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Tackling the maize haze

How protein diversification can clean up Thailand's air

madre brava

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We work on brave strategies and campaigns to rebalance our food system, working with diverse groups in civil society, government and the food industry to achieve a food system that works for everyone.

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Asia Protein Transition Platform

ARE launched the Asia Protein Transition Platform in December 2022, in collaboration with five founding investors representing USD 3 trillion in assets. The platform set a 2030 vision and goals for protein transition in Asia, along with investor expected disclosures for companies to move towards more responsible and sustainable proteins.

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Executive Summary

Air pollution is a well-known public health issue in Thailand. Public and media attention is particularly focused on poor air quality during agricultural burning season, when dangerous particulate matter pollution reaches its highest levels. But the impact of animal agriculture on the burning is significantly underdiscussed.

This report demonstrates the effect of animal agriculture on air pollution in Thailand, showing a link between agricultural burning and animal feed production. To combat this, it proposes shifting 50% of Thailand's meat and seafood protein production to plant-based proteins by 2050, modelling the associated fall in air pollution and premature deaths.

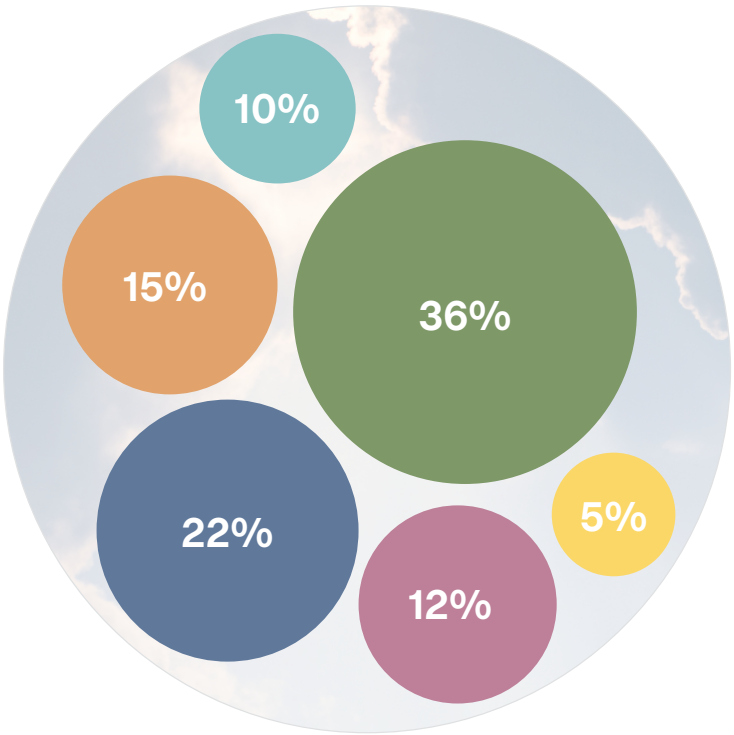
This protein production shift could avoid more than 100,000 premature deaths, and bring huge co-benefits to the economy and jobs in Thailand.

What is polluting the air Thai people breathe?

Thailand has been experiencing problems with air quality for years. One of the main pollutants is fine particulate matter (PM) with a diameter of less than 2.5 micrometres (PM2.5). There are many sources of PM2.5, including charcoal production, industry and transportation. In 2020, the biggest source of PM2.5 in Thailand was agricultural residue burning, contributing to more than a third of PM2.5 (1).

Sources of PM2.5 in Thailand

Source: Thailand Pollution Control Department (1)

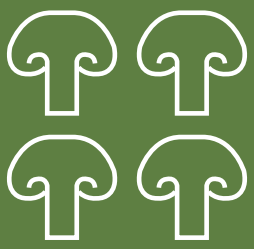


This report confirms that a significant proportion of agricultural burning comes from maize for animal feed production. In 2020, almost all the maize cultivated in Thailand went to animal feed production, with just 0.17% grown for human consumption.

Agricultural burning occurs from December to April every year. Its impact on PM2.5 is exacerbated by the dry season's weather conditions, causing PM2.5 levels to peak in March/April. The PM2.5 level during these months can reach up to 130 micrograms per cubic metre (µg/m^3). That's more than three times the Thai national standard of acceptable PM2.5 for short-term exposure, 37.5 µg/m^3. Apart from increasing the rate of agricultural burning of animal feed crops, the livestock industry is the main driver of other PM2.5 precursors, including ammonia, which comes from animal manure, animal housing, and manure and artificial fertilisers to grow animal feed.

What happens if we don't act?

Agricultural burning is estimated to contribute to more than 34,000 premature deaths annually in Thailand. We projected that the Thai meat and seafood sector will grow to 5.1 million tonnes in 2050 (from 3.9 million tonnes in 2020), driven both by exports and domestic consumption. If the meat and seafood industry grows as forecasted, the number of premature deaths associated with burning residues of maize alone, could reach 361,000 (between 2020 to 2050).

PROBLEM	SOLUTION	IMPACT
 high demand for maize production from meat and seafood industry	 shift 50% of Thailand's meat and seafood protein production to plant-based proteins by 2050	 **100,000+** premature deaths avoided

How does protein diversification mitigate risks from PM2.5?

Thailand has introduced a wide range of policy measures to reduce air pollution, including restricting crop burning. However, the persistent pollution problem has proven that more needs to be done to improve Thai air quality.

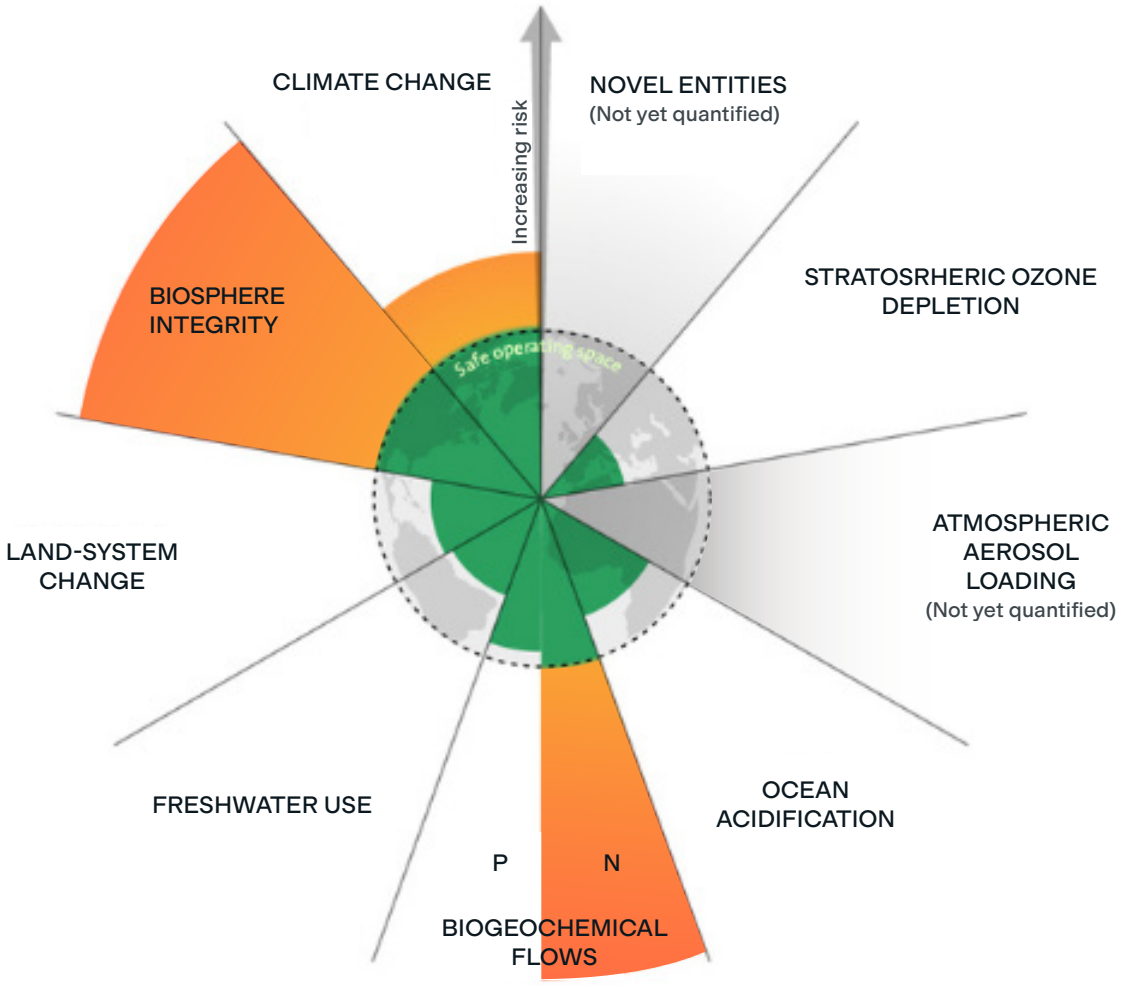
This report offers a long-term solution to address the root cause of agricultural burning of animal feed crops: protein diversification. This means rebalancing protein production in Thailand by introducing more plants to the current system. If 50% of Thai meat and seafood production can be replaced with vegetal protein sources by 2050, it will reduce demand for maize production. In turn, this could avoid more than 100,000 premature deaths related to maize crop burning for animal feed by 2050.

A 50% protein diversification by 2050 offers other benefits for Thailand. Previous research conducted by Madre Brava and Asia Research and Engagement, estimated an additional THB 1.3 trillion (approximately USD 38 billion) in economic value, up to 1.15 million more jobs, a saving of 35.5 million metric tonnes of CO2 emissions per year, and 2.17 million hectares of land.

Background

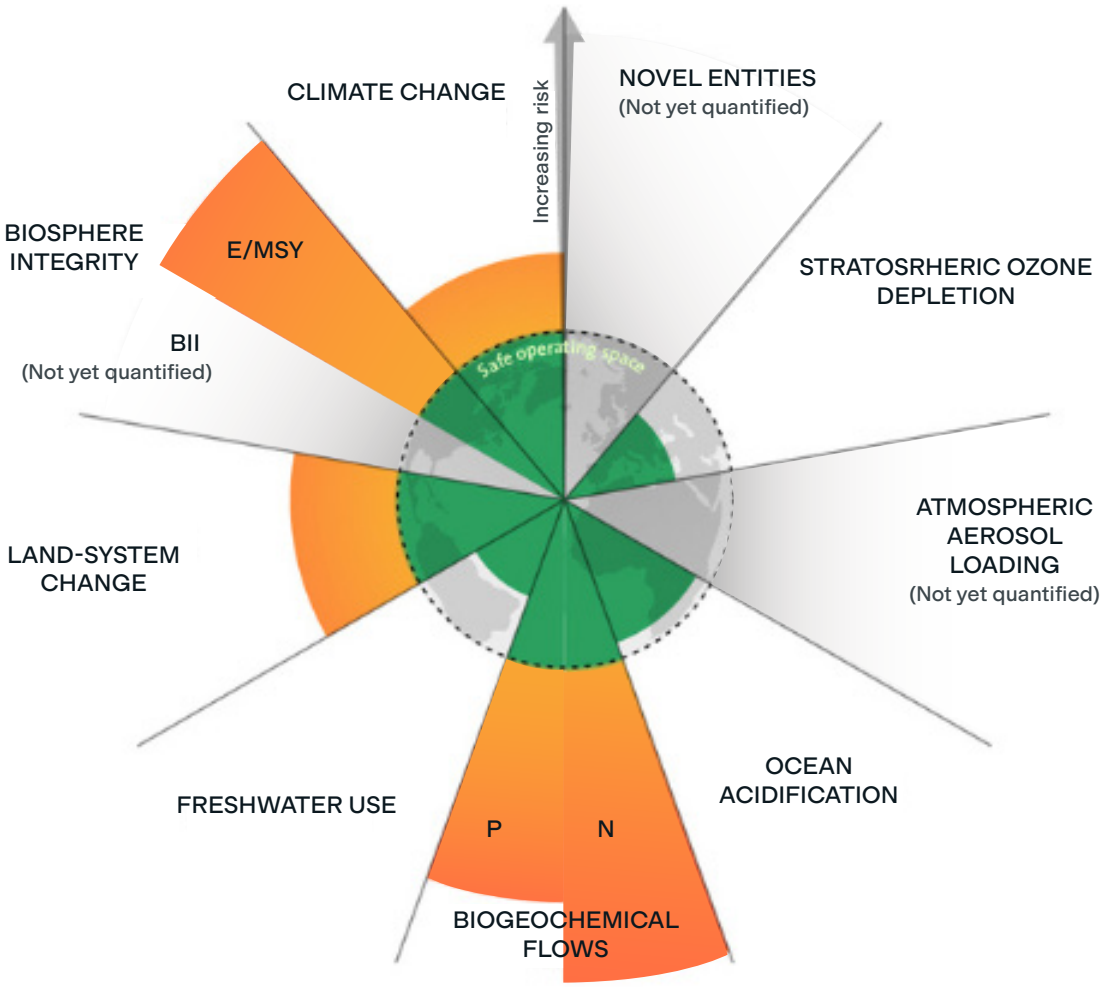
Why is PM2.5 pollution an environmental and human health Issue?

The planetary boundaries framework identified nine processes that are critical for regulating the stability and resilience of the Earth system to maintain life on Earth as we know it (2). Aerosols, or tiny liquid or solid particles suspended in the air, are included as a planetary boundary due to their multiple effects on the Earth system (3). PM2.5 particles, or fine particulate matter with a diameter of less than 2.5 micrometres, are one example.



Planetary Boundaries Framework 2009
7 boundaries assessed, 3 crossed

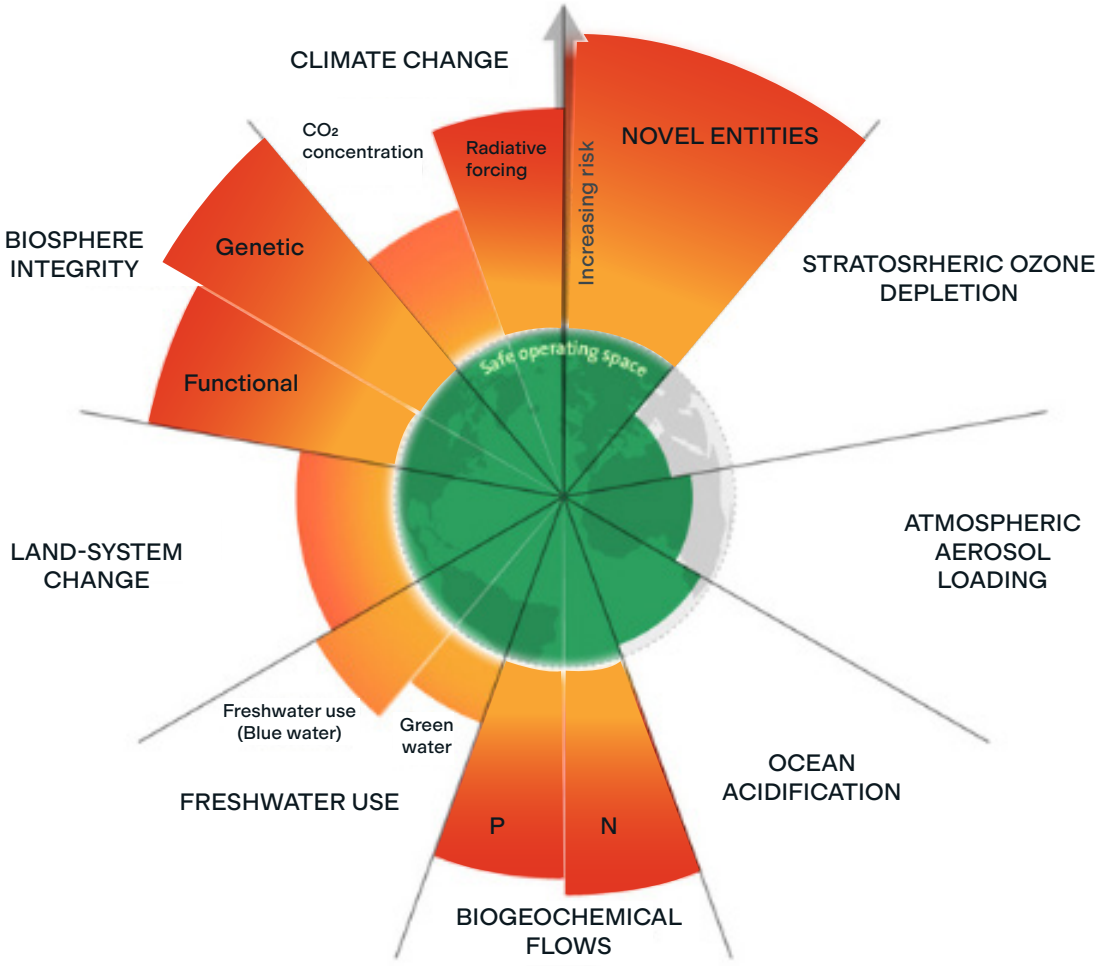
Source: Licenced under CC BY-NC-ND 3.0; Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on (2,3,5)



Planetary Boundaries Framework 2015
7 boundaries assessed, 4 crossed

Source: Licenced under CC BY-NC-ND 3.0; Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on (2,3,5)

They are small enough to penetrate deep into the respiratory system, reaching the lungs and even entering the bloodstream. This can cause serious health problems such as respiratory and cardiovascular diseases, aggravation of asthma, and reduced lung function, and contributes to premature death. It is also particularly harmful because it can remain suspended in the air and transported over long distances by wind, impacting a broad region and population.



Planetary Boundaries Framework 2023

9 boundaries assessed, 6 crossed

Source: Licenced under CC BY-NC-ND 3.0; Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on (2,3,5)

Atmospheric aerosol loading, measured as aerosol optical depth, is one of only three planetary boundaries not transgressed (see 2023 graphic). However due to the impact on human health, a just boundary of 15 µg/m^3 has been proposed, due to a moderate or greater likelihood of harm above this level of exposure (4).

The World Health Organization (WHO) air quality guidelines from 2021 recommend that annual average PM2.5 exposure should stay below 5 µg/m^3, and not exceed 15 µg/m^3 in a 24-hour period (6). However, for areas with high pollution, they suggested interim targets from 1 to 4 as progressive steps to incremental reduction (Table 1). In 2019, the global population was exposed to concentrations higher than 15 µg/m^3 on 70% of the days (7), with exposure to PM2.5 contributing to 4.72 million deaths in 2021, as measured by the global burden of disease (GBD) study (8).

Table 1: WHO Air Quality Guidelines and interim targets for short- and long-term exposure to PM2.5 (in µg/m^3)

Recommendation	Annual	24-hour
Interim target 1	35	75
Interim target 2	25	50
Interim target 3	15	37.5
Interim target 4	10	25
Target	5	15

Source: WHO Global Air Quality Guidelines (6)

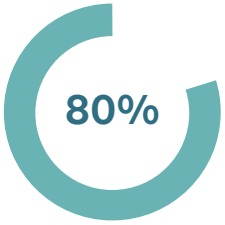
Where does PM2.5 come from?

There are many sources of PM2.5: power generation, transport, industrial activities and agriculture. The food system contributes to several of these categories — agriculture in particular — accounting for 58% of direct human-caused primary PM2.5, totalling 41 mega tonnes (Mt) (9). As well as direct PM2.5 emissions, the food system contributes to secondary production through PM2.5 precursors, including sulphur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOC), and ammonia (NH3). These account for 9%, 13%, 19% and 72% of these human-caused sources respectively.

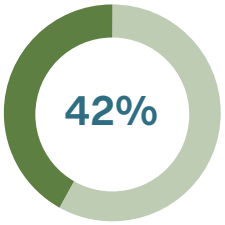
Primary and secondary sources of PM2.5 originating from agriculture include agricultural burning and the production and use of fertiliser, as well as on-farm energy use, grazing, manure management and other sources from on-farm operations, and handling and storage of agricultural products. Agricultural burning includes both the clearing of land for agriculture, and the burning of crop residues at the end of harvest as part of land preparation for the next crop cycle.

Animal agriculture dominates PM2.5 production from the food system. This is due to the disproportionate use of agricultural land, 80% of which is used for livestock production (10), including around 40% of global arable land to grow crops to feed them (11). Animal agriculture contributes significantly to ammonia production through manure management and grazing, alone producing 42% of all human-caused ammonia, a PM2.5 precursor (9,12).

Impact of livestock on land used & ammonia emissions



Agricultural land used for livestock



Human-caused ammonia from livestock

PM2.5 in Thailand

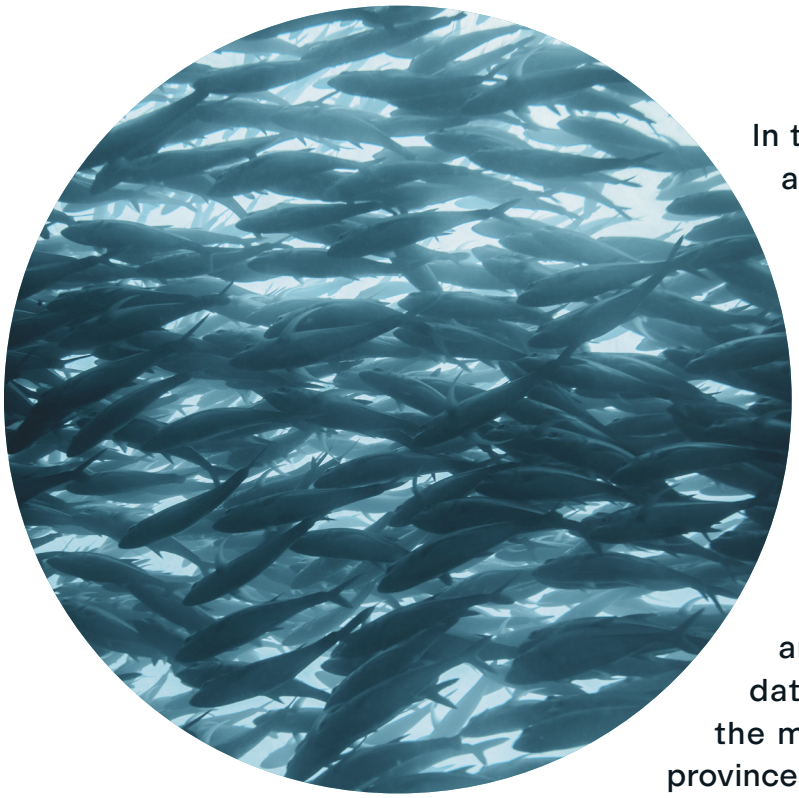
Poor air quality is a longstanding issue in Thailand. The global burden of disease (GBD) study reported that ambient particulate matter pollution attributed to 53,356 premature deaths in Thailand in 2021 (13). While another report using ground level air quality measurements found that long-term exposure to PM2.5 led to an estimated 29,000 premature deaths across 30 provinces in 2021 (14). The Thai national standard for PM2.5 was revised and came into force in 2023. It sets a target of 15 µg/m^3 for annual average exposure and 37.5 µg/m^3 for short-term exposure, to align with the WHO's interim target 3.

Thailand has introduced a wide range of policy measures to reduce air pollution. However, restricting crop residue burning has been challenging. An assessment conducted by the Thai Pollution Control Department with the Climate and Clean Air Coalition (CCAC) found that agricultural residue burning was the largest source of particulate matter in Thailand. Agriculture, forestry and fishing accounted for more than 35% of all PM2.5 in 2020 (1). The first recommendation from this assessment includes reducing open burning of crop residues.

> "Agriculture, forestry and fishing accounted for more than 35% of all PM2.5 in 2020"

Residue burning takes place in the dry season from December to April. Its impact on PM2.5 levels is enhanced by weather conditions and geography. An increase in temperature and reduction in relative humidity in the dry season increases PM2.5 concentration. In addition, temperature inversions (where temperatures increase with height) and narrow hills that reduce air flow, lead to the accumulation and lack of dispersion of PM2.5 (15). Due to existing forest encroachment and the lack of proper management, fires set from burning crop residues can easily spread into forested areas. These forest fires, even if unintended, are a consequence of agricultural production and another source of particulate matter. Long range transboundary transportation of PM2.5 from crop residue burning in neighbouring countries also contributes to the high levels in Thailand.

Analysis

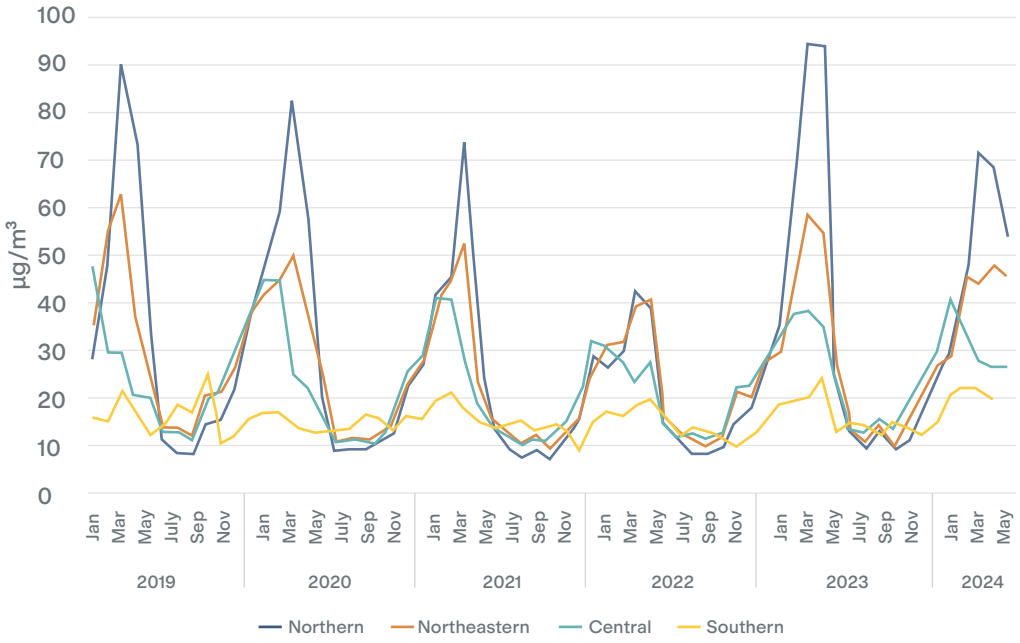


In this study, we limited the scope of this analysis to PM2.5 as it is the most relevant to agricultural production and the meat and seafood sector. We obtained ground level monitoring data, and used this to estimate the number of premature deaths attributed to PM2.5. In addition, we link this to crop residue burning by taking seasonal averages, and discuss the livestock sector's role in fine particulate matter pollution. There are several sources of PM2.5 data and various platforms aggregate these data. However, to ensure consistency in the methodology, we limited the scope to provinces with monitoring stations managed by Thailand's Pollution Control Department.

Long-term exposure to PM2.5

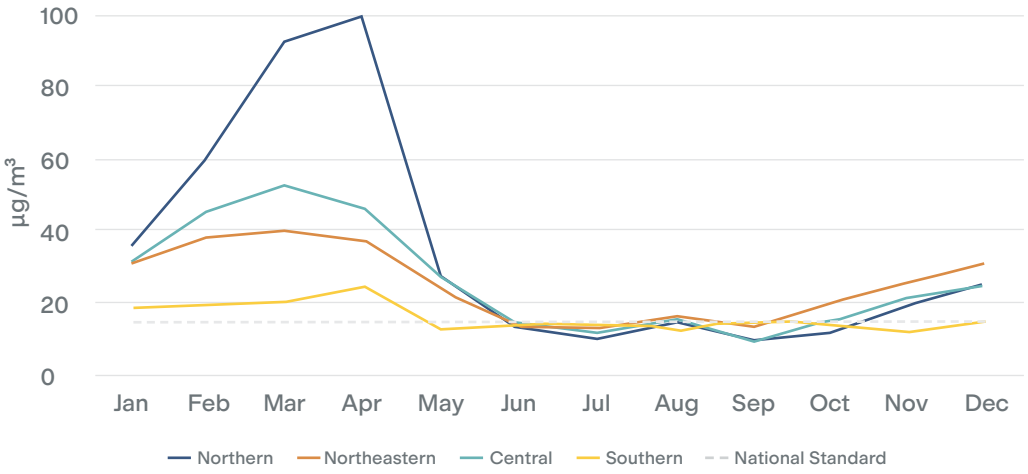
The annual population-weighted mean concentration of PM2.5 across the 35 provinces was 22 µg/m^3 (30 in the Northern, 25 in the Northeastern, 23 in the Central and 16 in the Southern provinces). Figure 1 shows the average monthly PM2.5 levels for 35 provinces in 2019-2024. The effect of agricultural residue burning is reflected in exceptionally high levels during the dry season, from December to April. The timings of the peaks for each region are similar each year but differ in the size of fluctuations. The Southern region does not have such a strong seasonal variation and its PM2.5 levels are generally in line with the national standard of 15 µg/m^3. Rubber and palm are the main crops in this region. The cultivation of these crops may involve burning forests for land clearing but does not result in cyclical crop residue burning. This is because the plantations rotate after 20-30 years, unlike a biannual cycle for rice, sugarcane and maize.

Figure 1: PM2.5 levels in Thailand during 2019-2024, by region.



Source: Thailand Pollution Control Department, ARE analysis

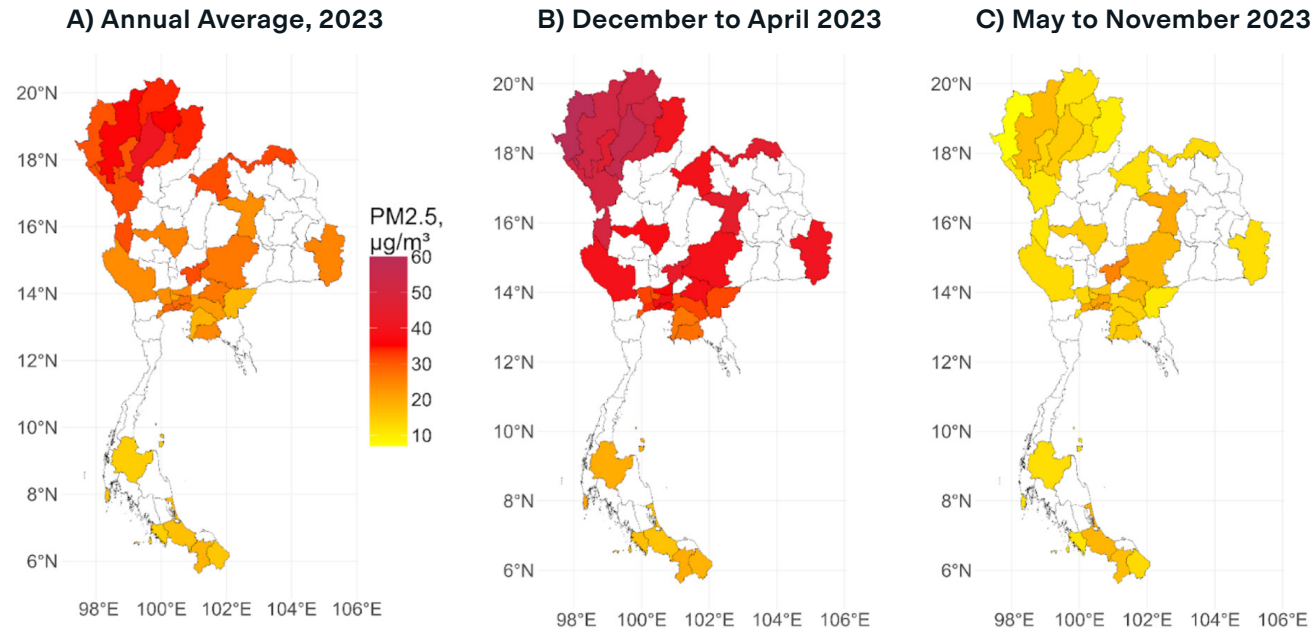
Figure 2: PM2.5 levels in Thailand in 2023, by region.



Source: Thailand Pollution Control Department, ARE analysis

Figure 2 observes that monthly average PM2.5 levels for each region were at or below the national standard and the WHO interim target 3 (15 µg/m³) for the period from June to October 2023, but clearly not below the WHO guideline of 5 µg/m³. **However, between December and April, these levels are significantly elevated, with peaks in March/April that reach two and a half times to six times the national standard, and up to 20 times the ultimate WHO recommended guideline. The Northern region saw the highest PM2.5 levels, corroborating previous media reporting that ranked Chiang Mai as the world's most polluted city during this period.**

Figure 3: Maps of A) average annual PM2.5 levels for 2023, along with averages for the months B) December to April and C) May to November



Source: Thailand Pollution Control Department data, map created by Madre Brava using the ggplot2 and sf packages in R (16-19)

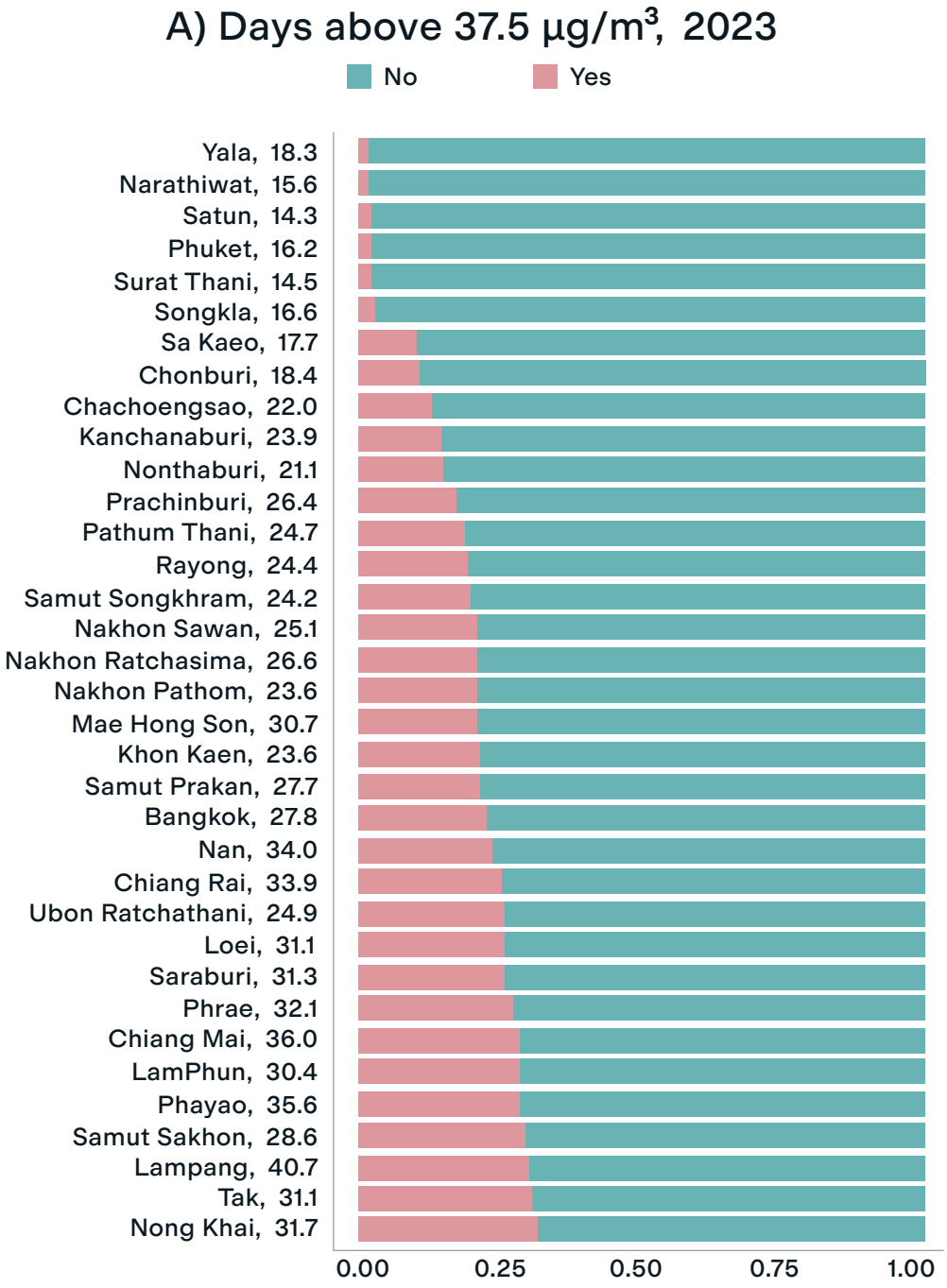
Figure 3 shows the contrast between the agricultural residue burning and non-burning season, with concentrations of PM2.5 between the months of December to April greatly increasing the annual average. However, the annual average across all provinces is relatively high. Only two Southern provinces – Satun and Surat Thani – had average annual PM2.5 concentrations below the Thai National Standard of 15 µg/m³ in 2023, which is still three times higher than the WHO guideline of 5 µg/m³.

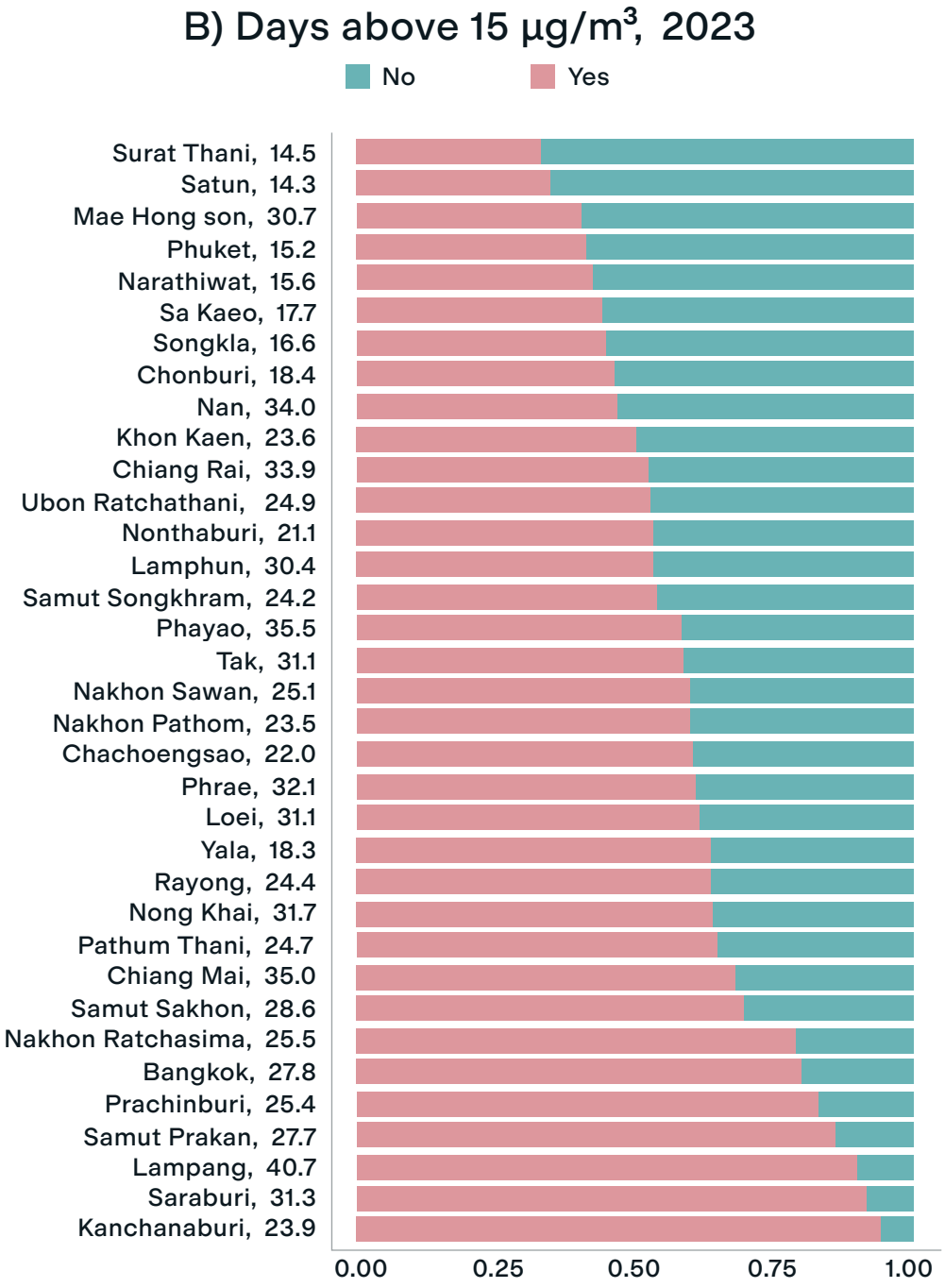
Short-term exposure to PM2.5

The WHO Air Quality Guidelines also provide limits for short-term exposure to PM2.5 over a 24-hour period, with a recommended level of exposure of 15 µg/m³, along with interim targets (6). The Thai National Standard has adopted the interim target 3 of 37.5 µg/m³ of PM2.5. Since the Thai Pollution Departments' monitoring stations record levels daily, we used this data to establish the number of days that levels went above these targets for the 35 provinces.

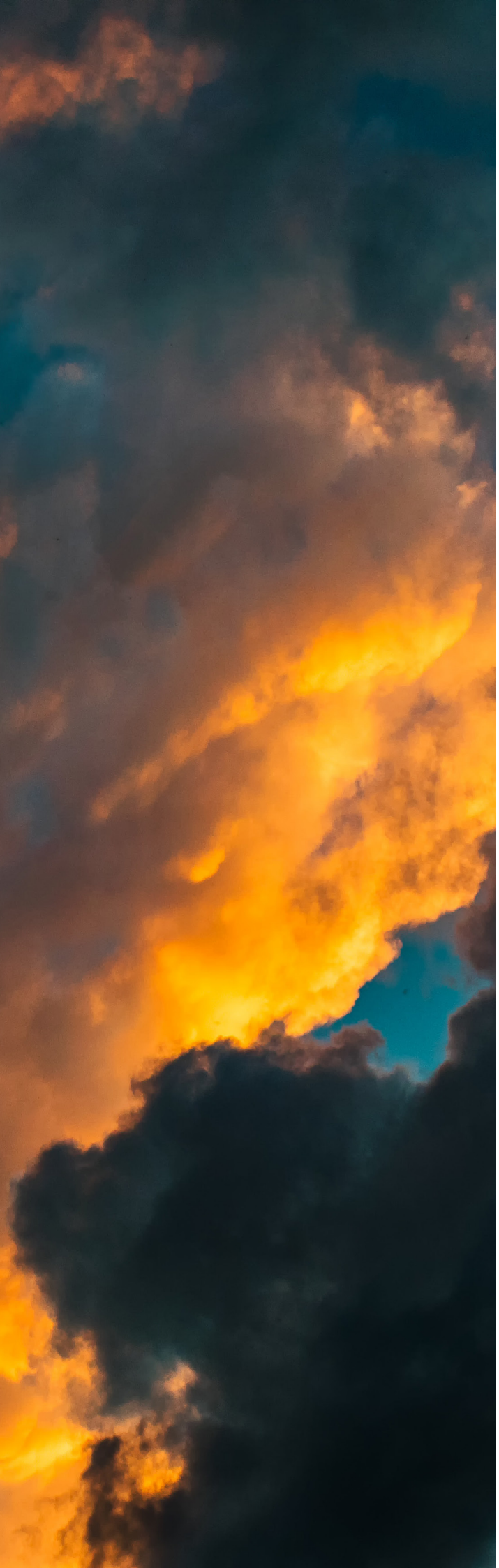
Figure 4 shows the proportion of days in 2023 where PM2.5 went above the Thai National Standard and WHO interim target 3, as well as the WHO recommended target. Across all 35 provinces, 19% of days recorded concentrations of PM2.5 over 37.5 µg/m^3 and 60% over 15 µg/m^3. The percentage of days over 37.5 µg/m^3 ranged from 1.5% in Yala, in the Southern region, to almost 32% in Nong Khai, in the Northeastern region. **More than 91% of the days over 37.5 µg/m^3 were between December and April, the crop residue burning season, peaking in March.** Days above 15 µg/m^3 ranged from more than 94% in Kanchanaburi in the Central region, to 33% in Surat Thani, and were more evenly spread across the year.

Figure 4: Proportion of days in 2023 where PM2.5 A) exceeded 37.5 µg/m^3, and B) exceeded 15 µg/m^3 for 35 provinces, along with the annual average for each province. Both plots place the 35 provinces in order of the highest (at the bottom) to the lowest (at the top) number of days over 37.5 or 15 µg/m^3.





Source: Thailand Pollution Control Department data, plots created by Madre Brava in R using the readxl to import the data, then the dplyr, and ggplot2 packages in R (16, 19-21)



Increased risk and estimated premature deaths from PM2.5

The risk of premature death rises with fine particulate matter pollution because both the incidence and fatality risk increase for conditions such as: stroke, diabetes, ischaemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), and lower respiratory tract infections. The GBD study estimates that of the 4.72 million outdoor air pollution-related premature deaths in 2021 globally, 37% were due to ischemic heart disease, 26% due to stroke, 18% to COPD and 6% to acute lower respiratory infections respectively. Further, 6% of deaths were due to cancer within the respiratory tract, and 4% due to type 2 diabetes (13).

In this report, the increased risk of premature death comes from the increased risk of these conditions, due to long-term exposure to PM2.5. This follows a systematic review and meta-analysis of all-cause non-accidental mortality, which shows that for every 10 $\mu g/m^3$ increase in PM2.5, the relative risk of death rises by 8% (or a relative risk ratio of 1.08) (22). The additional number of premature deaths attributed to the ground level measurements of PM2.5 in this report, were taken from the increased risk of premature death weighted by the population size exposed to the increased risk. This was conducted using the methodology from a previous study on air pollution in Thailand (14) and using baseline mortality rates for Thailand in 2019, taken from the 2021 GBD Study. This avoids the impacts of COVID-19 elevating premature deaths in later years (13).

Aggregating the populations at risk on a provincial population weighted basis, we estimate that the long-term exposure to PM2.5 led to 50,889 premature deaths annually between 2019 and 2023, across 35 provinces with a total population of 37 million people (Table 2).

Table 2: Estimated increased risk and number of premature deaths (PD) annually from PM2.5 exposure for each region, measured between 2019-2023.

Region	Popualation exposed	Annual average PM2.5	Increased risk of PD	Increase in no. of PD
Northern	6,603,000	30	24%	11,486
Northeastern	7,624,000	25	20%	11,215
Central	18,051,000	23	18%	24,091
Southern	4,613,000	16	12%	4,097
				50,889

Table 3 shows the regional average PM2.5 levels separated between the agricultural burning season and the non-burning season. The average PM2.5 levels from May to November is significantly lower than the annual average PM2.5 levels. This corroborates the earlier findings of the Thai Pollution Control Department and CCAC assessment, that agricultural residue burning is the largest source of PM2.5 (1).

Table 3: Average PM2.5 levels across the year, from December to April (burning season) and from May to November (non-burning season) for each region in 2019-2023.

Highest risk regions	Annual average PM2.5	Dec - Apr	May - Nov
Northern	30	51	14
Northeastern	25	39	16
Central	23	33	16
Southern	16	18	15

We used the average PM2.5 levels observed in the months of May to November (non-burning season) as an approximation of what the annual average PM2.5 levels might be if agricultural burning did not contribute to air pollution. Table 4 shows the increased risk and incidence of premature deaths associated with these lower approximated PM2.5 levels.

Table 4: Estimated increased risk and number of premature deaths annually from PM2.5 exposure for each region, excluding the effect of agricultural burning.

Highest risk regions	Annual average[a] PM2.5	Dec - Apr	May - Nov
Northern	14	11%	5,291
Northeastern	16	13%	6,812
Central	16	13%	16,514
Southern	15	12%	3,779
			32,396

[a] Approximated by regional averages from May to Nov as shown in Table 3

If the annual mean of PM2.5 levels stayed consistent with the level observed in the non-burning months, the estimated increased number of premature deaths would be 32,396 per year. Taking the difference between 50,889 and 32,396, eliminating agricultural burning could avoid 18,493 (36%) premature deaths annually.

The estimated number of 50,889 premature deaths significantly understates the impact as it is based on a limited geographical scope.[1] PM2.5 data was available only for 35 (out of 77) provinces and only for a total population of 37 million (out of 68 million) in Thailand.

Using these regional annual averages to approximate the PM2.5 levels in provinces where there is a lack of data, the increase in the annual number of premature deaths is 93,528. Approximating for lower PM2.5 levels without agricultural burning, this number would be 59,154, a reduction of 34,374 premature deaths per year.

The findings for this sub-section on the effect of agricultural burning on increased number of premature deaths are summarised in Table 5 below.

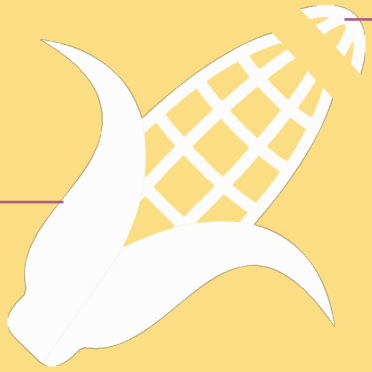
[1] Please refer to the appendix for the full list of provinces included

Table 5: Estimated increase in number of premature deaths with and without agricultural burning, for each data scope.

	Increase in no. of PD due to PM2.5	
Data scope	Limited: 35 provinces, 37 million population	Expanded: 77 provinces, 68 million population
Current no. of PD with agricultural burning	50,889	93,528
No. of PD in scenario without agricultural burning	32,396	59,164
No. of PD associated with agricultural burning	18,493	34,374

Source: ARE analysis

Almost all of
4.8 million tonnes
for animal feed



0.17%
84 thousand tonnes
for human consumption

Estimating meat and seafood's contribution – the Maize Haze

Agricultural residue burning occurs across rice, sugarcane, and maize cultivation. A significant proportion of this is tied to the livestock and aquaculture sector. Almost all of the 4.8 million tonnes of maize produced in Thailand in 2020 went to animal feed production, with just 84 thousand tonnes (0.17% of total production) grown for human consumption. For rice, 1.9 million tonnes (9.3% of total production) went into animal feed, mostly as broken rice.

Burning is more likely to occur on upland areas because the sloping terrain makes it especially laborious to clear crop residues manually, and limits machinery access and effectiveness. A majority (54%) of Thailand's maize cultivation is on upland areas (23) so crop burning is more likely to occur during the maize production cycle. An earlier study showed that maize cultivation areas accounted for 35% of total hotspots for agricultural burning in the Mekong Basin sub-region from 2015 to 2019 (24), which exceeds its proportion of total harvest area. Other research has found that air pollution from open burning produces the largest cost when assessing maize cultivation from a lifecycle impact perspective (25). It was estimated that 11.5kg of PM2.5 is released per tonne of maize production, translating to 76.1 thousand tonnes of PM2.5 released in 2023, due to maize production in Thailand and neighbouring countries.

We projected that meat and seafood production in Thailand will rise significantly from 3.9 million tonnes in 2020 to 5.1 million tonnes in 2050, driven by expanding export markets and domestic demand (26). This increase will place more burden on maize cultivation for animal feed, potentially causing more agricultural residue burning, exacerbating air pollution problems in Thailand.

Following on from Table 5, the estimated premature deaths related to all agricultural burning from 2020 to 2050 cumulatively tallies to 1,031,220 additional premature deaths in Thailand. **Given around 35% of all agricultural burning is due to maize cultivation, if meat and seafood production continues to grow as projected, we calculate there will be 360,927 additional premature deaths (2020 to 2050) due to maize burning, most of which contributes to livestock feed.**

35%
of agricultural burning is maize cultivation

if meat & seafood production continue to grow

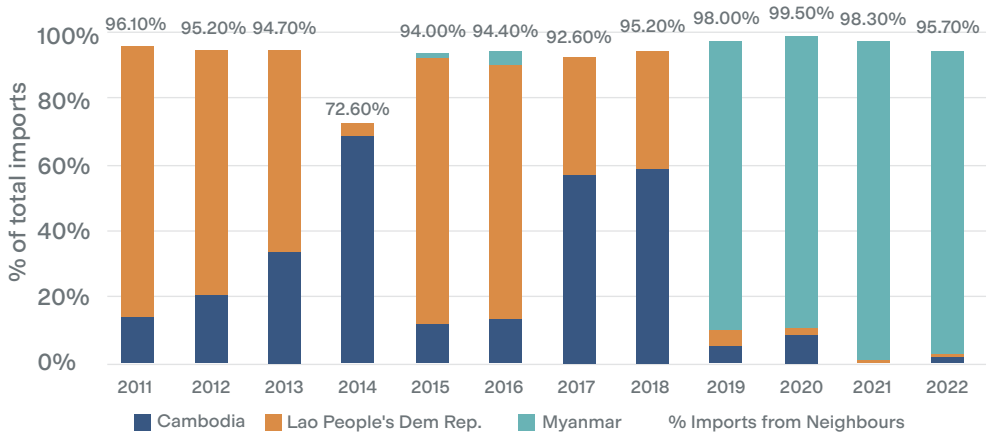
2020 - 2050

360,927
premature deaths

Madre Brava's previous report *Kitchen of the Future: The economic and environmental benefits of protein diversification in Thailand,* evaluated the environmental and economic implications of replacing 50% of total meat and seafood production with plant-based proteins by 2050 (26). **This scenario would reduce Thai animal production by 28% between 2020 and 2050. This in turn reduces demand for maize production, potentially avoiding up to 101,060 premature deaths by 2050, related to maize crop burning for animal feed alone.**

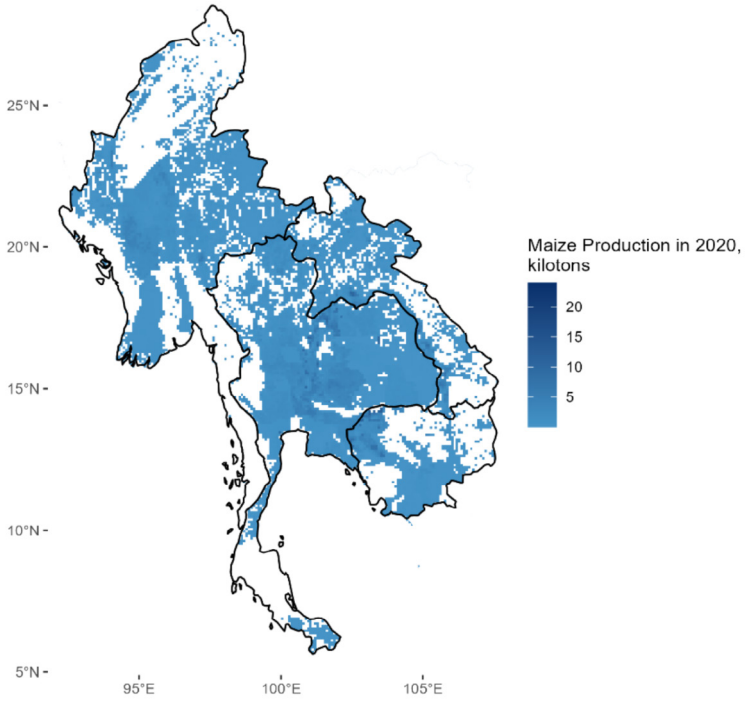
As the demand for animal production and animal feed raw materials increases, so does crop burning. Although the size of Thailand's harvested area for maize production has been stable over the last decade at 1.1-1.2 million hectares, it is unlikely that crop burning's contribution to poor air quality has stagnated. This is because the volume of maize imports grew from 147 thousand tonnes in 2015 to 1.9 million tonnes in 2020. With more than 90% of these imports sourced from neighbouring countries, this also contributes to poor air quality in and around Thailand. Figure 5 shows maize imports to Thailand from neighbouring countries, while Figure 6 shows maize production in Thailand and neighbouring importing countries: Myanmar, Cambodia and Laos.

Figure 5: Maize imports to Thailand, by country of source.



Source: UN Comtrade

Figure 6: Maize production in 2020 (kilotons) in Thailand, and neighbouring Cambodia, Laos, and Myanmar (26)



Source: Data on maize production is from a global gridded crop production data set (27), map created by Madre Brava using the ggplot2 package in R (16,19)

In response to this issue of transboundary haze, the Thai government is in the process of implementing a ban on maize imports from neighbouring countries associated with crop burning. While crop burning is illegal in Thailand, despite multiple attempts to control it, the country has yet to effectively enforce this legislation, and burning remains prevalent (28). It remains to be seen if this new legislation can be passed and enforced successfully. This is contingent on the Clean Air Act coming into effect and showing these import restrictions are compliant with World Trade Organization (WTO) rules. If, and when the legislation is passed, its impact on agricultural burning and particulate matter pollution will depend on effective monitoring and execution of the ban.

PM2.5 in animal agriculture

This section will discuss how crop residue burning and ammonia are key sources of PM2.5 from the animal agriculture sector.

No matter where it's grown, it is difficult to mitigate the negative impact of poor air quality and related premature deaths, without managing the demand for animal feed and the high volume of raw materials (mostly maize, rice) required. Thai residents and neighbours will continue to suffer and die from poor air quality. Our analysis assumes that if agricultural burning continues at today's rate, it will be linked to an additional 34,374 Thai premature deaths annually or 1,031,220 premature deaths cumulatively (2020 to 2050), with an estimated 360,927 from maize production alone.

There are other impacts; ten million people in Thailand sought treatment for pollution-related illnesses (morbidity) in 2023. The negative health impacts of PM2.5 go beyond the risk of premature deaths and respiratory illnesses. Research on the negative impact of air pollution on children's neurological development is surfacing (29). This presents challenges, not only for these children, but also

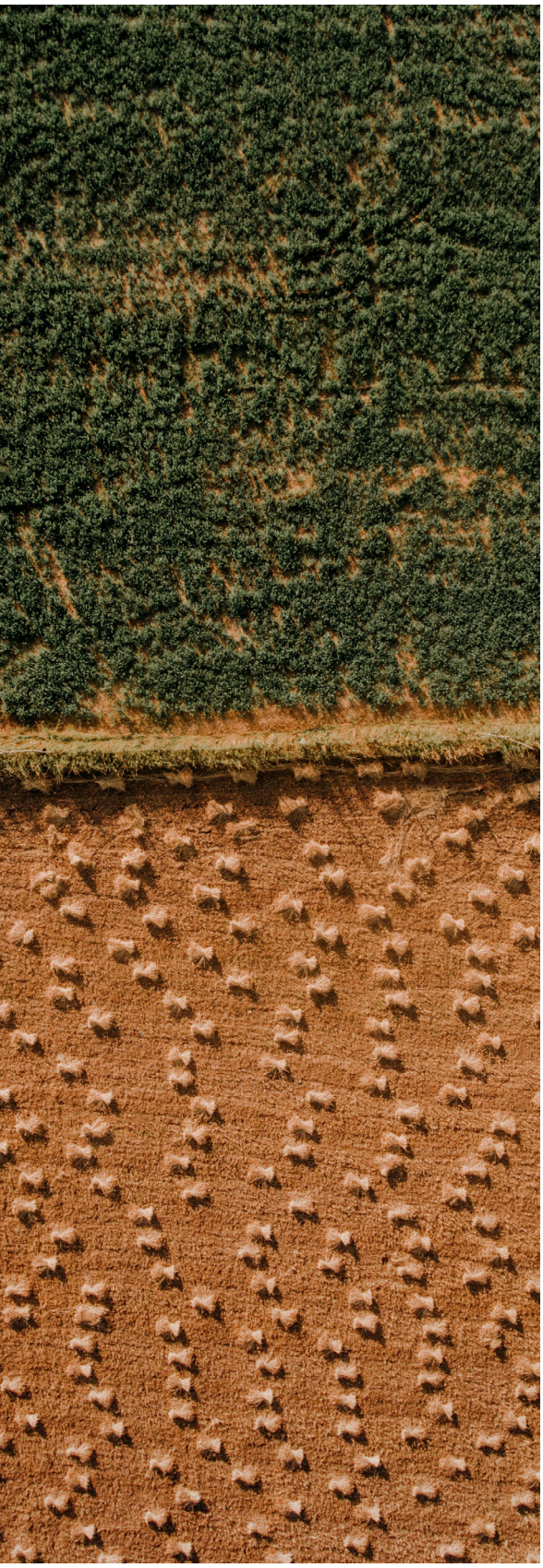
for an ageing society that will need to rely on its younger population more than ever.

One of the barriers to ending crop residue burning is the pressure facing farmers to grow more food quickly (1). The demand for animal feed contributes heavily to this pressure. The Organisation for Economic Cooperation and Development (OECD) outlook database predicts that Thai maize production will increase by 11.7% from 2022 (4,896t) to 2033 (5,468t) (30). As a result, if meat and seafood production continues to grow as we project, we estimate that crop burning will continue at a similar or greater intensity, resulting in similar seasonal trends of elevated PM2.5 levels. Limited progress from intervention measures to stop crop burning is likely to be negated or overwhelmed by higher demand for animal feed.

Our previous study: *Kitchen of the World: The economic and environmental benefits of protein diversification in Thailand* showed the more ambitious increase in plant-based proteins (50% by 2050) is expected to reduce animal production by 28%, and land use by 293,000 hectares (26). This could avoid significant numbers of premature deaths related to agricultural burning for animal feed crops in and around Thailand. However, given the broader contribution of animal agriculture to fine particulate matter from primary and secondary sources — ammonia in particular — this reduction in animal production could contribute to reducing air pollution beyond crop residue burning.

Thailand has a large animal production sector, which adds to the burden of air pollution. Ammonia (NH3) is a secondary source of PM2.5; it reacts with chemical compounds in the air to form fine particulate matter. As mentioned, the food system contributes 72% of human-caused ammonia (9), which is dominated by animal production from manure handling and storage, animal housing, and the application of manure and artificial fertilisers used to grow animal feed (31). Even if crop residue burning was phased out in Thailand, additional measures are needed to reduce levels of PM2.5 in line with the WHO recommended 5 µg/m^3.

In a recent Global Nitrous Oxide assessment, which modelled scenarios to reduce nitrous oxide emissions,

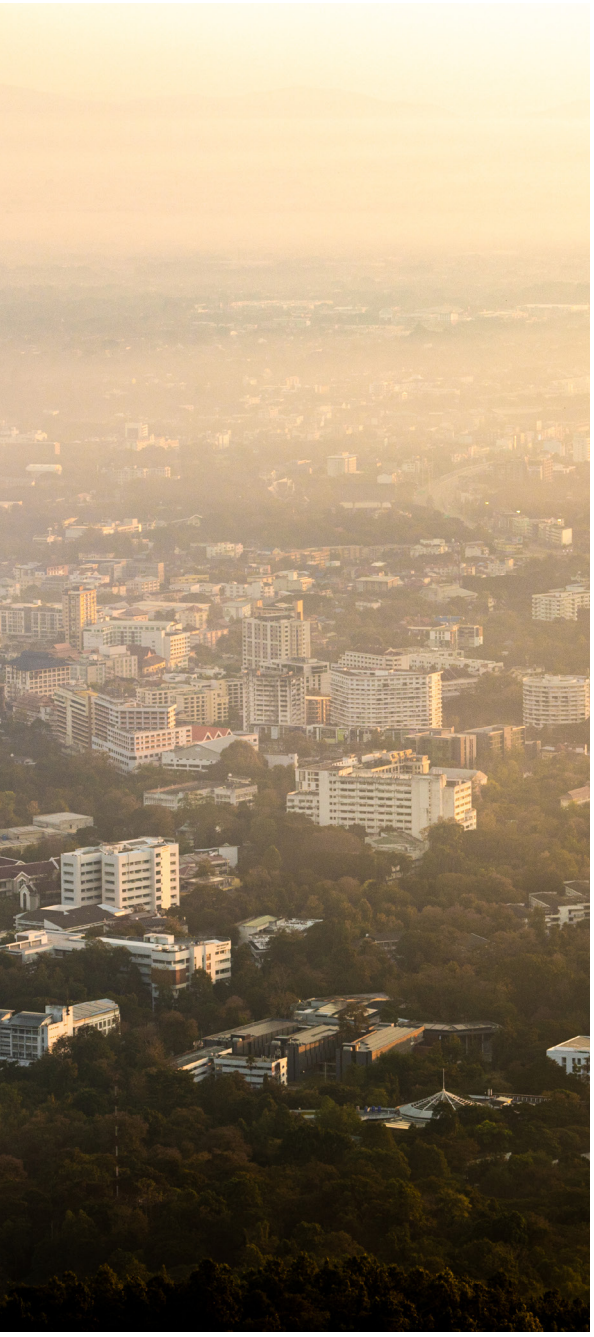


the impact on air pollution and premature deaths were highlighted as a key benefit to sustainable nitrogen management (32). The results showed that adopting a flexitarian diet (aligned with the EAT Lancet recommendations), and technical reductions (based on the implementation of all currently available technologies and practices) could avoid between 110,000 and 300,000 premature deaths globally each year, attributable to PM2.5. This provides a strong case for a policy of encouraging flexitarian diets and pursuing wide-scale diversification with plant-based proteins. This could achieve a sizeable reduction in demand for animal production and animal feed to benefit the health and welfare of Thai citizens.

Such policy coupled with other measures to direct production towards more suitable land areas, creates value streams for crop waste, increased access to machinery and transport, and could be sufficient to eliminate agricultural burning associated with the meat and feed sector. The Sustainable Rice Platform already prohibits the burning of rice crop residues and encourages inter-cropping with legumes to fix nitrogen, avoid excessive fertiliser, and maintain soil fertility (33). Such legume crops could be tailored to plant-based protein sources, enabling added value for rice (or maize) cropping farmers and companies. Air pollution policies and legislation should also cover ammonia (NH_3) emissions, given their impact on PM2.5 levels (9).

It's important to note that animal feed and animal-sourced food demand is also driven by exports and not entirely for domestic animal production and consumption. Thailand recorded an export volume of 1.86 million tonnes of animal feed in 2022 (34) (approximately 10% of total animal feed demand that year) and in 2020 exported 859,000 tonnes of meat (around 30% of production) (26). Reducing demand for animal feed exports, together with a reduction in overall animal production and the other strategies discussed, will be crucial to minimising the associated costs of air pollution and public health.

Conclusion & Recommendations



This report confirms that Thailand meat and seafood production, both for export and domestic consumption is linked to the quality of air Thai people breathe. The particulate matter (PM2.5) that is polluting Thai air — posing a critical threat to public health — is driven by the demand for animal feed. Although there are efforts to restrict crop burning, these are yet to have much impact. This report proposes a long-term, systemic solution that addresses a root cause of PM2.5: reducing the demand for animal feed through protein diversification.

Protein diversification – re-balancing protein sources by displacing meat and seafood protein with plant protein – has the potential to avoid premature deaths associated with agricultural burning. This report found that Thailand could potentially avoid more than 100,000 premature deaths related to maize burning for animal feed by 2050, if 50% of animal and seafood production is displaced by plant-based protein sources.

Apart from relieving the burden on the animal feed supply chain, 50% protein diversification by 2050 offers other benefits for Thailand. According to previous research conducted by Madre Brava and Asia Research and Engagement, this includes an additional THB 1.3 trillion (approximately USD 38 billion) in economic value, up to 1.15 million more jobs, saving 35.5 million metric tonnes of CO2 emissions per year, and 2.17 million hectares of land (26).

Given the outsized impact of the livestock industry on both air pollution and the environment, we urge the Thai government, business leaders, food producers, leading retailers, hotel chains, and especially meat producers to support protein diversification for more sustainable and balanced protein production.

For policymakers

Thailand is already taking notable steps to foster the growth of plant-based protein products, the main solution to the PM2.5 problem. For example, the Department of Industrial Promotion's 'Reshape the Future' programme supports small- and medium-sized business owners in the plant-based sector by providing access to technology and innovation. Building on these promising efforts, there are additional opportunities to further amplify the impact of these initiatives and encourage a plant-rich future for Thailand.

Encourage healthier and more sustainable food choices: Explore ways to create an enabling environment for plant-based food availability. Examples include financial incentives that make these products more accessible to Thai citizens.

Lead by example with plant-rich meals: Serve plant-based dishes at government-led events and conferences, and consider increasing plant-rich options in the canteens of public institutions such as administrative offices, schools and hospitals. These steps can demonstrate leadership while generating demand for plant-based products.

Support Thai farmers in diversifying agricultural practices: Develop pathways for farmers to transition into crop production for plant-based proteins through education, financial assistance and capacity-building initiatives.

These actions can help enhance health, sustainability and economic opportunities while positioning Thailand as a regional leader in plant-based innovation.

For corporations

Leading grocery retailers, restaurant chains and food services can play a significant role in introducing plant-based and plant-rich options to the public. We urge leading corporations in different sectors to consider the following measures:

Grocery retailers: Set targets to increase the sales and share of sustainable proteins. Lowering the price of plant-based products to match those of animal protein would remove the affordability barrier and support consumer access to healthier and more sustainable foods. Display plant-based products more prominently, accompanied by educational materials for consumers about the preparation, nutritional content and health benefits of plant-based products.

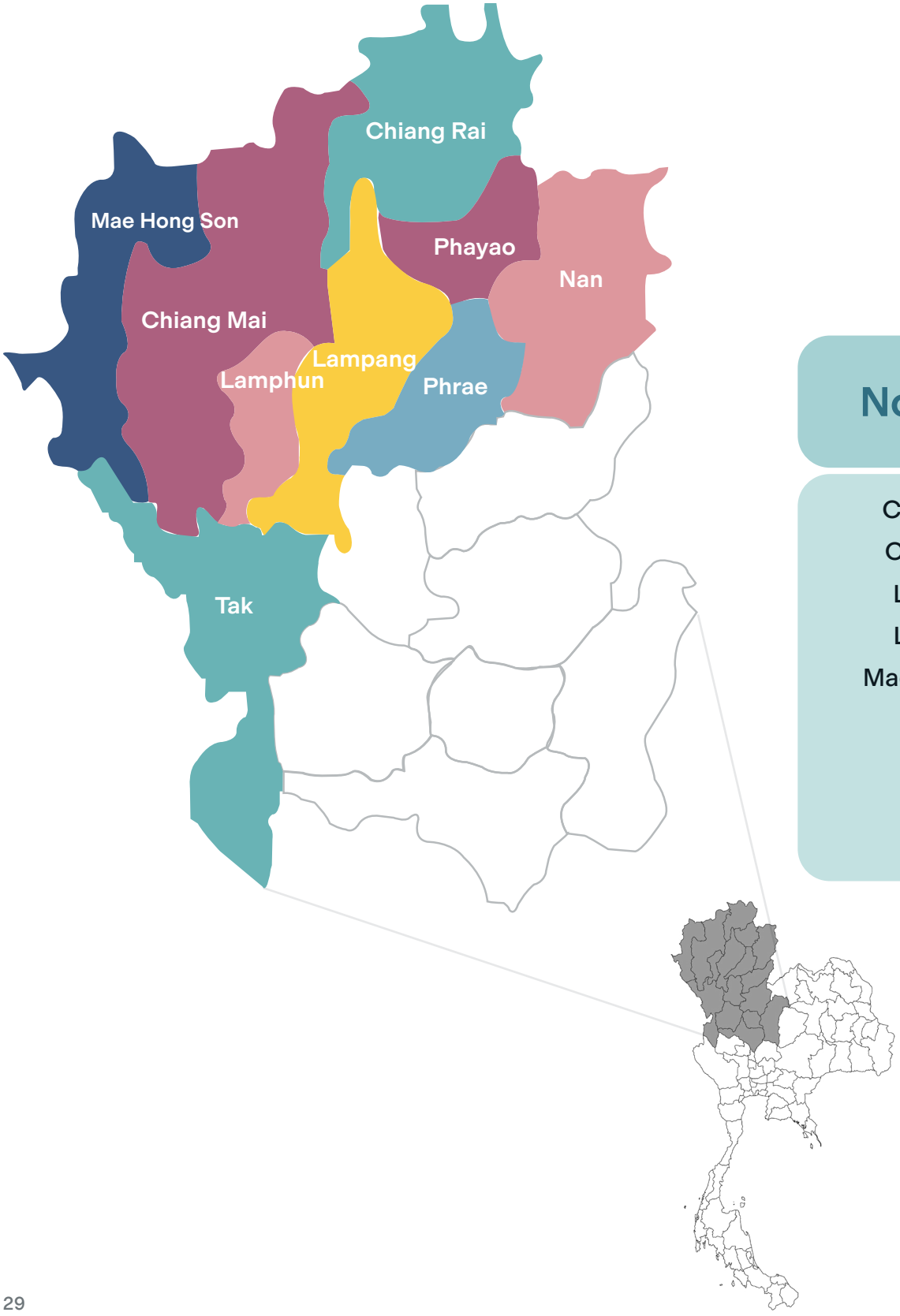
Hotel chains, restaurants and food services: Increase the offering of plant-based items and display the options alongside regular menus. Offer plant-based options at the same price range as regular menus and not at a premium.

Most importantly, key meat and seafood producers in Thailand must recognise the roles they play in polluting the air. We recommend meat and seafood producers incorporate a protein diversification strategy into wider emissions reduction and sustainability plans. They should also invest in research and development to make alternative protein products less processed, healthier, more nutritious and more affordable, both for domestic consumption and for export markets.

Appendix

Additional details

Provinces with PM2.5 data available

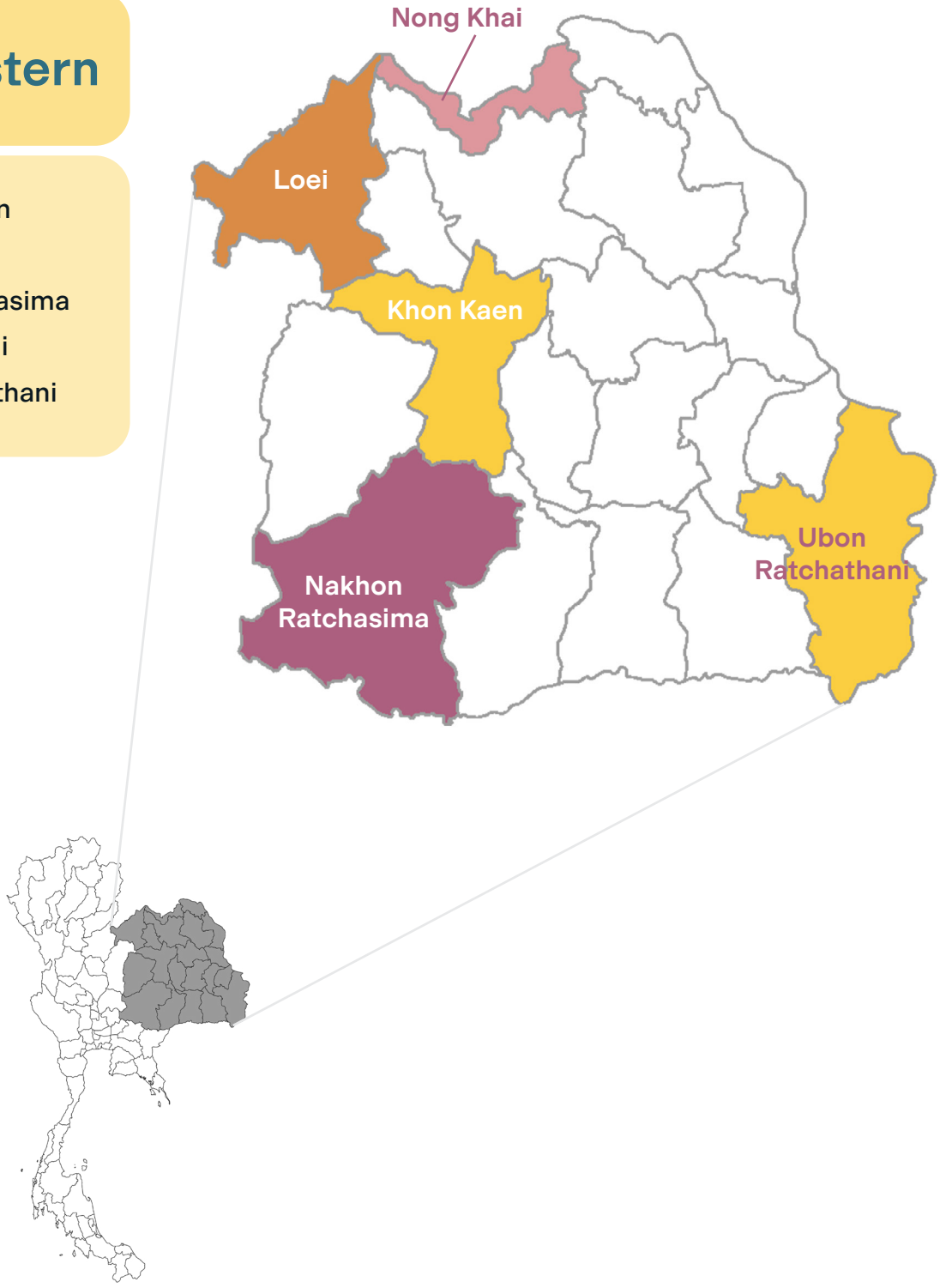


Northern

Chiang Mai
Chiang Rai
Lampang
Lamphun
Mae Hong Son
Nan
Phayao
Phrae
Tak

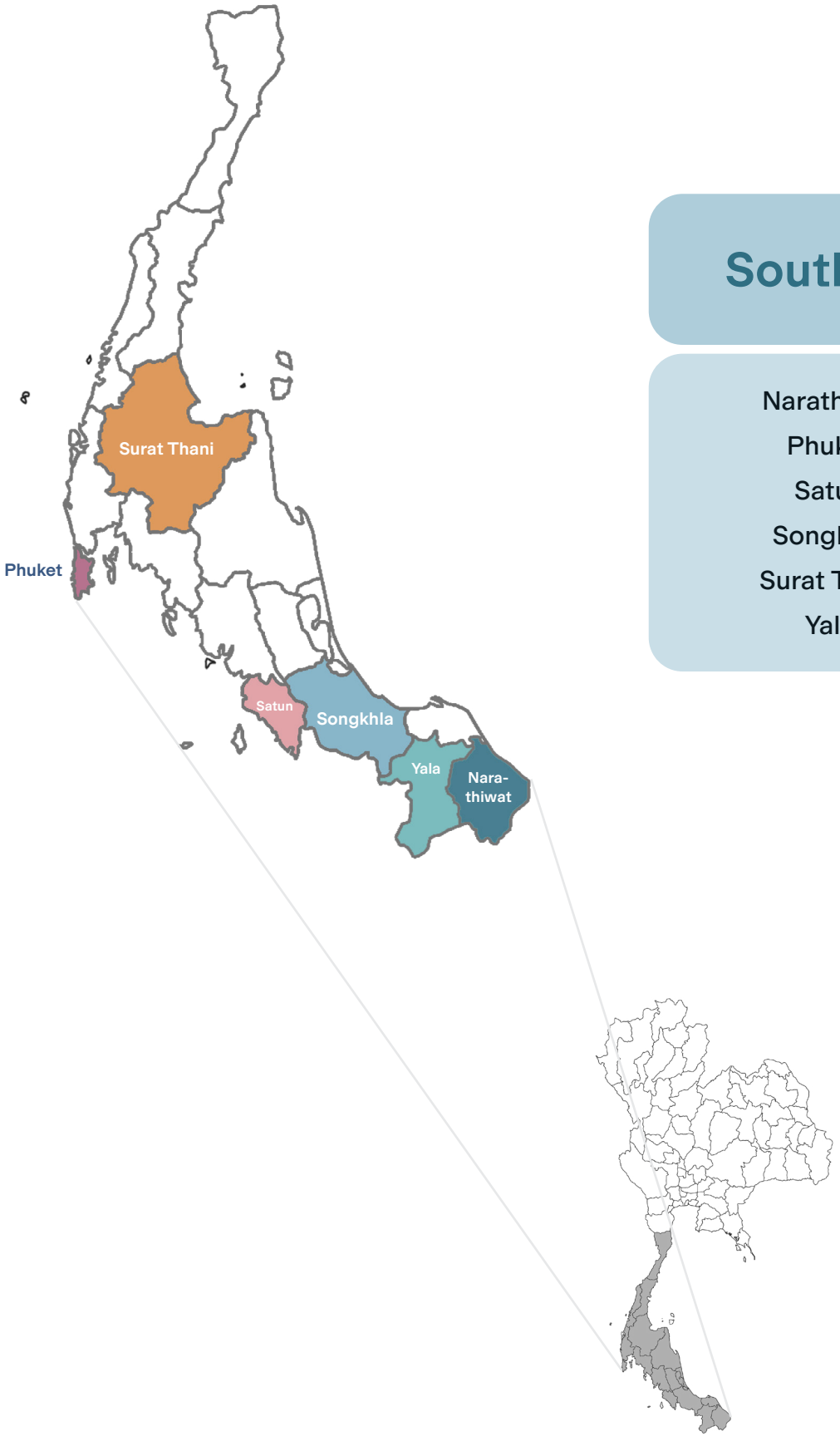
Northeastern

Khon Kaen
Loei
Nakhon Ratchasima
Nong Khai
Ubon Ratchathani



Central

Bangkok
Chachoengsao
Chonburi
Kanchanaburi
Nakhon Pathom
Nakhon Sawan
Nonthaburi
Pathum Thani
Prachinburi
Rayong
Sa Kaeo
Samut Prakan
Samut Sakhon
Samut Songkhram
Saraburi



Southern

Narathiwat
Phuket
Satun
Songkhla
Surat Thani
Yala

Quantity of PM2.5

released from maize production in Thailand and neighbouring countries

Year	Maize produced	PM2.5 released
2023	6.62 million tonnes	76.1 thousand tonnes
2030	7.23 million tonnes	83.2 thousand tonnes
2040	8.17 million tonnes	93.9 thousand tonnes
2050	9.24 million tonnes	106.3 thousand tonnes

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