDR 75.5 billion (USD 4.87 million) per year or an increase of more than 700%. Likewise, the income of farmers and fishermen increased dramatically by 23 times from IDR 1.7 billion (USD 109.68 thousand) per year to IDR 40.5 billion (USD 2.61 million) per year. The positive impact of APC implementation and increased RE is particularly evident in the case of this province.

Impact on regional inequality

The implications for regional/provincial inequality levels are explained by the Williamson Index. This index describes the inequality in per capita income between regions with a value range of 0 to 1. The closer to 1, the more unequal or higher the inequality. The RE and APC scenario emphasises APC and increasing the portion of RE can reduce income inequality by decreasing the Williamson Index figure according to projections. However, it is expected that the discussed negative externalities from the projects will result in major burdens to the economy such that despite the mitigation measures, inequality will not be significantly combatted. Inequality could even worsen in the later years as the impact of those externalities become more pronounced.

This inequality in mining areas is a consequence of capital-intensive industrial development. For example, in Central Sulawesi in 2023,[10] the agricultural sector is able to contribute 38.85% more employment than the mining sector which is only 2.39% and the processing industry 9.36%. In addition, high economic growth is still followed by an increase in poverty, especially in the nickel smelter industry area. In Morowali[11], the poverty rate is 12.58% in 2022, higher than other regions without smelters. The poverty rate in Sigi Regency, which does not have smelters, is only 12.30%. Morowali's poverty rate is even higher than the provincial average.

The small economic contribution of the nickel industry in the smelter and mine location areas is also due to the fact that almost all industry stakeholders are controlled by multinational companies and foreign banks. Both from labour, industrial technology, to banking financing are controlled by foreign private parties. This leads to uneven distribution of economic benefits. Communities in mining or smelter areas will not receive sufficient benefits, instead having to bear social, economic, environmental and health losses that are not taken into account at the policy level.

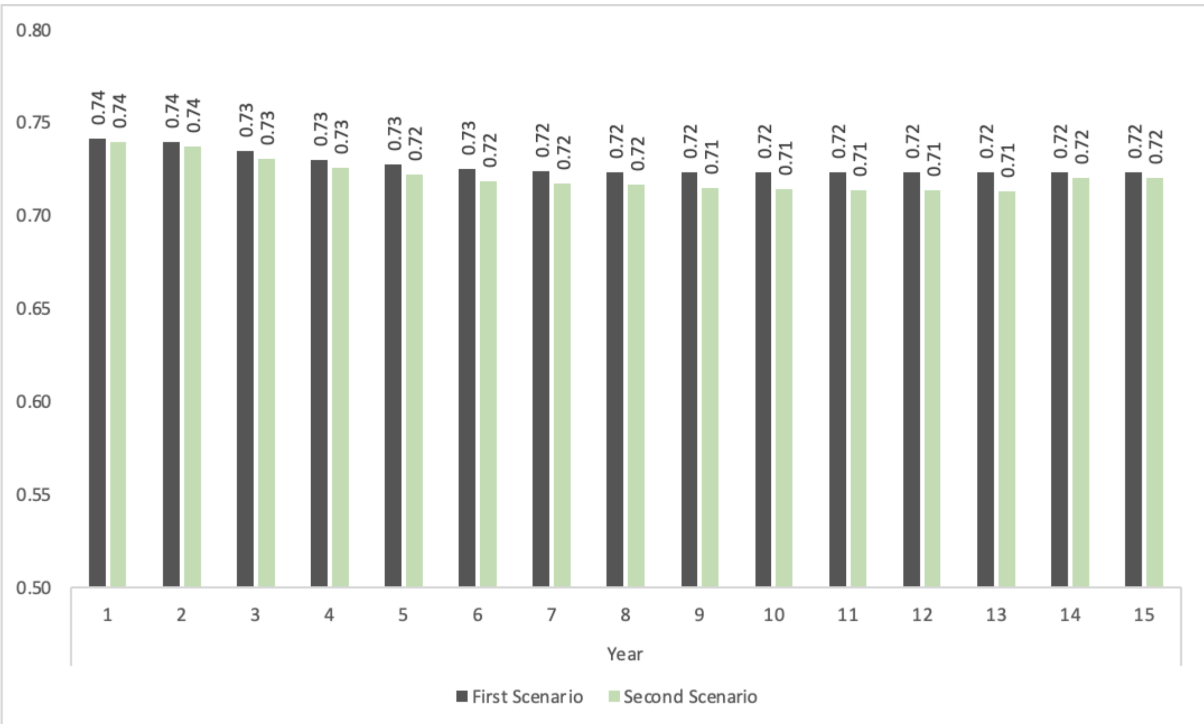


Figure 26. Williamson Index from nickel industry analysis in Central Sulawesi, Southeast Sulawesi, and North Maluku

[10] BPS Central Sulawesi Employment Situation February 2023
[11] BPS Morowali Poverty 2011-2022

Impacts on health and environment

Emissions from captive power and metal processing

Mineral extraction and processing bring significant benefits to the economy, but often with many ramifications to the environment and the welfare of the surrounding populations. Mining activities most visibly alter the natural landscapes and ecosystems. Less visible to the naked eye, toxic air pollutants generated at each stage, from mining and extraction, transportation, mechanical and thermal processing, smelting, and refining are emitted into the atmosphere.

As explained in the Methodology section, this study focuses on air pollutant emissions that would be generated from two major source categories, namely;

1) **captive power generation**, representing captive CFPPs, as well as diesel generators and gas-fired captive power plants that are operated exclusively to generate electricity for industrial or commercial users own consumption — in this case, those that have been identified to power the operations of specific nickel producer(s) operating in Central Sulawesi, Southeast Sulawesi, and North Maluku;
2) **coal-based metal processing**, representing facilities or point sources where metallurgical processes for metal refining and manufacturing take place — in this case, smelting facilities of all nickel producers operating in Central Sulawesi, Southeast Sulawesi, and North Maluku.

Provided in Figure 27 below, a distribution map of facilities that are producing different types of metal commodities produced across Indonesia, along with the estimates of annual emissions for major air pollutants: particulate matter (PM), nitrogen oxides (NO_x), and sulphur dioxide (SO_2).

Nickel industries are mainly centralised in the three provinces in Eastern Indonesia, near the reserves. Emissions from each circle representing nickel-producing companies or clusters are noticeably greater than any other metal commodities producers in other parts of Indonesia. Not only does this illustrate the scale of the presence of the industry, but also highlights the significance of potential impacts from air pollution exposure, deposition, and transport.

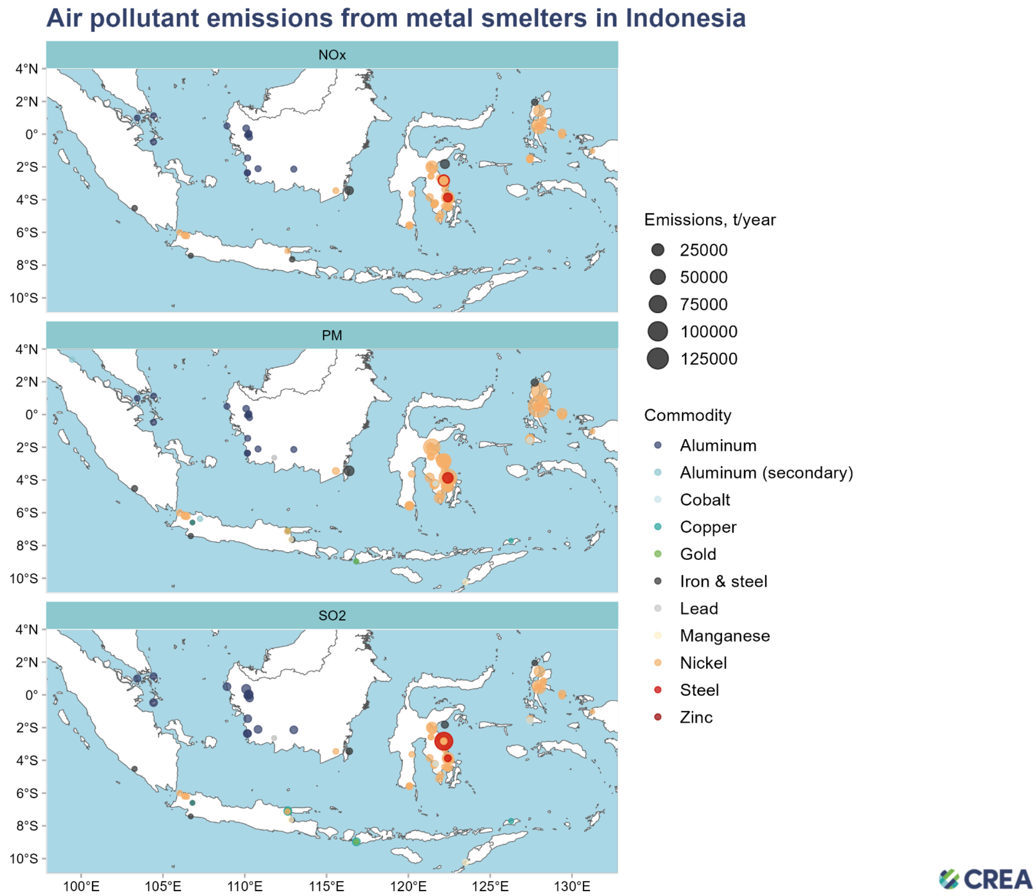


Figure 27. Distribution of metal smelting facilities across Indonesia by commodity type and the estimated annual air pollution emissions

Figure 28 provides data on emissions burden based on metal commodity by province, annual mercury emissions and the breakdown for fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}). In the subsequent Figure 29, emissions estimates are grouped based on the two source categories defined — captive power and metal processing. Nearly 80% of PMs, NO_x, and SO_2 emissions can be attributed to the refining and manufacturing process and the remaining portion from captive power generation. Mercury released from coal-fired power plants would be linked to captive CFPPs.

The significant contribution share from metal processing shows that efforts to reduce and minimise air emissions must be prioritised to safeguard workers and local communities. The International Finance Corporation's (IFC) Environmental, Health, and Safety Guidelines for Base Metal Smelting and Refining highlights that the recommended measures and the air emissions guideline values are generally achievable at reasonable costs and are to be applied when one or more members of the World Bank Group are involved in a project (World Bank Group, 2007).

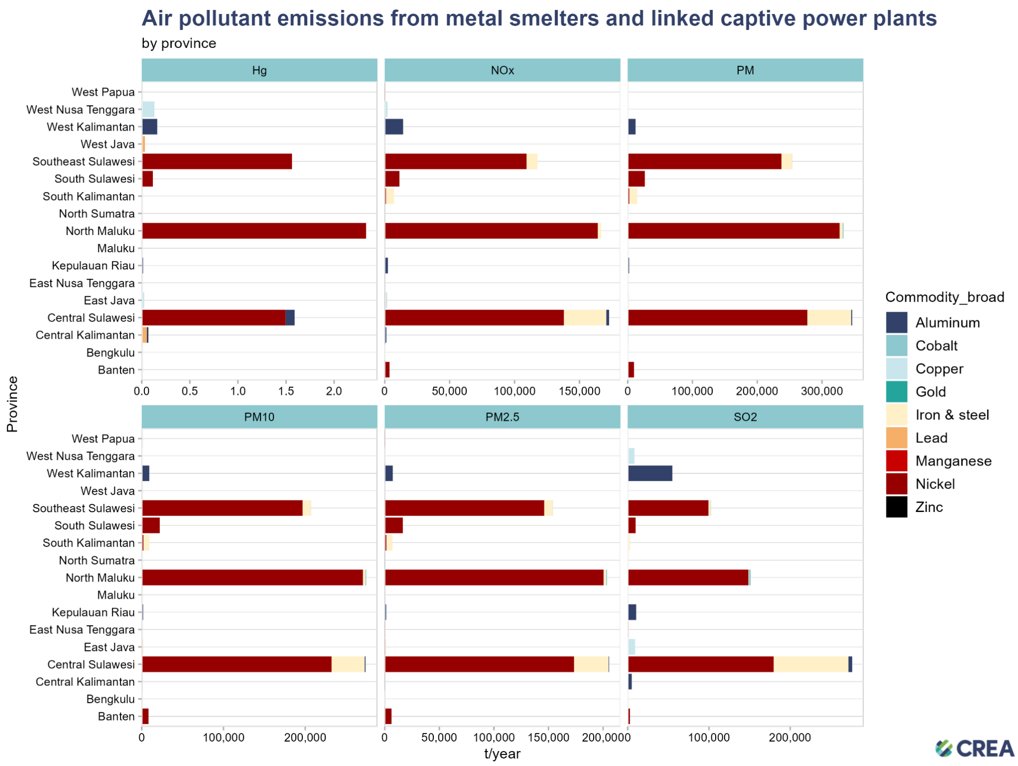


Figure 28. Air pollution contribution shares from emitting provinces by commodity

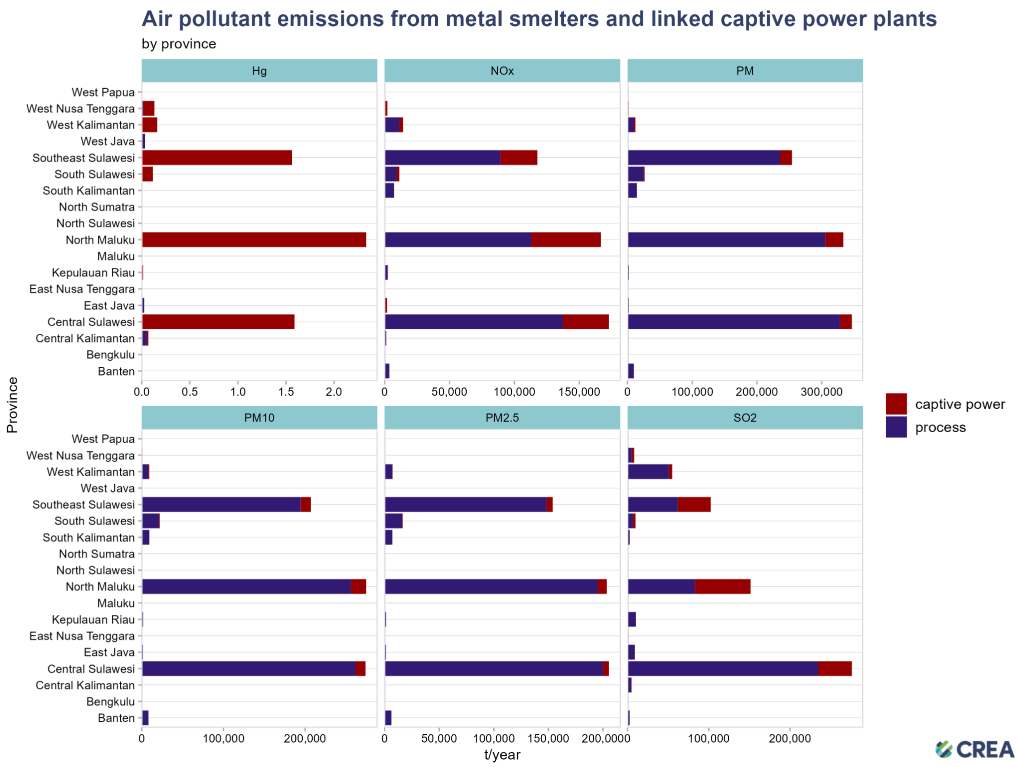


Figure 29. Air pollution contribution shares from emitting provinces by source categories

Figure 30, 31, and 32 are maps that illustrate the extent of dispersion of air pollutants emitted from the nickel-producing facilities along with the associated captive power plants in 2027, the time when all known nominal capacities are assumed to be operational based on available data on construction date and progress.

As shown, impacts would be centralised around the clusters of the processing centres. The analysis shows that the highest annual mean concentrations would reach up to 10 µg/m^3 for NO_2, 15 µg/m^3 for SO_2, and 20 µg/m^3 for $PM_{2.5}$. Illustrated in the contour map, the distribution varies between these key pollutants, with NO_2 and $PM_{2.5}$ declining faster with distance, and SO_2 maintaining high concentrations over larger areas.

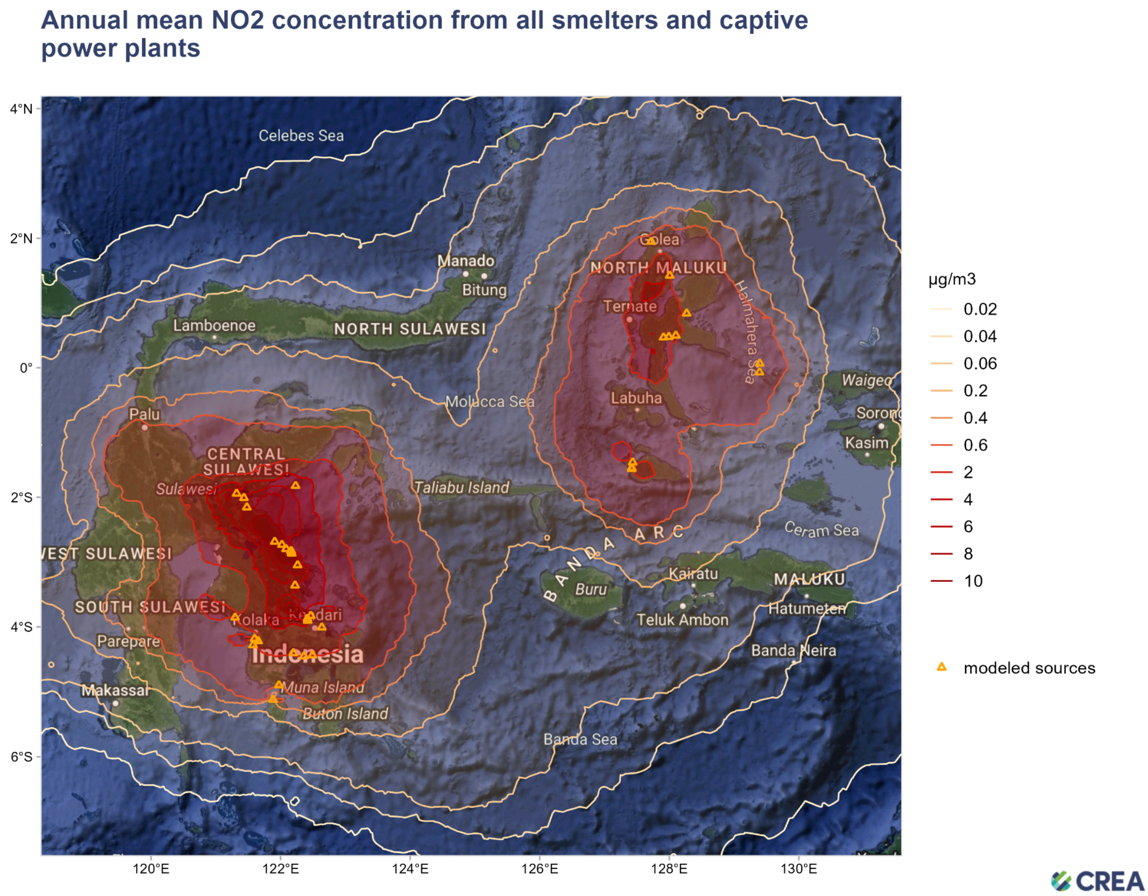


Figure 30. Annual average concentration of NO_2 from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

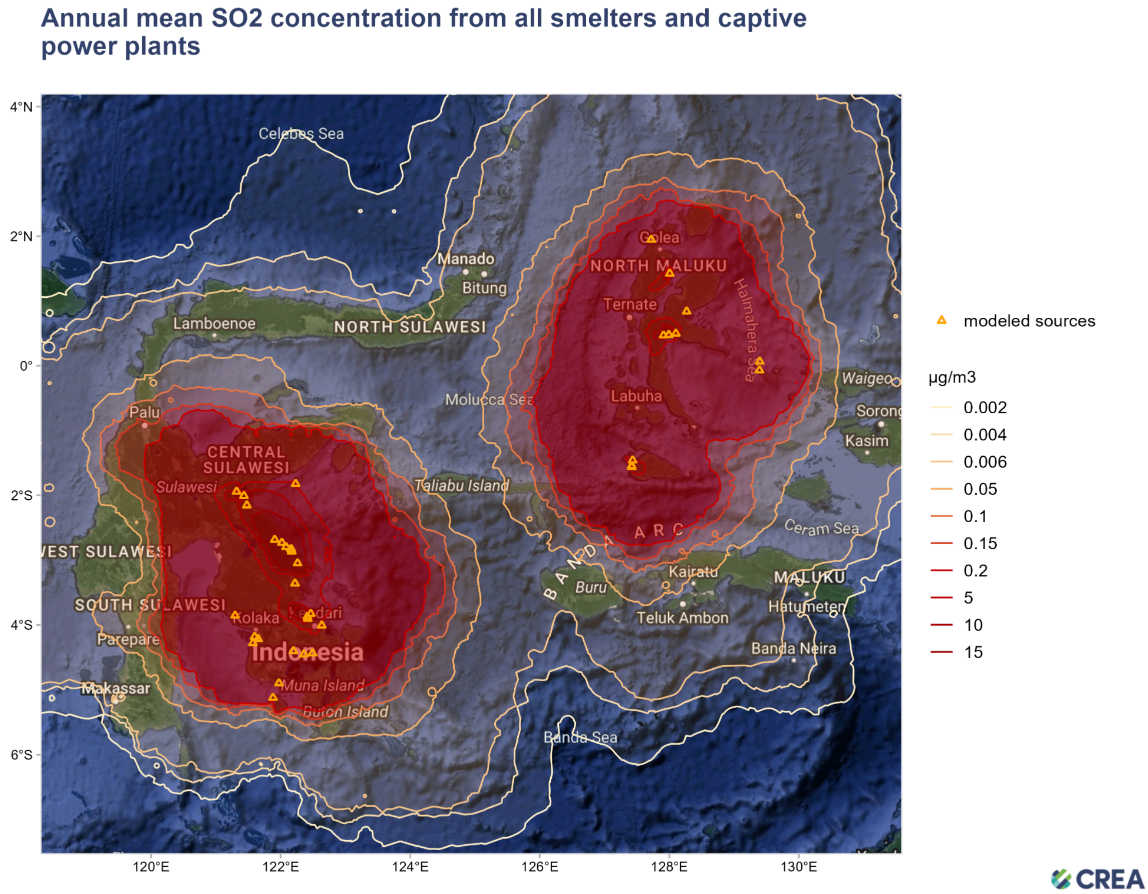


Figure 31. Annual average concentration of SO_2 from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

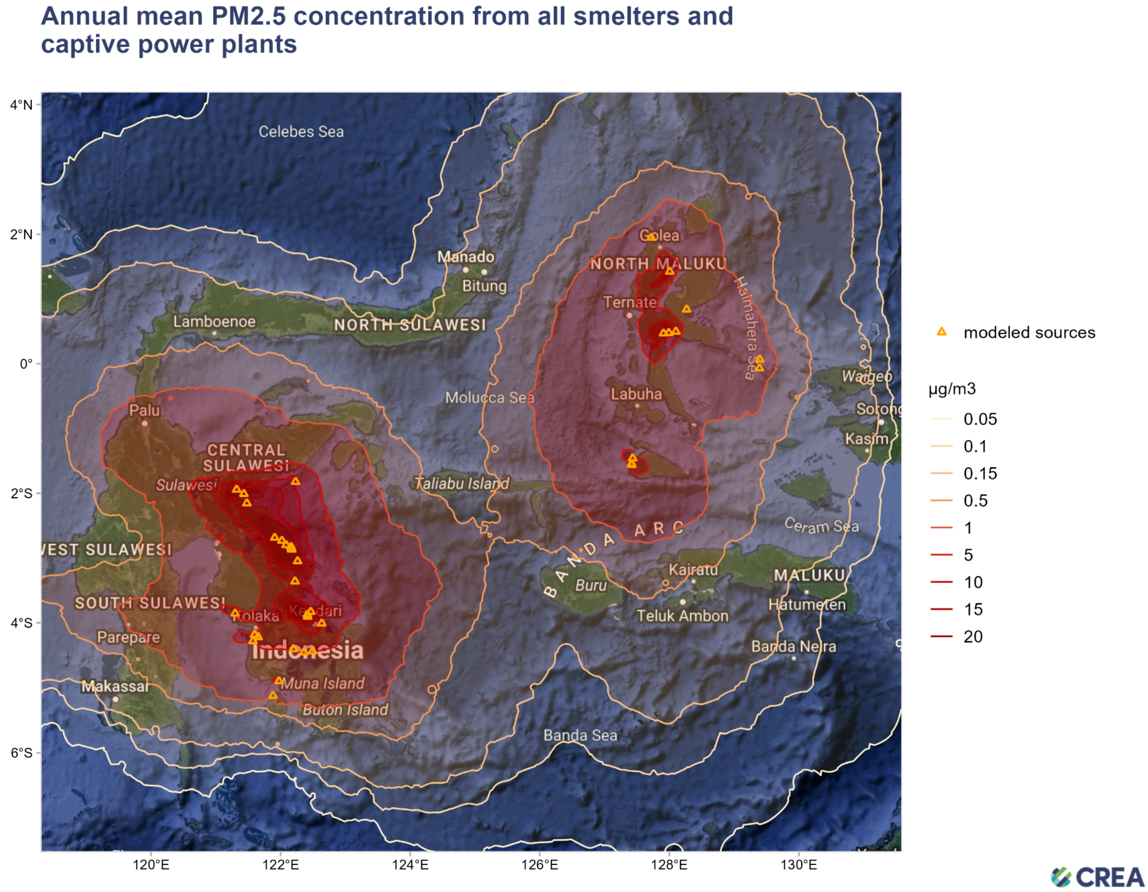


Figure 32. Annual average concentration of $PM_{2.5}$ from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

The 1-hour and the 24-hour maximum plots for each pollutant were chosen for comparison with the metric defined in WHO 2005 Air Quality Guidelines, which were used as the basis for Indonesia's national ambient air quality standards.

Figure 33 shows the maximum 1-hour concentration of NO_2 attributed to the three provinces' smelters and captive power plants, reaching 300 µg/m^3 at its peak. The current national ambient air quality standard sets a 1-hour NO_2 threshold at 200 µg/m^3, a 24-hour threshold at 65 µg/m^3, and an annual threshold of 50 µg/m^3. This means potential maximum exceedance might be 50% times higher than the 1-hour national standard.

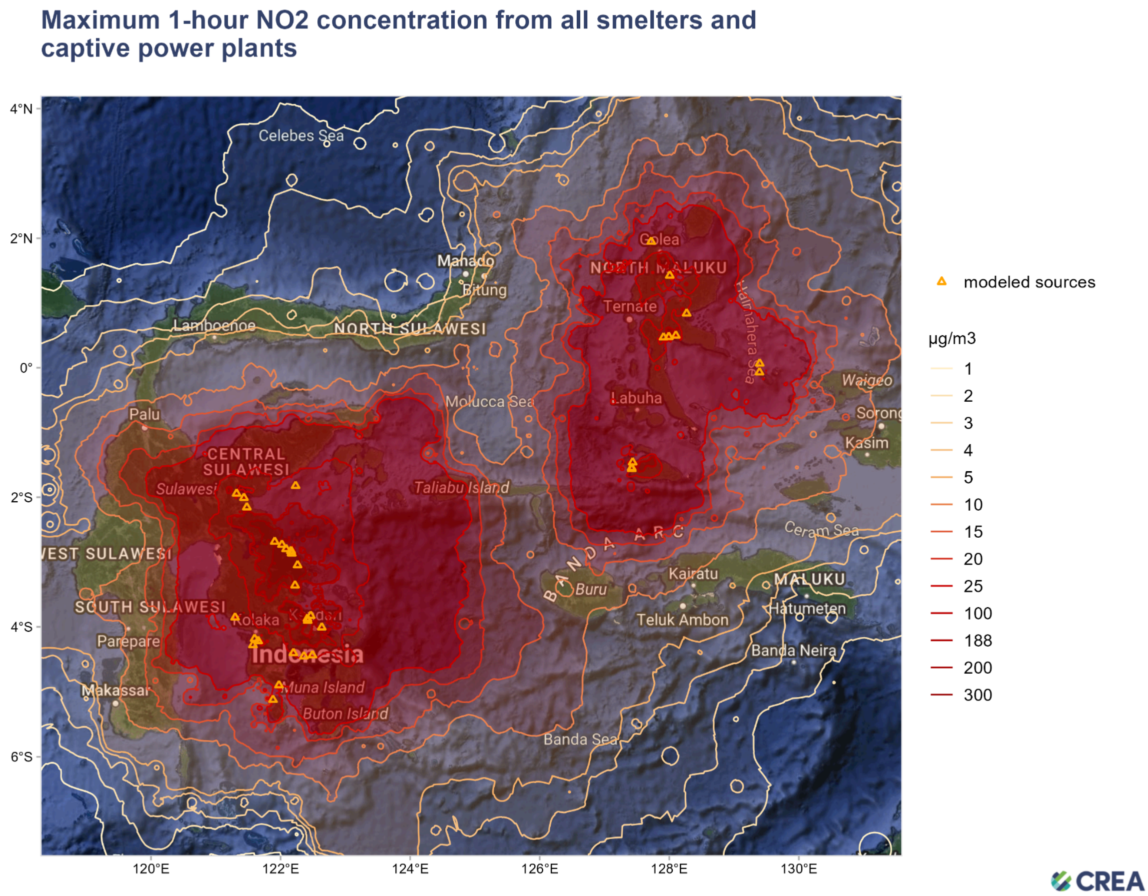


Figure 33. Maximum 1-hour concentration of NO_2 attributed to emissions released from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

The following Figure 34 provides the maximum 1-hour concentration of SO_2 and shows that the level may reach 1,000 μg/m^3 nearest to the emissions sources. The current national ambient air quality standard sets a 1-hour SO_2 threshold at 150 μg/m^3, a 24-hour threshold at 75 μg/m^3, and an annual threshold of 40 μg/m^3. Potential maximum exceedance may be over 5.5-fold higher than the 1-hour threshold.

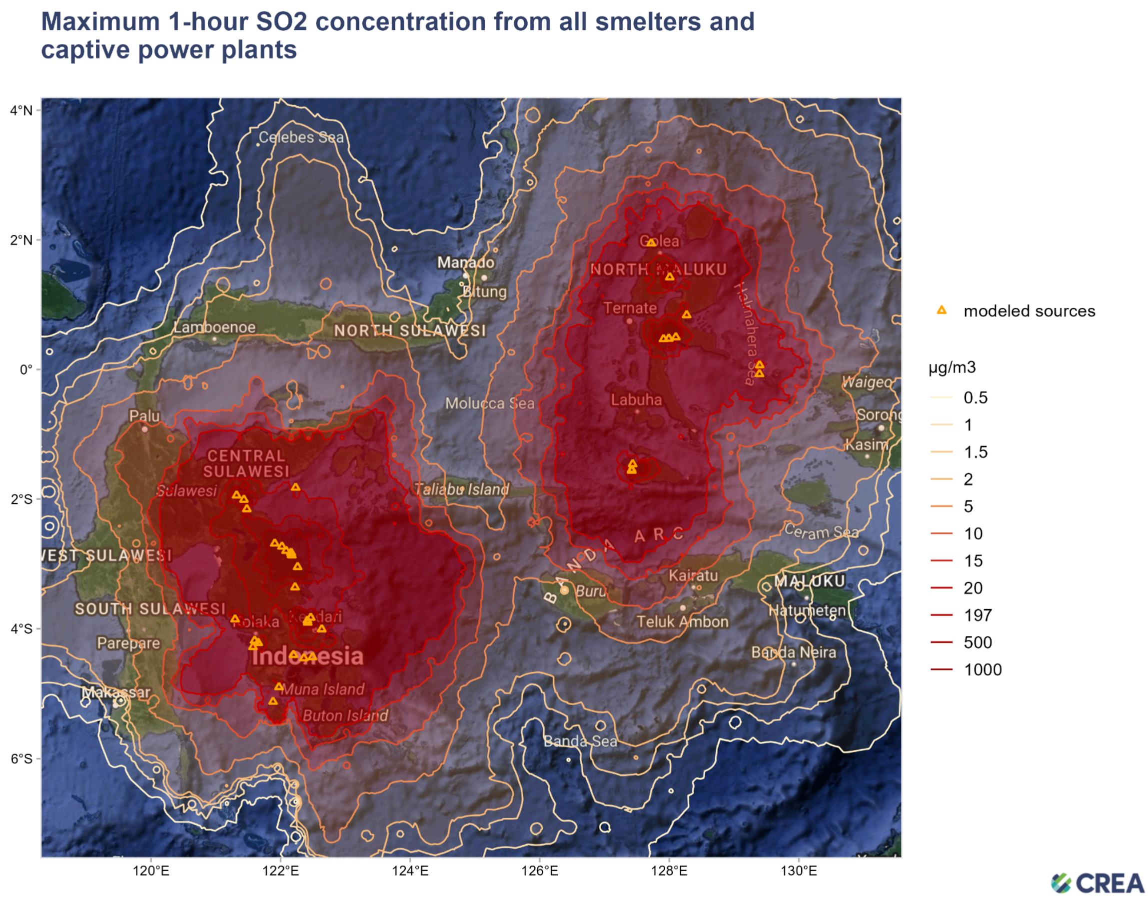


Figure 34. Maximum 1-hour concentration of SO_2 attributed to emissions released from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

Figure 35 below illustrates the maximum 24-hour concentration of $PM_{2.5}$. In unfavourable atmospheric conditions, levels may be as high as 150 μg/m^3 over most of Sulawesi and North Maluku. The current national ambient air quality standard sets a 24-hour $PM_{2.5}$ threshold at 55 μg/m^3 and an annual threshold of 15 μg/m^3. This indicates that the worst 24-hour $PM_{2.5}$ level over the three provinces may be nearly three times higher than the national standard or nine times higher than the 24-hour $PM_{2.5}$ threshold recommended in the 2021 WHO Air Quality Guideline at 15 μg/m^3.

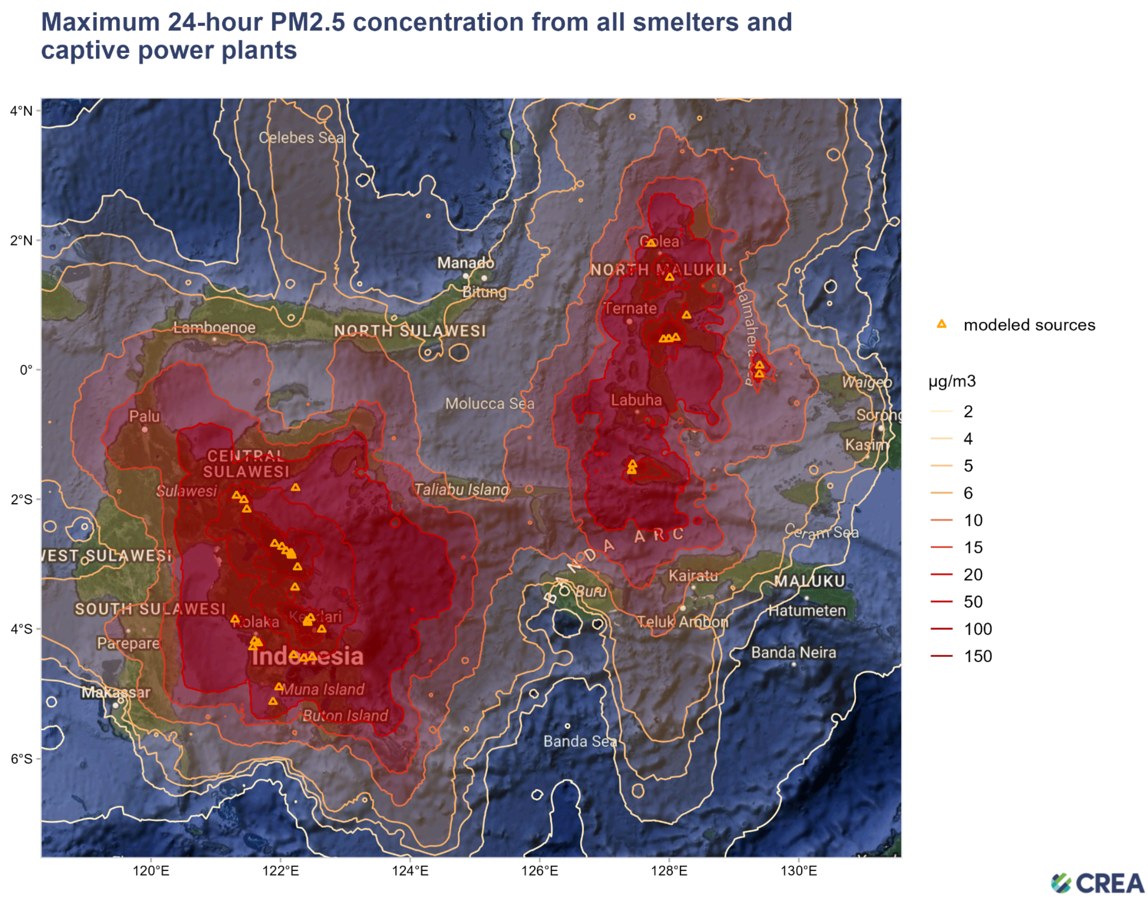


Figure 35. Maximum 24-hour concentration of $PM_{2.5}$ attributed to emissions released from the three provinces' metal smelting facilities and captive power plants (ca. 2027, all known capacities are operational)

The following three figures, Figure 36, 37, and 38, show how emissions from NO_2, SO_2, and $PM_{2.5,}$ respectively, are projected to grow in 5-year intervals from 2015 to 2030. The rapid rise in nickel production capacity that began in late 2020 clearly reflected in these figures. As capacities continue to be added in the next decade, emissions are projected to rise and accumulate in parallel, at the same pace, if not faster.

Unless proper measures are taken, concentration levels of health-harming pollutants in the mapped hotspots can be expected to remain at high levels, causing health impacts to the populations living in the area and contributing to significant release of atmospheric heavy metals in the region.

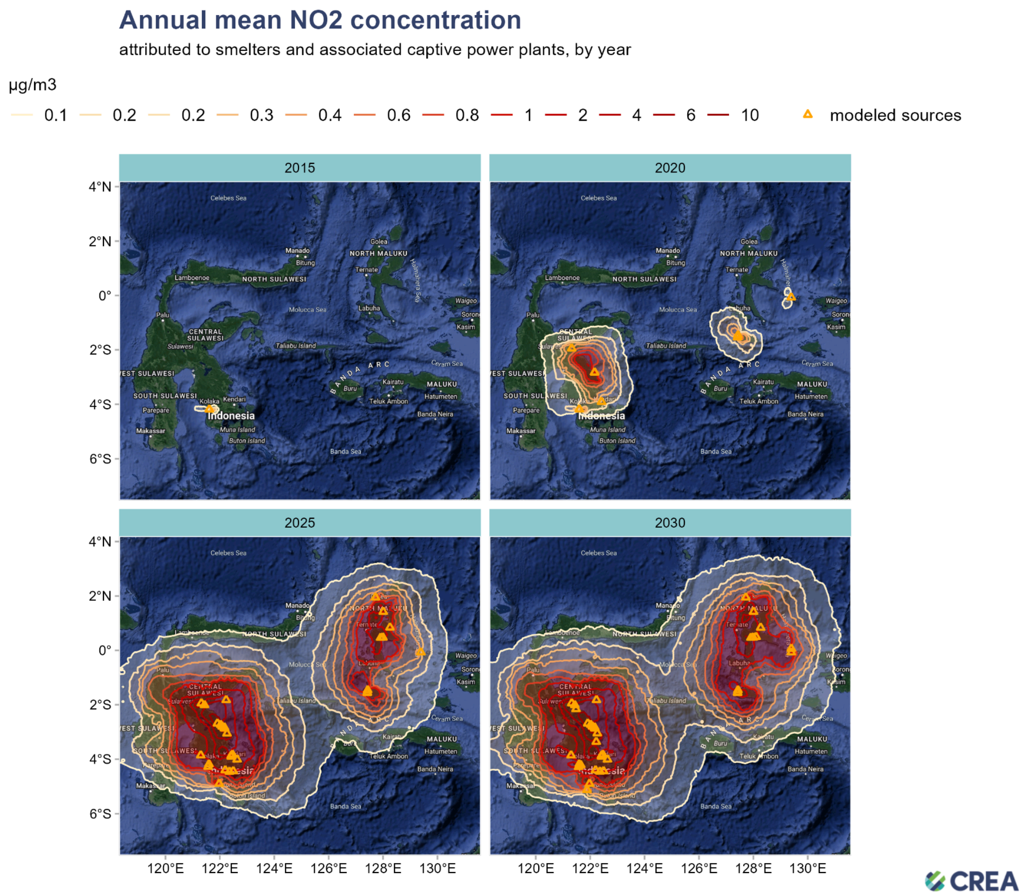


Figure 36. Distribution estimates of the annual mean concentration of NO_2 from the three provinces' metal smelting facilities and captive power plants from 2015 to 2030

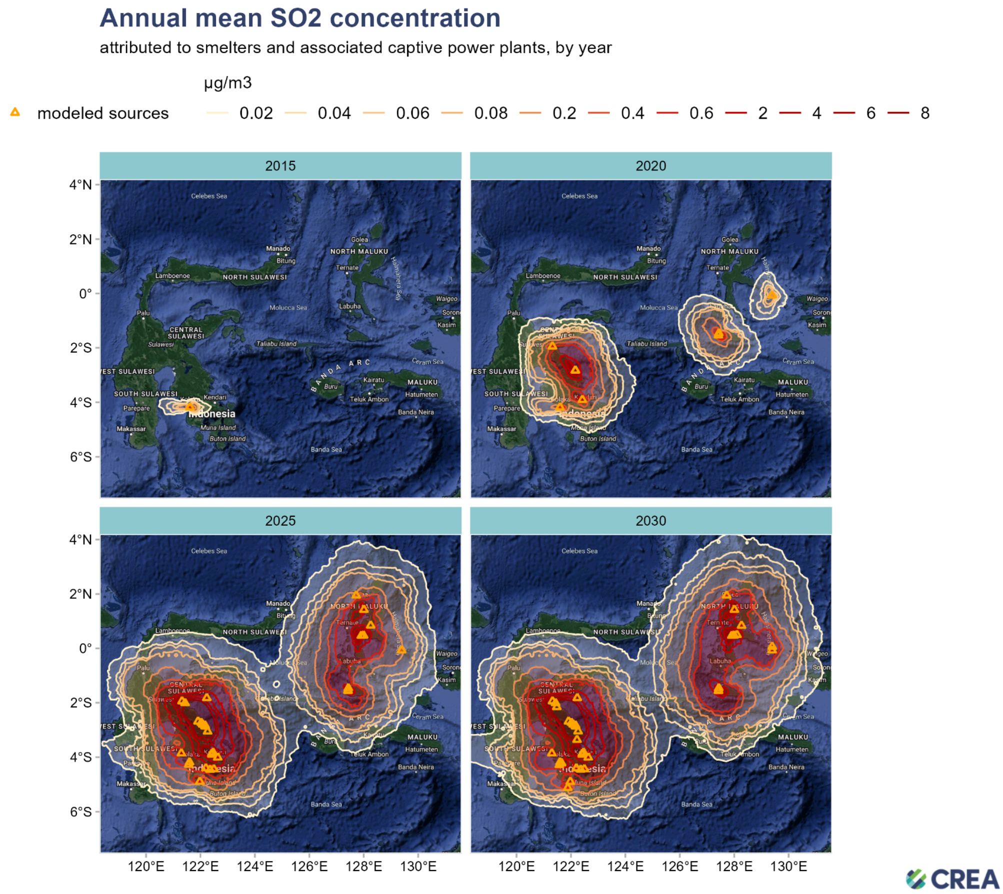


Figure 37. Distribution estimates of annual mean concentration of SO_2 from the three provinces' metal smelting facilities and captive power plants from 2015 to 2030

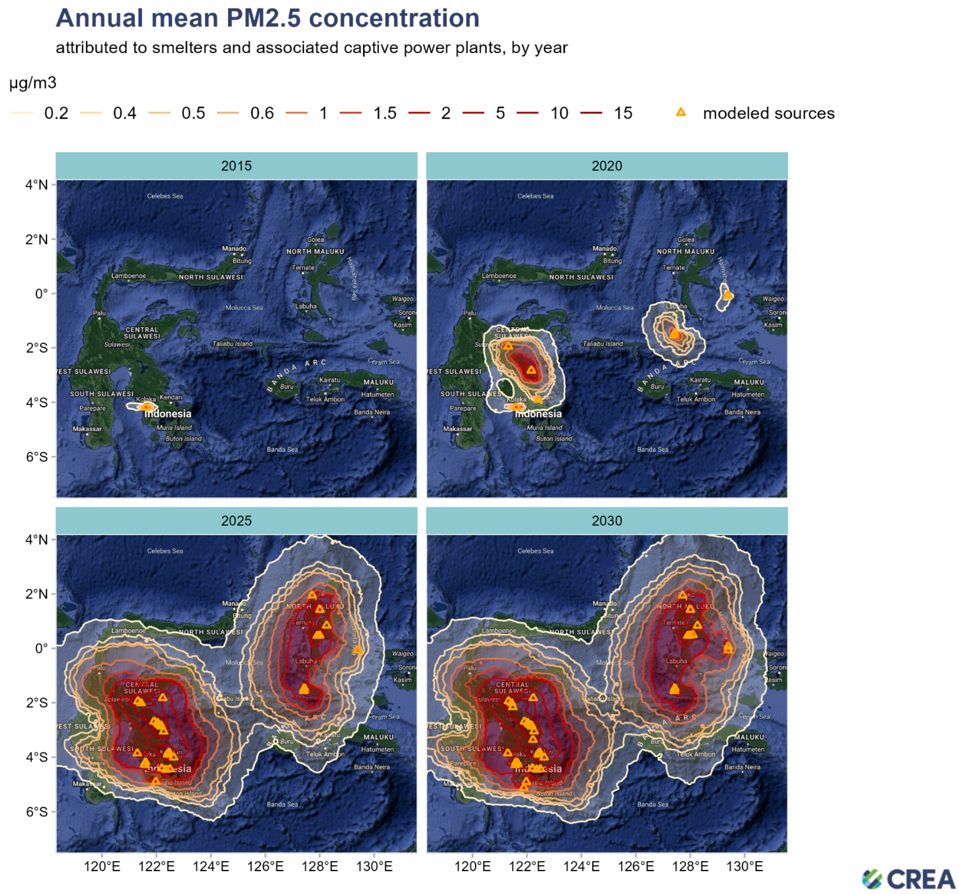


Figure 38. Distribution estimates of annual mean concentration of $PM_{2.5}$ from the three provinces' metal smelting facilities and captive power plants from 2015 to 2030

Figure 39 below shows the maximum ambient concentration levels that could be reached as a result of emissions released from all of the evaluated metal processing plants and the captive power plants supplying electricity over the years from 2015 to 2030.

Between 2020 and 2025, a significant rise in emissions can be expected without stringent intervention. Maximum levels would far exceed evidence-based safe levels as recommended in the 2021 WHO Global Air Quality Guidelines (WHO, 2021) for all major health-harming pollutants, as well as Indonesia's national ambient air quality standards specified in Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management (BPK-JDIH, 2021).

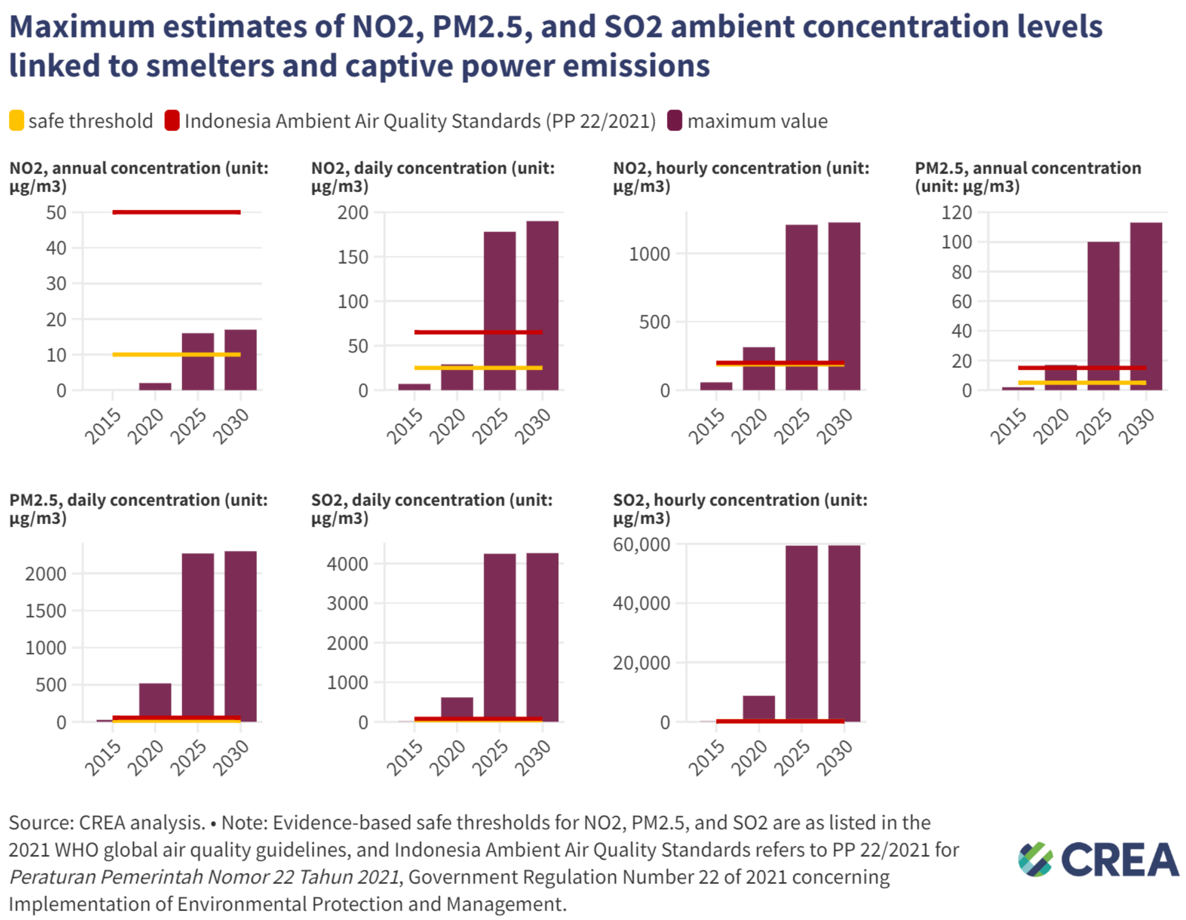


Figure 39. Maximum estimates of NO_2, $PM_{2.5}$, and SO_2 ambient concentration levels linked to emissions from three provinces' metal smelting facilities and captive power plants, from 2015 to 2030

The subsequent Table 10 below summarises population sizes and areas affected by the maximum exceedances of NO_2, SO_2, and $PM_{2.5}$ daily ambient concentration levels. Due to the nature of pollutant dispersion, $PM_{2.5}$ is projected to be distributed over a larger distance, impacting more people and a greater area compared to NO_2 and SO_2.

Table 10. Total population size and area affected by the maximum exceedances in NO_2, SO_2, and $PM_{2.5}$ daily ambient concentration levels linked to emissions from three provinces' metal smelting facilities and captive power plants, from 2015 to 2030

year	NO_2		SO_2		$PM_{2.5}$	
	affected population (people)	affected area (km^2)	affected population (people)	affected area (km^2)	affected population (people)	affected area (km^2)
2015	-	-	-	-	3,106	50
2020	727	39	29,546	4,376	156,110	10,651
2025	1,033,704	42,014	1,201,554	54,824	7,105,404	363,085
2030	1,377,678	48,736	1,331,115	59,831	8,148,930	428,798

Air pollution-related health impacts

Based on the modelled air pollution dispersion, CREA calculated the corresponding health risks from exposure to elevated concentration levels. The number of deaths attributed to the processing facilities and captive CFPPs operating to meet the energy demand is expected to rise significantly up to 2030, parallel to the anticipated rise in production capacity. The total number of deaths is expected to rapidly rise from 215 in 2020 to 3,833 in 2025, nearly 18-fold in five years. Without intervention, death counts are expected to continue to rise to 4,982 in 2030, and 8,325 in 2060 (Figure 40).

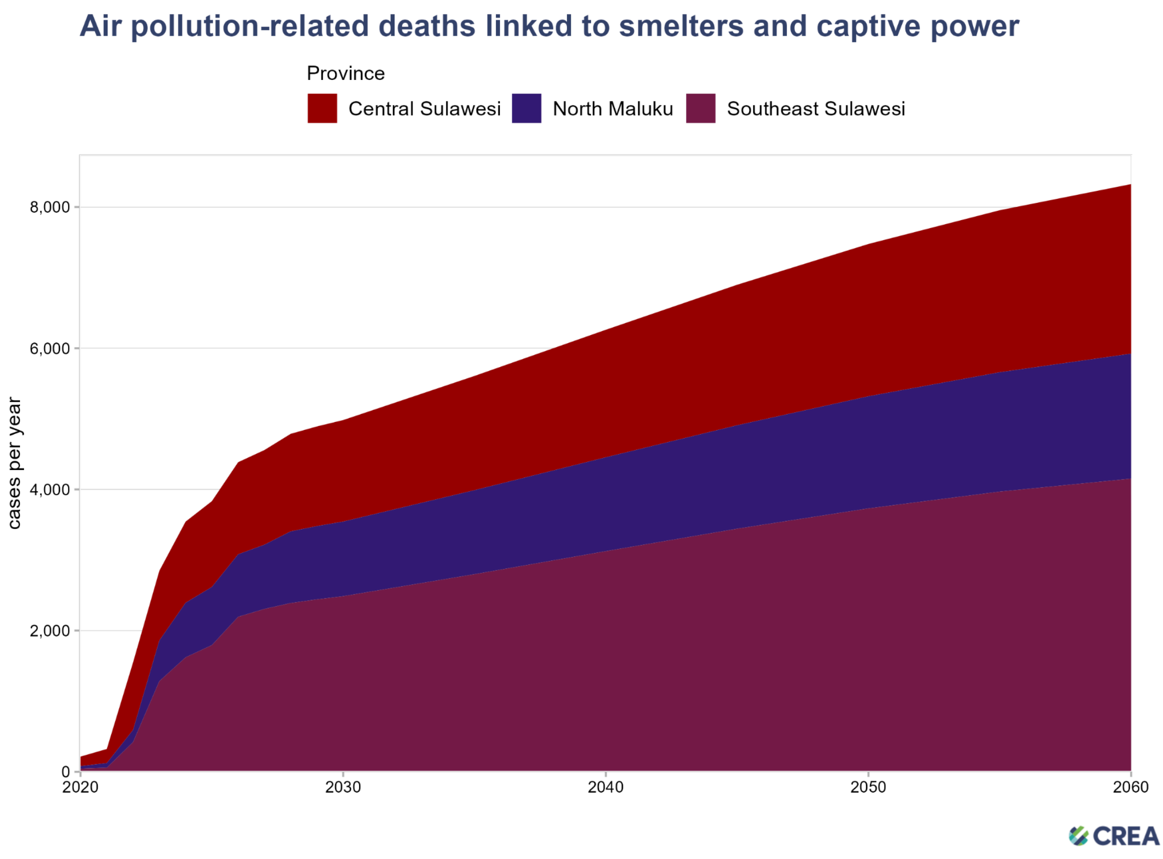


Figure 40. Air pollution-related deaths attributed to smelters and captive powers, grouped by emitting province, namely Central Sulawesi, Southeast Sulawesi, and North Maluku

Air pollution-related costs are calculated from all the health impacts that are linked to elevated concentration levels. In adults, air pollution causes and aggravates respiratory diseases, such as asthma, and chronic obstructive pulmonary disease, as well as increased risks of stroke and diabetes. Impacts are particularly profound on newborns and children, causing low birth weight, premature births, lower respiratory tract infections, asthma, and

decreased lung function. Work absences for the need to take sick leave or care for someone else who is sick are also quantified, as such costs directly cause GDP losses.

Total annual economic costs from air pollution linked to the evaluated smelters and captive power emitted in the three provinces is estimated at USD 148 million (IDR 2.29 trillion) in 2020, and is projected to increase by nearly 18-fold to USD 2.63 billion (IDR 40.7 trillion) in 2025. Without meaningful intervention, the economic burden would steadily increase to reach nearly USD 3.42 billion (IDR 53.0 trillion) in 2030, and USD 5.69 billion (IDR 88.2 trillion) in 2060 (Figure 41).

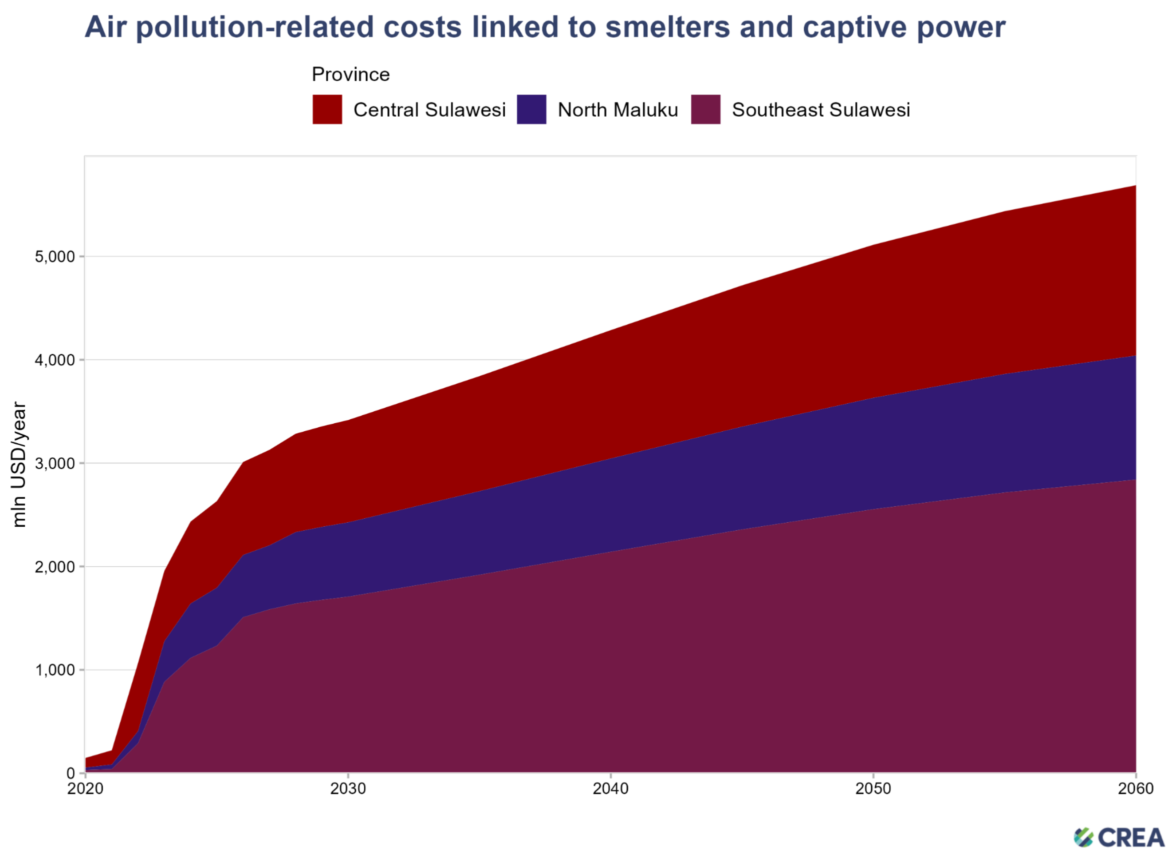


Figure 41. Air pollution-related costs attributed to smelters and captive powers, grouped by emitting province, namely Central Sulawesi, Southeast Sulawesi, and North Maluku

Evaluating costs by the affected provinces, impacts would be greater to populations living in close distance to the emission sources. Citizens living in Southeast Sulawesi, North Maluku, South Sulawesi, and Central Sulawesi would be most affected. Following the same proportion, mortality and health-related economic impacts at provincial-level as shown in Figure 42 and 43 below respectively.

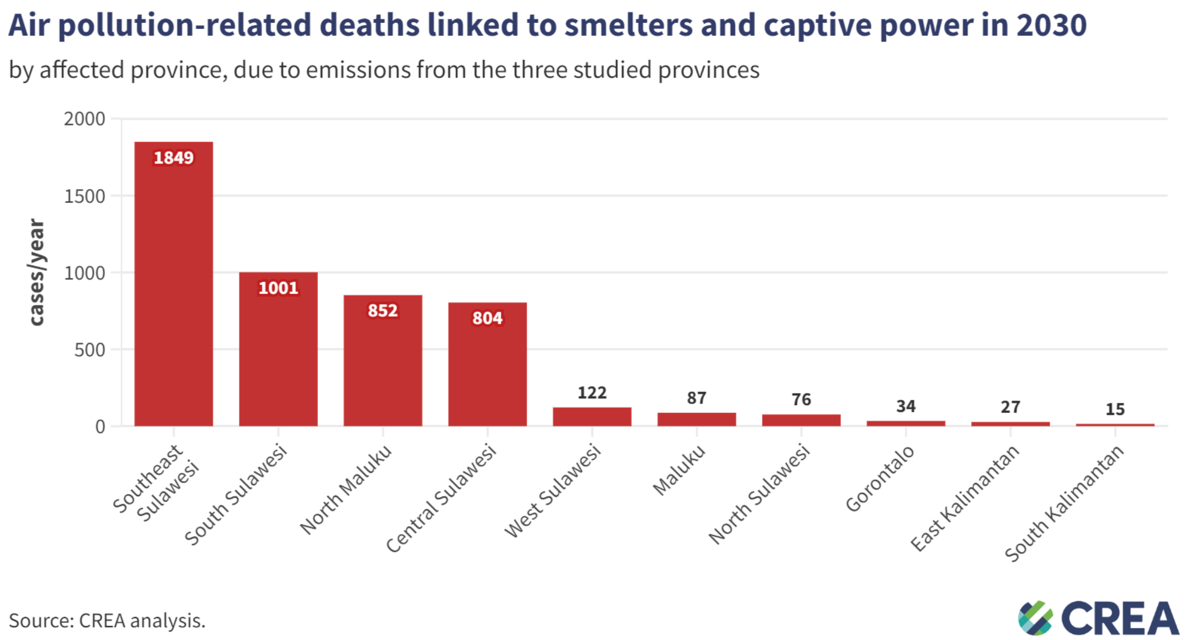


Figure 42. Air pollution-related deaths attributed to smelting and captive power emissions in 2030, originating from the three provinces, grouped by affected province

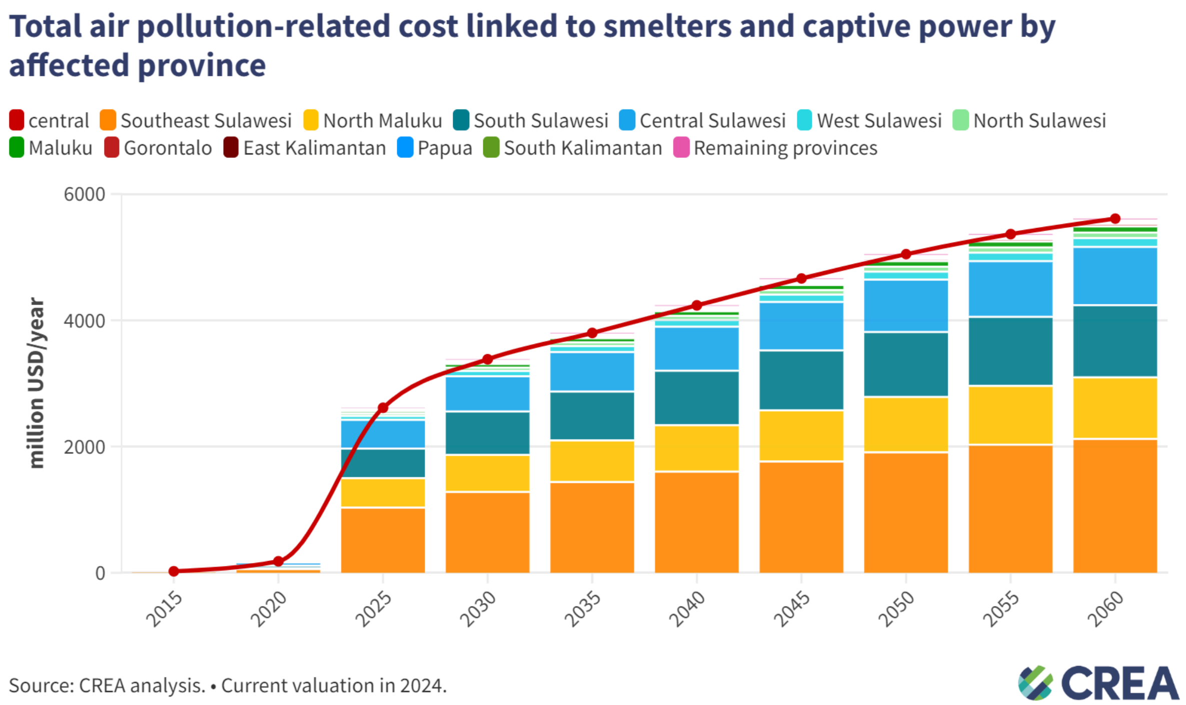


Figure 43. Air pollution-related costs attributed to smelting and captive power emissions originating from the three provinces, by affected province, listed in decreasing order

A summary of the central estimates of the annual health impacts in 2030, grouped by emitting province and aggregated for the national total, is provided in Table 11 below.

Table 11. Central estimate of annual health impacts by emitting province in 2030

Outcome	Central Sulawesi	North Maluku	Southeast Sulawesi	Total - National
Count of sick leave days				
Work absence	316,805 (269,596 - 363,668)	193,398 (164,578 - 222,006)	519,313 (441,927 - 596,133)	1,029,516 (876,101 - 1,181,807)
Number of cases				
New cases of asthma in children	95 (22 - 207)	18 (4 - 39)	155 (36 - 337)	268 (62 - 583)
Total cases of asthma in children	406 (108 - 824)	76 (20 - 154)	663 (177 - 1,346)	1,145 (305 - 2,324)
Asthma emergency room visits	109 (66 - 152)	18 (11 - 25)	97 (58 - 135)	224 (135 - 312)
Low birthweight births	195 (61 - 337)	35 (11 - 60)	224 (70 - 388)	454 (142 - 785)
Preterm births	15 (7 - 15)	3 (1 - 3)	24 (12 - 26)	42 (20 - 44)
Years of lives lost (YLL)				
All causes from NO_2 exposure	756 (322 - 1,739)	131 (56 - 303)	1,337 (570 - 3,077)	2,224 (948 - 5,119)
All causes from SO_2 exposure	1,785 (1,059 - 2,689)	757 (449 - 1,141)	1,650 (978 - 2,485)	4,192 (2,486 - 6,315)
Years lived with disability (YLD)				
COPD	482 (175 - 900)	301 (109 - 562)	807 (293 - 1,505)	1,590 (577 - 2,967)
Diabetes	2,320 (119 - 5,838)	986 (26 - 5,663)	3,548 (154 - 11,358)	6,854 (299 - 22,859)
Stroke	721 (232 - 1,480)	433 (139 - 888)	1,210 (390 - 2,485)	2,364 (761 - 4,853)

Health impacts quantified in 2030 would negatively affect productivity, with the total projection of over 1 million days of work absences or sick leave days affecting the emitting provinces and the neighbouring affected provinces. Air pollution-related impacts on newborn and infants are concerning, with 1,145 total cases of children having asthma per year and nearly 500 cases of low birthweight births and preterm births per year in 2030.

All citizens exposed to NO_2 and SO_2 emitted from the metal processing facilities and captive power plants in the three provinces may have to bear 6,400 years of lives lost in total, not to mention raised risks of COPD, diabetes, and stroke annually. These estimates are used to calculate air pollution-related economic costs and used to supplement the provincial economic modelling.

Facilities that are located in or near higher populations can be expected to cause higher health impacts and costs. The scale of the production capacity would also determine the extent of impacts on air quality and the corresponding health impacts, in addition to meteorological conditions, temperature, and wind speed.

In Figure 44 below, health impacts in annual deaths linked to air pollution are listed for the top emitting facilities, ranked by the projected health impacts in 2030. The numbers are estimated from emissions that would be released without proper emissions control.

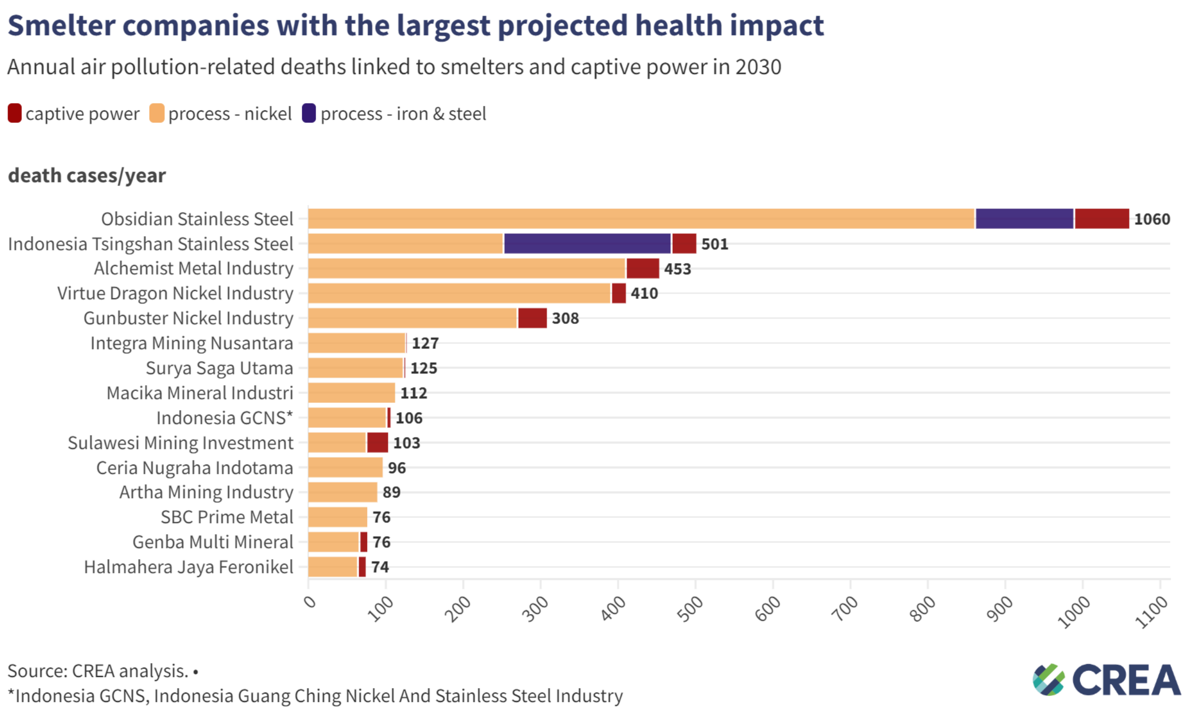


Figure 44. Air pollution-related deaths in 2030 by company, listed in decreasing order

In 2030, Obsidian Stainless Steel would be responsible for 1,060 deaths annually in this case. Indonesia Tsingshan Stainless Steel's operation would be linked to 500 annual deaths. Alchemist Metal Industry, Virtue Dragon Nickel Industry, and Gunbuster Nickel Industry are also on the top list, releasing air pollutants linked to 453 deaths, 410 deaths, and 308 deaths in 2030, respectively. The majority of impacts are attributed to emissions released from the smelting process itself, as noted in the beginning of the section.

Air Pollution Control

CREA also quantified estimates on benefits that can be gained through the implementation of Air Pollution Control (APC) technologies with higher performance levels that would effectively reduce emissions of health-harming and toxic air pollutants.

Proper installation and operation of APC would avoid 247 deaths from captive power plants preventing release of pollutants, and 3,519 deaths from processing facilities meeting more stringent standards in 2030 as illustrated in Figure 45. Since a large portion of air pollutants originate from the metal smelting process, it becomes clear that APC is an essential component to sustainable and responsible nickel operations.

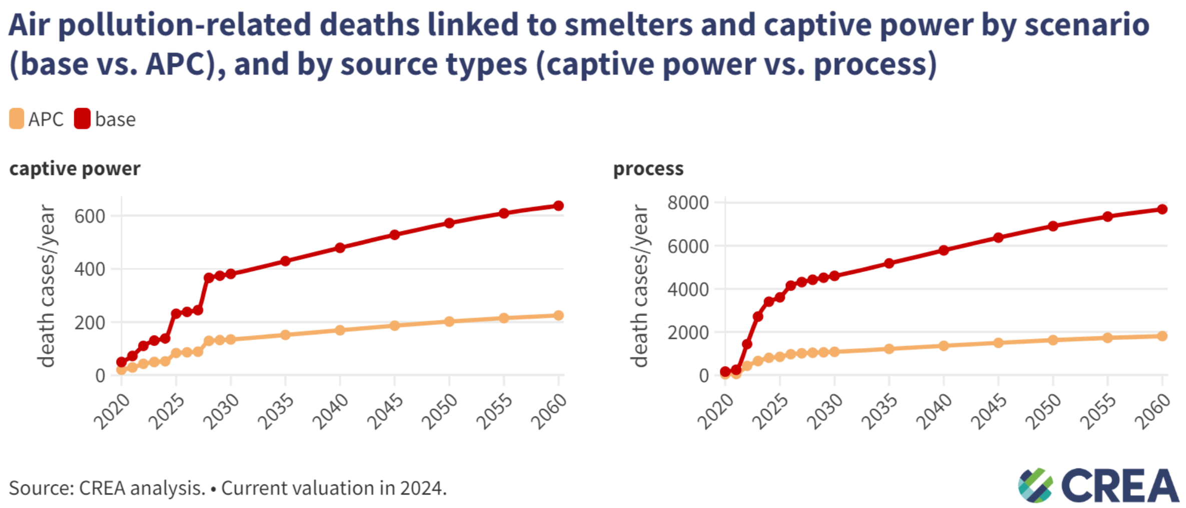


Figure 45. Annual air pollution-related deaths without intervention (base) and with APC installation (APC) , linked to smelters and captive power plants

Shown in Figure 46 below is the illustration of annual economic costs and deaths that could be avoided from proper APC installation and management. In 2030, a total of 3,766 deaths would be saved if air quality standards are maintained through the use of APC, as well as up to USD 2.60 billion (IDR 40.3 trillion) from mitigated air pollution-related health costs. Cumulatively to 2060, a total of 55,600 deaths and USD 38.2 billion (IDR 592 trillion)

could be avoided if the processing centres operating in Central Sulawesi, Southeast Sulawesi, and North Maluku aimed to uphold stringent air quality standards.

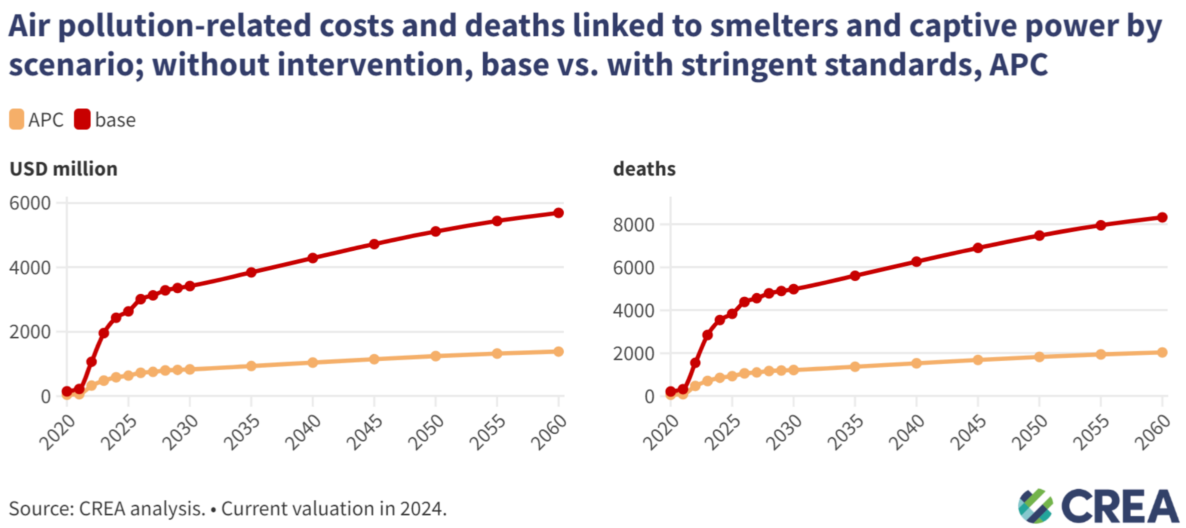


Figure 46. Annual air pollution-related economic costs and deaths without intervention (base) and with APC installation (APC)

Toxic deposition

While the study focuses on air pollution emitted from captive power generation and coal-based processing, CREA also estimated depositions from the dispersed coarse and fine particulate matter, which contains mercury and other heavy metals.

As illustrated in Figure 47 below, deposition which would occur during rain events can be expected to occur across the three provinces, as well as others in the island of Sulawesi and Maluku. Mercury deposition rates as low as 125 mg/ha/year can lead to the accumulation of unsafe levels of mercury in fish (Swain et al., 1992).

The highest mercury deposition rates may reach 300 mg/ha/year in the hotspots, which implies significant risks of mercury accumulation in fish. The analysis shows that in 2025, mercury deposition above 125 mg/ha per year would cover a total area of 24,700 km^2 where 627 thousand people reside.

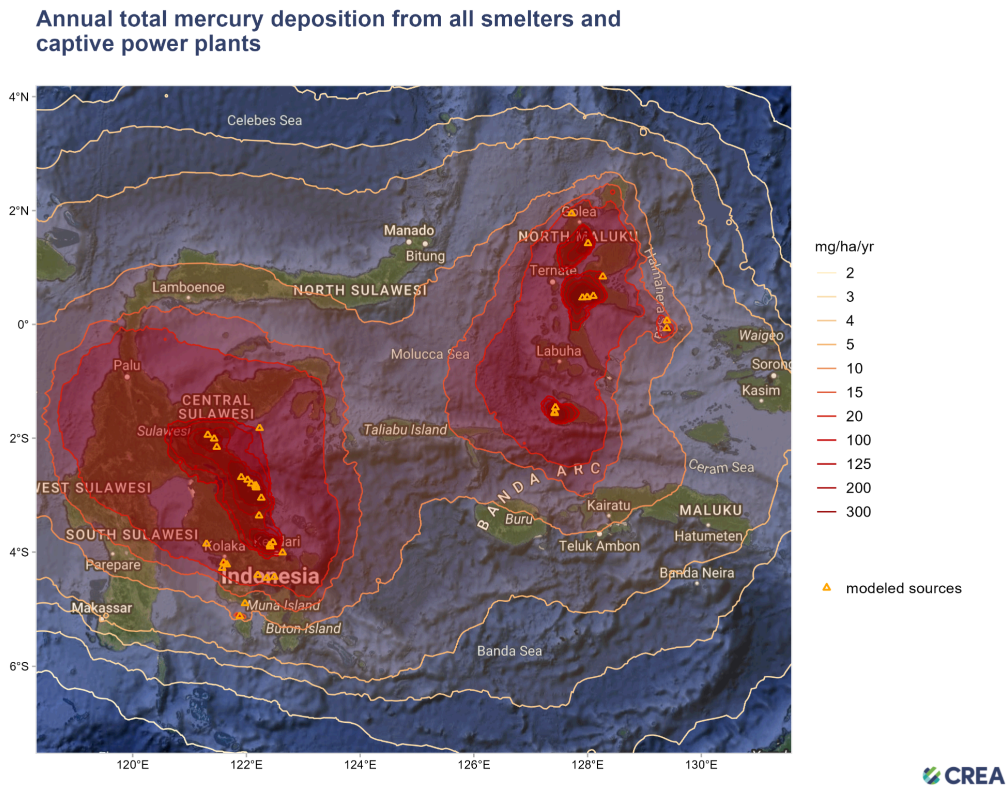


Figure 47. Annual average concentration of total mercury deposition from the three provinces' metal smelting facilities and captive power plants

In this study, we refer to toxic particles as airborne complex microparticles that are generated from coal with varied composition, containing toxic elements which include heavy metals, Polycyclic Aromatic Hydrocarbons (PAH), and other environmentally sensitive elements. Coal fly ash makes up for the majority of toxic particles.[12] As it is dispersed over long distances in land and water surfaces, these heavy metals-laden particles would leach heavy metals and organic pollutants, contaminating soil and water, and impacting agricultural lands and marine ecosystems (Chen et al., 2024).

Toxic particle deposition rates as high as 80 kg/ha/year are apparent in the vicinity of the clusters, as shown in Figure 48. This indicates tremendous risks to the biodiversity and forest-rich Indonesian islands of Sulawesi and Maluku, as heavy metals bring persistent and irreversible biotoxicity to the environment.

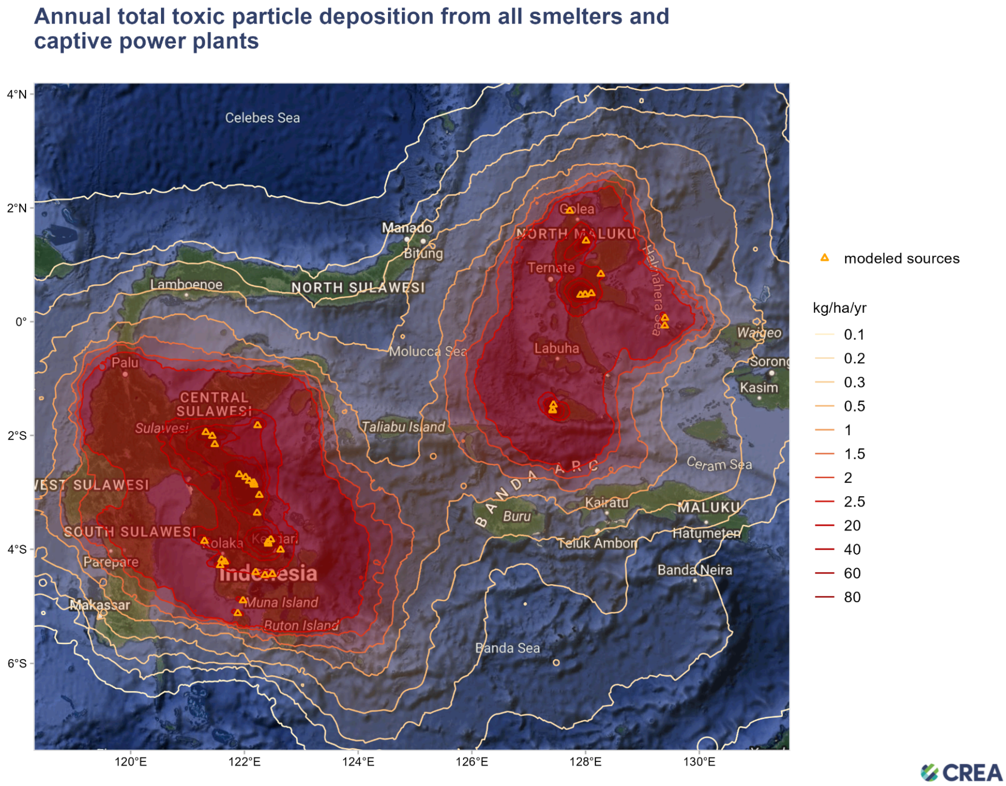


Figure 48. Annual average total toxic particle deposition from the three provinces' metal smelting facilities and captive power plants

[12] Coal fly ash contains 2 to 10 times higher heavy metals than the parent coal, comprising microparticles sized from 0.1 to 100 micrometres (Chen et al., 2024)

Figure 49 and 50 below provide an illustration of the projected increase in five-year intervals in annual deposition of mercury and toxic particles, respectively. As shown in both figures, dramatic increase can be expected between 2020 and 2025 as total capacity significantly increases to over three-fold, and will be sustained beyond 2030.

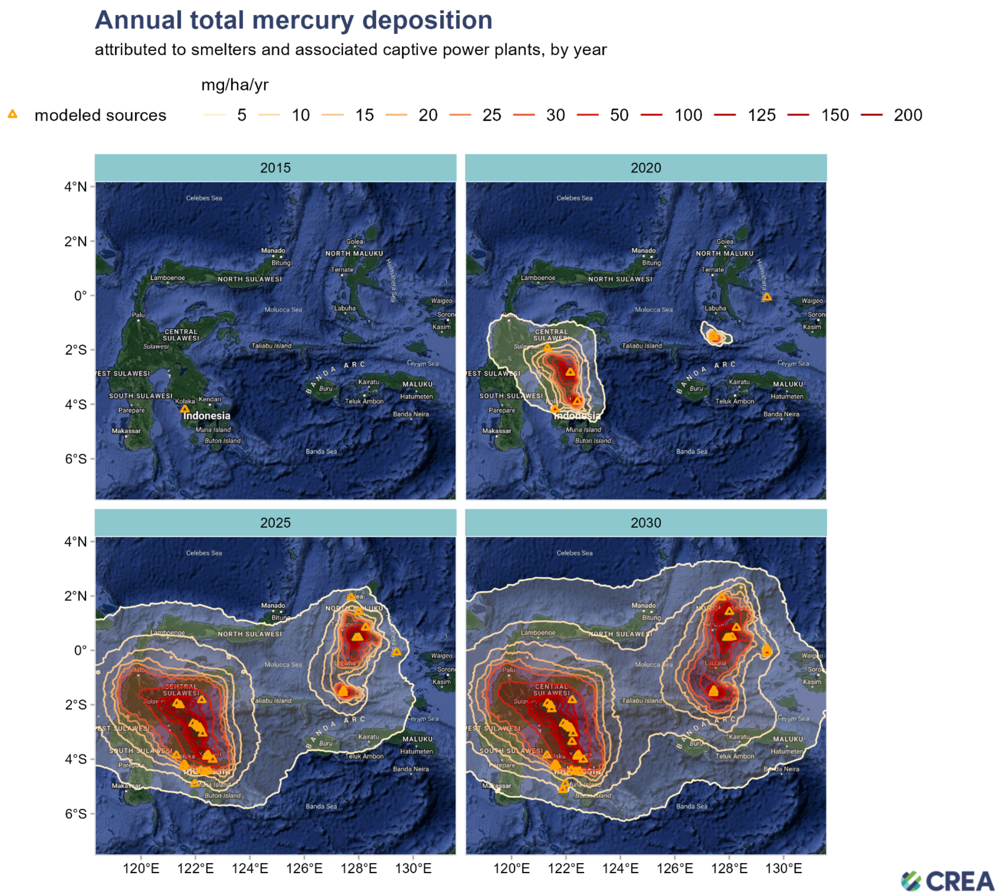


Figure 49. Distribution estimates of annual total mercury deposition from the three provinces' metal smelting facilities and captive power plants from 2015 to 2030

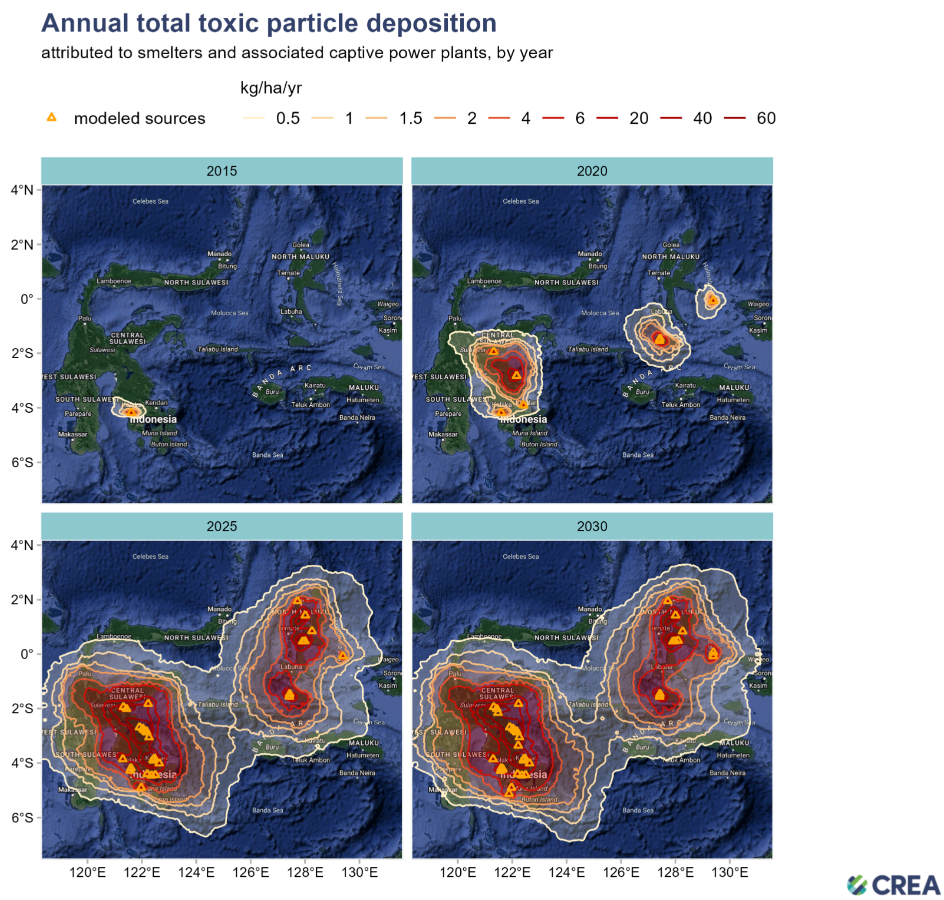


Figure 50. Distribution estimates of annual total toxic particle deposition from the three provinces' metal smelting facilities and captive power plants from 2015 to 2030

The following Figure 51 provides a summary of the projected increase of mercury and particulate matter deposition between 2020 and 2030, as well as the extent of impacts on the different land categories, namely cropland, forest, freshwater, ocean, and other surfaces.

As much as 3,700 kg of mercury and 715,000 tons of particulate matter will be deposited annually across Sulawesi and North Maluku in 2030. Annual deposition would increase by nearly 6-fold for mercury in a decade as compared to the 2020 value, and by over 10-fold for particulate matter.

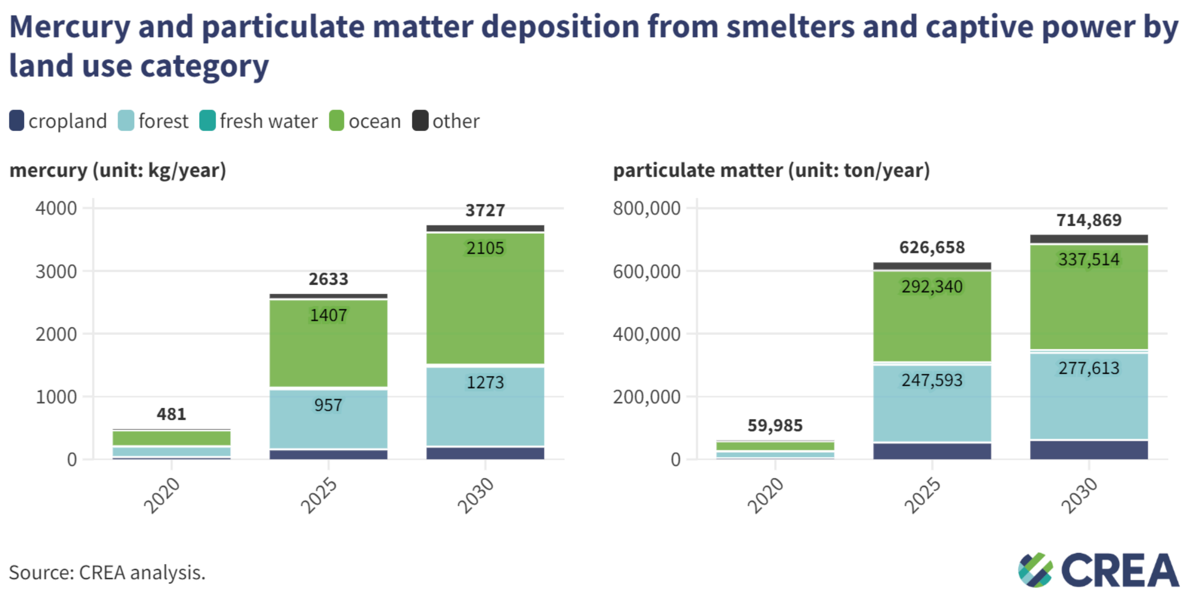


Figure 51. Annual deposition of mercury and particulate matter from smelters and captive power by land use category

Not only rich in mineral resources, the islands of Sulawesi, North Maluku, and Maluku have been long recognised for its richness in biodiversity. The region is a significant part of the Coral Triangle, one of the most diverse and biologically complex marine ecosystems on the planet (CTI-CFF, 2009). The most recent total of forest and marine conservation areas designated by the Ministry of Environment and Forestry for the islands of Sulawesi, North Maluku, and Maluku is 5 million hectares or 18% of Indonesia's nationwide total in 2022 (BPS, 2024).

Although actual uptake and biomagnification strongly depend on local conditions, the predicted mercury deposition rates are greatly concerning. Assessment of current impacts is urgent, as well as the immediate implementation of measures to capture mercury emissions. Figure 52 and 53 below list protected areas with the highest mercury and particulate matter deposition projected in 2030.

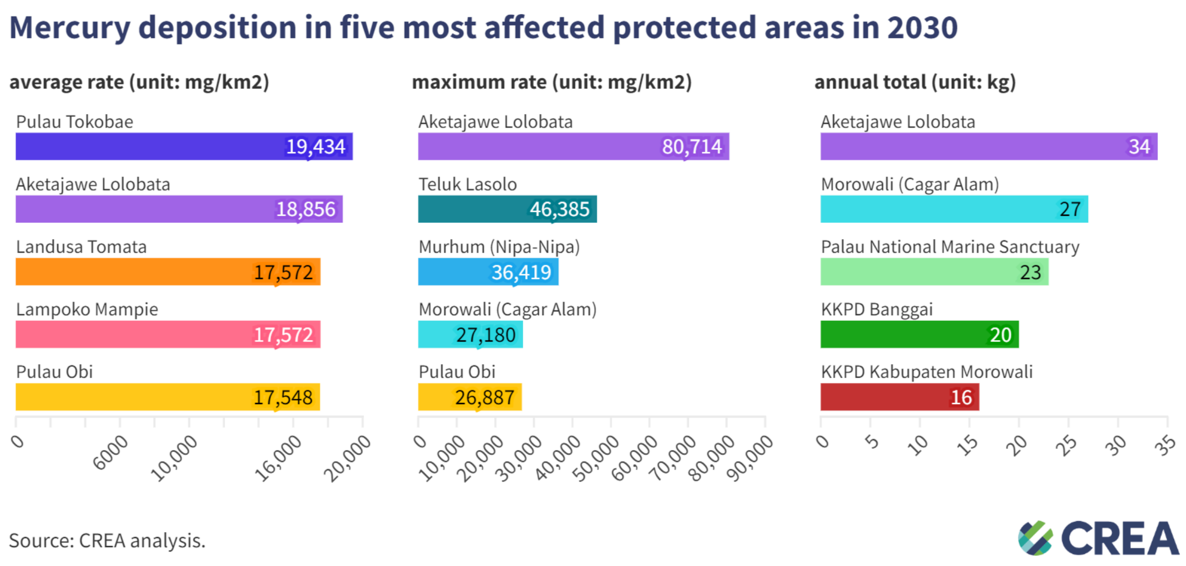


Figure 52. Mercury deposition in five most affected protected areas in 2030

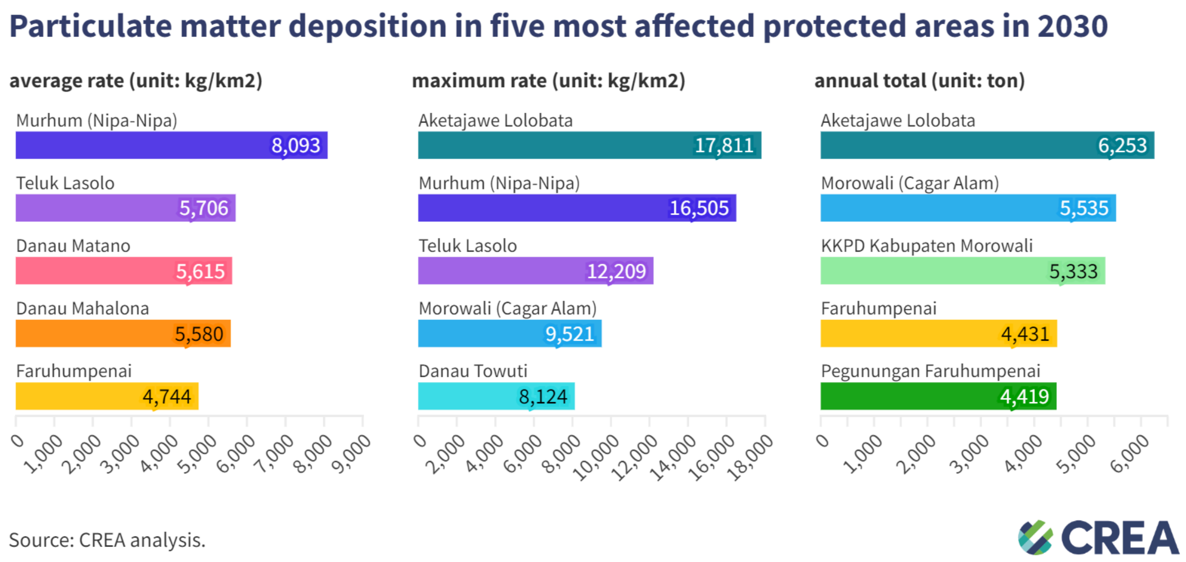


Figure 53. Particulate matter deposition in five most affected protected areas in 2030

Conclusions and recommendations

Nickel downstreaming has been in the public spotlight, especially considering environment, social, and governance (ESG) issues, falling prices due to nickel supply surpluses of Indonesian nickel, and potential changes in nickel policy as the country transitions to the new administration.

The current administration led by President Joko Widodo has emphasised domestic value added as the main drive for the downstreaming policy. Exports value has skyrocketed, but there are questions on whether the strategy truly and sustainably benefits the national economy. The domestically produced nickel products are used as raw materials for further processing into products that would end up being sold back to Indonesia. Contribution to the local economy seems limited as well, considering incentives and tax holidays offered to the nickel industry, not to mention wage gaps between local and foreign workers.

In this analysis, CREA and CELIOS seized the opportunity to conduct an assessment of the impacts of nickel downstreaming policy in the key three provinces — Central Sulawesi, Southeast Sulawesi, and North Maluku. The analysis was built to provide a comprehensive overview of economic impacts, as well as health and environmental impacts from the emissions linked to metal processing and captive power.

Despite the limited availability of emissions data, CREA was able to obtain an estimate on the health and economic burden caused by air pollution linked to nickel processing centres in Central Sulawesi, Southeast Sulawesi and North Maluku, directly impacting communities living near and around these islands. Analysis shows that full operation of nominal production capacity would result in 5,000 deaths and an economic burden of USD 3.42 billion per year due to health impacts related to air pollution.

CREA and CELIOS recommend the following measures to mitigate further environmental and economic losses linked to the current state of nickel industry development:

1. **Revise regulations related to captive coal power plants in industrial areas** by freezing plans to build new CFPP, and providing incentives for renewable energy electricity on-grid and off-grid to nickel processing industrial areas.
2. **Immediately include plans for early retirement of captive coal power plants in the JETP and government plans in the electricity sector**, namely the General National Electricity Plan (RUKN) and the Electricity Supply Business Plan (RUPTL).

3. **Limit new smelter permits in industrial areas and evaluate all standards related to waste management, flue gas emissions control, and work safety** for all new and existing smelter companies. Internationally recognized standards and relevant industry-wide standards should be considered in considering safe thresholds and setting regulatory limits.
4. **Increase contributions in the form of royalties and profit sharing funds (*Dana Bagi Hasil*) from smelter and nickel mining activities to the regions.** Apart from that, the government can implement special taxes to compensate for losses and damages to the environment and public health around the smelter factory area.
5. **Foster active involvement of the local communities through frequent public discussions and implementation of communication, education and public awareness programs.** Local communities have the right to fully understand the impacts, and should be brought into all stages of decision-making.
6. **Establish transparency and accountability of company-level emissions data and environmental permits,** including all results of monitoring and evaluation. When the data is well established and is made public, policymakers would be able make informed decisions and maintain public trust. Most importantly, it would also incentivise the industry as a whole, to take accountability and showcase mitigation efforts and commitments in sustainable practices.
7. **Strengthen local governance** by involving the Local Government in monitoring smelter activities, granting access to all smelter company planning documents, and responding to public complaints.
8. **Prepare a roadmap and the necessary technical policies to diversify the local economy into non-extractive sectors** that provide greater value added and more sustainable for long-term growth.
9. **Establish stringent ESG requirements in the financial sector.** Banks should avoid financing companies that fail to meet standards for environmental and labour protection, and integrate ESG disclosure to demonstrate operational integrity. The Financial Services Authorities or OJK should exclude captive coal power plants in the Green Taxonomy revision.
10. **Foster Indonesia's nickel industry by diversifying the processed market with high-standard nickel commodities to stabilise selling prices**, particularly in response to the US Inflation Reduction Act (2022) and the European Union Critical Mineral Law.
11. **Consistently develop an integrated domestic nickel supply chain to accelerate the national deployment of renewables and electric transportation** by inviting investments that apply advanced and environmentally conscious technologies.

12. **Reform fiscal incentives priorities by including the battery recycling industry, instead of the current sole focus on the nickel mining and processing industry.** This would increase the use of recycled transition minerals for Energy Saving Storage (ESS) and other uses in renewables technologies, which support efficient use and help secure long-term availability of nickel reserves in Indonesia.

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Lampiran

Appendix A1 - Emissions inventory inputs and assumptions

Table A1a. *Flue gas volumes and concentrations*

Variable	Value		
Flue Gas Volume (FGV)			
Captive power, coal (corrected at 7% O_2)	3,411 Nm^3/MWh (40% thermal efficiency) 3.411 Nm^3/h/kW		
Diesel generator	3,241 Nm^3/MWh (35% thermal efficiency) 3.241 Nm^3/h/kW		
Smelters	30,443 Nm^3/t 3.475 Nm^3/h/tpa		
Flue Gas Concentration (FGC)			
Captive power, coal (Permen LHK NOMOR P.15/MENLHK/SETJEN/KUM.1/4/2019; measurement condition 25°C, 1 atm, 7% O2) Unit: mg/Nm^3	Before 2019 NO_x, 550 SO_2, 550 PM, 100 Hg, 0.03	After 2019 NO_x, 200 SO_2, 200 PM, 50 Hg, 0.03	
Captive power, coal (measurement data summary, corrected to 7% O_2) Unit: mg/Nm^3	12 CFPPs in IMIP NO_2, 228 (180-276) SO_2, 220 (150-291) PM, 130 (54-206)		
Diesel generator (Permen LHK NOMOR 11 TAHUN 2021; measurement condition 25°C, 1 atm, 15% O2) Unit: mg/Nm^3	100-500 kW NO_x, 3400 SO_2, - PM, - CO, 170	501-1000 kW NO_x, 1850 SO_2, 160 PM, 95 CO, 77	1001-3000 kW NO_x, 2300 SO_2, 150 PM, 90 CO, 168
Smelters - Dryer, furnace or boiler (measurement data summary, corrected to 10% O_2) Unit: mg/Nm^3	36 Dryers in IMIP NO_2, 440 (182-698) SO_2, 143 (4-253) PM, 130 (50-710)	32 Furnaces in IMIP NO_2, 105 (15-226) SO_2, 105 (42-167) PM, 1787 (921-2653)	

Variable	Value
Smelters - Aluminium production, primary	NO_x, 1 (0.5-2) kg/Mg aluminium SO_x, 4.5 (0.8-25) kg/Mg aluminium TSP, 0.9 (0.2-4) kg/Mg aluminium PM_{10}, 0.7 (0.17-3.2) kg/Mg aluminium $PM_{2.5}$, 0.6 (0.13-2.4) kg/Mg aluminium
Smelters - Ferroalloys production	TSP, 1,000 (100-10,000) g/Mg alloy PM_{10}, 850 (85-8,500) g/Mg alloy $PM_{2.5}$, 60 (600-6,000) g/Mg alloy
Smelters - Gas use as process fuel - Public electricity and heat production, Public power - Gas turbines, Gaseous fuels	NO_x, 48 (28-68) g/GJ SO_x, 0.281 (0.169-0.393) g/GJ TSP, 0.2 (0.05-0.8) g/GJ PM_{10}, 0.2 (0.05-0.8) g/GJ $PM_{2.5}$, 0.2 (0.05-0.8) g/GJ Hg, 0.002857142857 (0.01-1) mg/GJ
Smelters - Gas use as process fuel - Public electricity and heat production, Public power - Gas turbines, Gas Oil	NOx, 398 (239-557) g/GJ SOx, 46.5 (4.65-465) g/GJ TSP, 1.95 (0.65-5.85) g/GJ PM10, 1.95 (0.65-5.85) g/GJ PM2.5, 1.95 (0.65-5.85) g/GJ Hg, 0.053 (0.005-0.53) mg/GJ

Table A1b. *Production capacity of metal processing companies operating in the three evaluated provinces; Central Sulawesi, Southeast Sulawesi, and North Maluku, along with commodity type and Commercial Operations Date (COD)*

Central Sulawesi

Company	Metal commodity	Metal category	Output (ton per annum, tpa, assuming gross weight)	COD
Hua Chin Aluminum Indonesia	Aluminium		500,000	2023
Indonesia Ruipu Nickel Chrome Alloy	Iron & steel		1,146,000	2018
Dexin Steel Indonesia	Iron & steel		3,250,000	2020
Indonesia Tsingshan Stainless Steel	Iron & steel		1,800,000	2021
Cahaya Smelter Indonesia	Nickel	FeNi	150,000	2020
Hengjaya Nickel Industry	Nickel	FeNi	150,000	2021
Gunbuster Nickel Industry	Nickel	FeNi	1,800,000	2021
QMB New Energy Materials Indonesia	Nickel	MHP	20,000	2022
Ang and Fang Brother	Nickel	FeNi	130,508	2023
Sulawesi Resources	Nickel	FeNi	152,400	2023
Wanxiang Nickel Indonesia	Nickel	FeNi	351,018	2023
Fajar Metal Industry	Nickel	Ni Sulfide	60,000	2024
Teluk Metal Industry	Nickel	Ni Sulfide	60,000	2024
Ocean Sky Metal Industry	Nickel	FeNi	380,000	2025
Vale Indonesia (Bahodopi Nickel Smelting Indonesia)	Nickel	FeNi	73,000	2025
Sulawesi Mining Investment	Nickel	NPI	300,000	2015
COR Industri Indonesia	Nickel	NPI	92,400	2017
Tsingshan Steel Indonesia	Nickel	NPI	507,000	2017
Indonesia Ruipu Nickel Chrome Alloy	Nickel	NPI	307,500	2018

Company	Metal commodity	Metal category	Output (ton per annum, tpa, assuming gross weight)	COD
Bukit Smelter Indonesia	Nickel	NPI	140,500	2020
Ranger Nickel Industry	Nickel	NPI	150,000	2021
Lestari Smelter Indonesia	Nickel	NPI	300,000	2021
Walsin Nickel Industrial Indonesia	Nickel	NPI	300,000	2021
Indonesia Guang Ching Nickel and Stainless Steel Industry	Nickel	NPI	600,000	2021
Indonesia Tsingshan Stainless Steel	Nickel	NPI	600,000	2021
Zhao Hui Nickel	Nickel	NPI	50,000	2023
Arthabumi Sentra Industri	Nickel	NPI	72,965	2023
Anugrah Tambang Sejahtera	Nickel	NPI	144,000	2023

Southeast Sulawesi

Company	Metal commodity	Metal category	Output (ton per annum, tpa, assuming gross weight)	COD
Vale Indonesia (Pomalaa)	Cobalt		15,000	2026
Obsidian Stainless Steel	Iron & steel		3,000,000	2022
Aneka Tambang (Pomalaa)	Nickel	FeNi	90,000	2010
Virtue Dragon Nickel Industry	Nickel	FeNi	1,000,000	2021
Obsidian Stainless Steel	Nickel	FeNi	2,200,000	2022
Ceria Nugraha Indotama	Nickel	FeNi	252,728	2023
SBC Prime Metal	Nickel	FeNi	200,000	2025
Surya Saga Utama	Nickel	FeNi	302,506	2025
Adhikara Cipta Mulia	Nickel	MHP	76,500	2025

Company	**Metal commodity**	**Metal category**	**Output (ton per annum, tpa, assuming gross weight)**	**COD**
Vale Indonesia (Pomalaa)	Nickel	MHP	120,000	2026
Kinlin Nickel Industri	Nickel	NPI	17,000	2021
Mapan Asri Sejahtera	Nickel	NPI	21,531	2023
Bintang Smelter Indonesia	Nickel	NPI	40,000	2023
Mahkota Konweeha	Nickel	NPI	62,000	2023
Artha Mining Industry	Nickel	NPI	200,000	2023
Macika Mineral Industri	Nickel	NPI	276,264	2023
Integra Mining Nusantara	Nickel	NPI	285,220	2024
Sambas Minerals Mining	Nickel	NPI	104,544	2025
Asia Mining Minerals	Nickel	NPI	160,712	2025
Genba Multi Mineral	Nickel	NPI	500,000	2025

North Maluku

Company	Metal commodity	Metal category	Output (ton per annum, tpa, assuming gross weight)	COD
Obi Nickel Cobalt	Cobalt		75,000	2024
Weda Bay Nickel	Iron & steel		300,000	2020
Karunia Mitra Abadi	Iron & steel		601,920	2023
Megah Surya Pertiwi (1620)	Nickel	FeNi	198,158	2016
Megah Surya Pertiwi (1219)	Nickel	FeNi	66,053	2017
Wanatiara Persada	Nickel	FeNi	161,740	2019
Weda Bay Nickel	Nickel	FeNi	180,000	2020

Aneka Tambang (Expansion)	Nickel	FeNi	64,655	2021
Yashi Indonesia Investment	Nickel	FeNi	300,000	2021
Youshan Nickel Indonesia	Nickel	FeNi	300,000	2021
Angel Nickel Industry	Nickel	FeNi	637,500	2022
Sunny Metal Industry	Nickel	FeNi	400,000	2023
Obi Nickel Cobalt	Nickel	FeNi	65,000	2024
First Pasific Mining	Nickel	FeNi	30,000	2025
Perkasa Metal Industry	Nickel	FeNi	150,000	2025
Fajar Bhakti Lintas Nusantara (Expansion)	Nickel	FeNi	363,655	2025
Halmahera Jaya Feronikel	Nickel	FeNi	780,000	2025
Halmahera Persada Lygend	Nickel	MHP	96,000	2021
Huayue Nickel Cobalt	Nickel	MHP	115,000	2021
Huake Nickel Indonesia	Nickel	Ni Matte	58,000	2023
Fajar Bhakti Lintas Nusantara	Nickel	NPI	120,000	2015
Alchemist Metal Industry	Nickel	NPI	1,600,000	2022
Aneka Tambang (Niterra Haltim)	Nickel	NPI	160,000	2023
Teka Mining Resources	Nickel	NPI	300,000	2023

Table A1c. *Power generation capacity of captive power plants by fuel source, mapped to companies operating in the three evaluated provinces; Central Sulawesi, Southeast Sulawesi, and North Maluku*

Company	**Power generation capacity (MW)**				
	Coal	**PLN**	**Diesel**	**Gas**	**Hydro**
Arthabumi Sentra Industri	15				
COR Industri Indonesia	15				
Sulawesi Resources	60				
Metal Smeltindo Selaras	130				
Tsingshan Steel Indonesia	130				

Company	Power generation capacity (MW)				
	Coal	PLN	Diesel	Gas	Hydro
Wanxiang Nickel Indonesia	150				
Morowali Power Mandiri	250				
Indonesia Guang Ching Nickel and Stainless Steel Industry	300				
Lestari Smelter Indonesia	350				
Walsin Nickel Industrial Indonesia	350				
Hua Chin Aluminum Indonesia	380				
Sulawesi Mining Investment	510				
Indonesia Tsingshan Stainless Steel	1400				
Gunbuster Nickel Industry	2295				
Ang and Fang Brother		100	10		
Anugrah Tambang Sejahtera		146			
Bukit Smelter Indonesia					
Cahaya Smelter Indonesia					
Dexin Steel Indonesia					
Fajar Metal Industry					
Hengjaya Nickel Industry					
Indonesia Ruipu Nickel Chrome Alloy					
Ocean Sky Metal Industry					
Oracle Nickel Industry					
QMB New Energy Materials Indonesia					
Ranger Nickel Industry					
Teluk Metal Industry					

Company	Power generation capacity (MW)				
	Coal	PLN	Diesel	Gas	Hydro
Vale Indonesia (Bahodopi Nickel Smelting Indonesia)				500	
Zhao Hui Nickel					
Karunia Mitra Abadi	6				
Aneka Tambang (Niterra Haltim)	24				
First Pacific Mining	41				
Megah Surya Pertiwi (1620)	120				
Wanatiara Persada	150				
Megah Surya Pertiwi (1219)	165				
Perkasa Metal Industry	206				
Huake Nickel Indonesia	250				
Huayue Nickel Cobalt	250				
Libai Indonesia Metal Co	250				
Weda Bay Nickel	250				
Yashi Indonesia Investment	250				
Youshan Nickel Indonesia	250				
Fajar Bhakti Lintas Nusantara	300				
Halmahera Persada Lygend	360				
Sunny Metal Industry	380				
Angel Nickel Industry	760				
Halmahera Jaya Feronikel	1074				
Indonesia Weda Bay Industrial Park	1140				
Obi Nickel Cobalt	1520				
Alchemist Metal Industry	2202				

Company	Power generation capacity (MW)				
	Coal	PLN	Diesel	Gas	Hydro
Aneka Tambang (Expansion)			96		
Fajar Bhakti Lintas Nusantara (Expansion)			300		
Teka Mining Resources			14		
Trimegah Bangun Persada					
Kinlin Nickel Industri	2		2		
Mapan Asri Sejahtera	3				
Asia Mining Minerals	24		2		
Surya Saga Utama	30		10		
Aneka Tambang (Pomalaa)	60		100		
Virtue Dragon Nickel Industry	530				
Genba Multi Mineral	700				
Obsidian Stainless Steel	1780				
Adhikara Cipta Mulia			1		
Artha Mining Industry			2		
Bintang Smelter Indonesia		100			
Ceria Metalindo Prima					
Ceria Nugraha Indotama		350			
Integra Mining Nusantara			4		
Macika Mineral Industri		3			
Mahkota Konweeha			3		
SBC Prime Metal		120			
Sambas Minerals Mining			3		

Appendix A2 - Air pollution-related health impacts references

Table A2a. *Input parameters and data used in estimating physical health impacts*

Age group	Effect	Pollutant	Conc. response function	Conc. change	No-risk threshold	Reference	Incidence data
1–18	New asthma cases	NO_2	1.26 (1.10 – 1.37)	10 ppb	2 ppb	Khreis et al. (2017)	Achakulwisut et al. (2019)
0–17	Asthma emergency room visits	$PM_{2.5}$	1.025 (1.013 – 1.037)	10 µg/m^3	6 µg/m^3	Zheng et al. (2015)	Anenberg et al. (2018)
18–99	Asthma emergency room visits	$PM_{2.5}$	1.023 (1.015 – 1.031)	10 µg/m^3	6 µg/m^3	Zheng et al. (2015)	Anenberg et al. (2018)
New born	Preterm birth	$PM_{2.5}$	1.15 (1.07 – 1.16)	10 µg/m^3	8.8 µg/m^3	Sapkota et al. (2012)	Chawanpaiboon et al. (2018)
20–65	Work absence	$PM_{2.5}$	1.046 (1.039 – 1.053)	10 µg/m^3	N/A	WHO (2013)	EEA (2014)
0–4	Deaths from lower respiratory infections	$PM_{2.5}$	IHME (2020)		5.8 µg/m^3	IHME (2020)	IHME (2020)
25–99	Deaths from noncommunicable diseases, disaggregated by cause, and from lower respiratory infections	$PM_{2.5}$	Burnett et al. (2018)		2.4 µg/m^3	Burnett et al. (2018)	IHME (2020)
25–99	Disability caused by diabetes, stroke and chronic	$PM_{2.5}$	IHME (2020)		2.4 µg/m^3	Burnett et al. (2018)	IHME (2020)

Age group	Effect	Pollutant	Conc. response function	Conc. change	No-risk threshold	Reference	Incidence data
	respiratory disease						
25–99	Premature deaths	NO_2	1.02 (1.01 – 1.04)	10 µg/m^3	4.5 µg/m^3	Huangfu & Atkinson (2020); NRT from Stieb et al. (2021)	IHME (2020)
25–99	Premature deaths	SO_2	1.02 (1.01–1.03)	5 ppb	0.02 ppb	Krewski et al. (2009)	IHME (2020)

Note: Numeric values in the column "Concentration-response function" refer to odds ratio corresponding to the increase in concentrations given in the column "concentration change." Literature references indicate the use of a non-linear concentration-response function. No-harm threshold refers to a concentration below which the health impact is not quantified, generally because the studies on which the function is based did not include people with lower exposure levels. Data on concentration-response relationships do not exist for all geographies, so a global risk model is applied to all cities. Incidence data are generally unavailable at the city level so national averages have to be applied.

Table A2b. *Input parameters and data used to estimate economic costs of health impacts*

Outcome	Valuation at world average GDP/GNI per capita (2017 int. USD)	Valuation in Indonesia (current USD)	(current IDR)	Reference
Work absence (sick leave days)	85	22	335,300	EEA (2014)
Number of children suffering from asthma due to pollution exposure (increased prevalence)	1,077	274	4,228,000	Brandt et al. (2012)
Deaths	2,637,000	663,900	10,260,000,000	Viscusi & Masterman (2017)
Deaths of children under 5	5,273,000	1,328,000	20,510,000,000	OECD (2012)
Asthma emergency room visits	232	59	911,800	Brandt et al. (2012)
Preterm births	107,700	27,370	422,800,000	Trasande et al. (2016)
Years lived with disability	28,480	7,171	110,800,000	Birchby et al. (2019)

Table A2c. *Air Pollutant Control costs estimates applied to smelters and captive power*

Control technology	Controlled pollutant	Capital cost, one-time installation (current USD/kW)	Capital cost, one-time installation (current IDR/kW)	Operations and maintenance, annual (current USD/kW)	Operations and maintenance, annual (current IDR/kW)
Assumed for captive coal power plants					
Flue Gas Desulfurization (FGD)	SO_2	69	1,026,000	1.21	17,913
Selective Catalytic Reduction (SCR), with limestone	NO_x	58	860,000	0.87	12,957
	Combined	**127**	**1,886,000**	**2.08**	**30,870**

Control technology	Controlled pollutant	Capital cost, one-time installation (current USD/ton nickel output)	Capital cost, one-time installation (current IDR/ton nickel output)	Operations and maintenance, annual (current USD/ton nickel output)	Operations and maintenance, annual (current IDR/ton nickel output)
Assumed for smelters **Note: CFPPs assumed to be equipped with particle control systems**					
Electrostatic precipitator (ESP)	PMs	19	294,000	2	29,000
	Combined	**19**	**294,000**	**2**	**29,000**

Appendix A3 - APC cost of investment and operations, and the reduced air pollution economic costs with APC installation

Unit: USD million; Economic burden - APC, combines costs of APC one-time investment and annual operating costs, and the reduced economic burden with APC installation

Year	Province	APC investment, one time at installation	APC operation, annual	Reduced economic burden with APC	Economic burden - APC	Economic burden - BAU
2020	Central Sulawesi	236,25	5,91	23,71	265,87	82,45
2021		56,31	7,32	27,30	90,93	106,95
2025		332,60	24,46	197,81	554,86	666,14
2030		0,00	27,40	233,38	260,78	796,61
2035		0,00	27,40	262,37	289,78	895,39
2020	National	371,26	9,19	38,30	418,75	137,30
2021		178,50	12,91	48,49	239,90	188,99
2025		980,82	64,01	522,58	1567,41	2371,55
2030		0,00	86,08	700,66	786,74	3119,41
2035		0,00	86,08	787,89	873,97	3507,20
2020	North Maluku	58,34	1,88	5,79	66,02	24,17
2021		70,74	3,34	9,35	83,43	42,63
2025		368,40	20,84	98,51	487,75	550,04
2030		0,00	34,63	135,79	170,42	706,26
2035		0,00	34,63	152,80	187,42	794,58
2020	Southeast Sulawesi	76,66	1,41	8,80	86,86	30,68
2021		51,46	2,25	11,83	65,53	39,41
2025		279,82	18,72	226,26	524,80	1155,37
2030		0,00	24,05	331,49	355,54	1616,53
2035		0,00	24,05	372,72	396,77	1817,23