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Environment and Sustainable Development

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Evidence from China, Vietnam, and the Philippines

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1 2 3 4 20 19 18 17

ISBN (paper): 978-1-4648-1201-9
ISBN (electronic): 978-1-4648-1202-6
DOI: 10.1596/978-1-4648-1201-9

Cover design: Debra Naylor, Naylor Design, Inc.

Library of Congress Cataloging-in-Publication Data has been requested.

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Foreword

In East Asia, agricultural growth has contributed significantly to the massive poverty reduction that has taken place in that region in recent decades. Success in this sector has been demonstrated by more abundant yields, higher agricultural exports, and improvements in food security, all of which have translated into gains in economic and human development. However, these achievements have come at a high price, as evidenced by the experiences of China, Vietnam, and the Philippines.

In addition to being a significant source of greenhouse gas emissions, agricultural production has contributed to environmental degradation in these three countries. Excessive fertilizer and pesticide use has degraded the quality of soil and water systems and reduced the quality and safety of food. Improper management of agricultural waste has further contributed to local and regional air pollution.

The Challenge of Agricultural Pollution: Evidence from China, Vietnam, and the Philippines draws attention to the significant environmental footprint of agriculture in these countries, thereby shedding light on areas where action can be taken to protect the health of people and the planet that sustains them. Measures that keep pollutants out of the air, water, soil, and food have the potential to benefit both farmers and consumers at a time when citizens and governments around the world are seeking to ensure that development is sustainable.

Tackling agricultural pollution is not a straightforward task, however. Agricultural pollutants are numerous, and they emanate from many different and often diffuse sources. Field runoff from millions of farms, drugs and pathogens, organic matter, particulate matter, toxic compounds, and greenhouse gases are only a few examples. In addition, many of these pollutants are undetectable to the senses. Further complicating matters is the fact that agriculture is both a victim and a source of pollution, all of which implies that solutions are complex and need to be multifaceted.

This report aims to break down some of this complexity and provide in a single document, accessible to both specialists and nonspecialists, an overview of the potential impacts of agricultural pollution in three major Asian economies. It analyzes some of the main factors contributing to farm pollution and outlines technical and policy options for preventing or mitigating it.

The report synthesizes empirical evidence from peer-reviewed literature collected by national and international experts. It also provides recommendations for addressing agricultural pollution in a more strategic, forward-looking manner.

Prevention and control of agricultural pollution will require a better understanding of its physical and socioeconomic consequences; a better alignment of agricultural, environmental, and health policies; and a more effective application of regulatory, market-based, and other policy instruments. Although many knowledge gaps remain, our hope is that this report will deepen efforts to develop more sustainable food systems in the region and beyond.

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Acknowledgments

This synthesis report was written as part of a regional study of agricultural pollution undertaken by the World Bank's Agriculture and Environment and Natural Resources Global Practices between June 2015 and June 2017.

The study was made possible by funding from the AusAid-EAP Infrastructure for Growth Trust Fund and the collaboration of several government agencies, including China's Rural Energy and Environment Agency within the Ministry of Agriculture, Vietnam's Ministry of Agriculture and Rural Development, and the Philippines's Department of Agriculture, as well as the Food and Agriculture Organization (FAO) of the United Nations. The effort was managed by Jiang Ru, Steven M. Jaffee, and Emilie Cassou, with Wendao Cao (China), Maria-Theresa Quinones (the Philippines), and Binh Thang Cao (Vietnam). It involved teams of experts in the three study countries, as well as multiple international experts. Several consultative workshops were held during the study period in Beijing, Guangzhou, Hanoi, and Manila to identify questions of primary concern, to identify and validate evidence, and to share findings. The study was reviewed by the chief economist of the World Bank's East Asia and Pacific Region.

The report was written by Emilie Cassou, together with Steven M. Jaffee and Jiang Ru, with inputs from the many people who prepared or contributed to the various papers on which this report is partly based. They include Binh Thang Cao and Pierre Gerber (World Bank); Crystal Romeo Upperman (consultant); Patrick White (consultant); Sara Marjani-Zadeh and Thierry Facon (FAO); Ge Backus (consultant); and the authors of the country study reports:

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- From Vietnam: Tin Hong Nguyen, Tung Xuan Dinh, Cong Van Nguyen, and Dai Nghia Tran
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The team would like to thank Sudhir Shetty, Iain Shuker, Nathan Belete, Erick Fernandes, Katelijn Van den Berg, Yewande Aramide Awe, Bekele Debele, Paavo Eliste, Garo Batmanian, Lilanie Olarte Magdamo, Vickram Cuttaree, Frauke Jungbluth, Madhu Raghunath, Jennifer Drost, and James F. Loomis for their valuable guidance throughout the process.

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Executive Summary

In Many Respects, Agriculture Has Been a Success Story in East Asia

Agricultural intensification and growth have provided a solid footing for East Asia's development over the past three to five decades.

In East Asia, agriculture has largely succeeded—despite significant intraregional disparities—at feeding some of the world's fastest-developing societies and providing a solid foundation for the region's economic growth. Across much of the region, agricultural output has expanded somewhat rapidly, even as the share of agriculture in GDP has fallen with these economies' structural transformation. For example, from 1990 to 2016, real agricultural value added grew at an annual average rate of 3.9 percent in China and 3.6 percent in Vietnam (it grew at only 2.2 percent in the Philippines). While serious nutritional challenges remain, agricultural output expansion has contributed to plummeting rates of hunger. Since 1990, the prevalence of food inadequacy has more than halved in China and decreased by nearly 70 percent in Vietnam.

This achievement has rested centrally on the region's ability to multiply its production of grains despite being land-constrained—and thus on agricultural intensification.[1] In the space of 50 years, for example, China's grain output increased fivefold—a doubling on a per capita basis—even though land devoted to farming remained remarkably stable. Greater use of inputs, irrigation, and mechanization have played major roles in multiplying cereal output by helping to improve yields, often by allowing producers to grow more crops per year on a given plot of farmland. The bulk of this expansion in grain production has come from small-scale farmers operating on less than one or two hectares of land. Gains in agricultural productivity have played an important role in poverty reduction across the region.

Regional agriculture has also proven responsive to rapid changes in people's food preferences and budgets, especially to the surging demand for animal products. Animal production has kept up by expanding in area, but also by intensifying and industrializing. The enormous expansion of aquaculture has rested on both extensification and intensification, for example. Between 1990 and 2014,

China's aquaculture output increased from less than 10 million tons to nearly 60 million tons. Over that same period, Vietnam's aquaculture output rose from less than 200,000 tons to nearly 3.5 million tons.

The expansion of agricultural output has also enabled the region to become an agricultural commodity export powerhouse. Over a 20-year period, Vietnam went from being a food-deficit country to being among the top five world exporters of rice, aquatic products, cashews, and various beverage and industrial crops. The East Asia region now dominates world exports of rubber, shrimp, and oil palm products, and it is a major global supplier of fresh and processed fruits and vegetables. Both area expansion and production intensification have contributed to this increase in trade and market share.

Yet Pollution from Farms Has Begun to Tarnish This Success Story

Intensive farming operations are a major and often underrecognized source of water, soil, and air pollution in certain parts of East Asia.

The intensification of agriculture in the region has frequently featured poor farm management practices related to both inputs and outputs of crop and animal production. Some examples follow:

- *Poor livestock waste management*. The dumping of untreated manure and feces-laden waste and wastewater from livestock and aquaculture operations into the environment is a rampant, often uncontrolled, and expanding problem, as is its improper storage. For example, an estimated 36 percent of livestock waste generated in Vietnam is dumped directly into the environment without treatment, and up to 80 percent of livestock waste has been disposed of in this manner in some parts of the Philippines.

- *Improper use of feed, drugs, other growth enhancers, and other chemicals in aquaculture and livestock breeding.* Reliance on feeds and supplements is a key feature of industrial animal agriculture on both large and small scales, and it gives rise to pollution in several ways. Aquaculture operations lose most of the feed (or fertilizer) they add to their waters, and nutrient pollution has become particularly problematic in the open systems that have come to dominate the subsector, as these systems entail the release rather than the recycling of excess nutrients. Furthermore, the prophylactic and growth-enhancing use of drugs, hormones, and heavy metals is now a standard practice in the livestock and aquaculture industries in the region. For example, over 45 antibiotics are widely used in Vietnamese livestock and aquaculture production.

- *Excessive or improper fertilizer and pesticide use.* The East Asia region now features some of the heaviest fertilizer users globally in both absolute terms and per unit of land. Most of these fertilizers are not taken up by the targeted

plants but instead disperse through the air, soil, and water. In China's intensive grain-producing areas, there is potential for cutting nitrogen applications by 30–60 percent without harming yields; similar "triple win" opportunities for yields, incomes, and the environment have been identified in relation to the use of fertilizer (and water) to grow coffee in Vietnam's Central Highlands. Pesticide use has also soared in China and parts of Vietnam. Highly toxic pesticides remain in use, and nonnegligible volumes of counterfeit and obsolete pesticides are thought to be in circulation.

- *Use and improper disposal of plastics.* Another emerging concern is the use and improper disposal of agricultural plastics, many after only a single growing season. This is a significant concern in China, where the use of plastic film "mulch" has transformed and enabled the expansion of vegetable and cotton production in the country's cold and arid regions. In China, plastic film use grew more than 150-fold between 1982 and 2014 in area terms, and 200-fold in tonnage terms. The use and disposal of plastics are associated with many concerns, including ones related to soil fertility, food safety, and the protection of wildlife.

- *Open burning of crop residues.* In many parts of the East Asia region, maize, rice, and wheat residues are systematically burned for the sake of expedience and labor savings. Time and labor scarcity, the lack of market channels for straw and husks, and certain agronomic beliefs are among the factors thought to contribute to this practice.

These and other agricultural practices have given rise to significant environmental pollution, with the breadth and severity of problems varying among countries. Agricultural pollution is most pronounced and best documented in China. Its first national pollution survey, released in 2010, found agriculture to be the leading source of surface water quality impairment by nutrients and organic pollutants in 2007. Agriculture has been the leading cause of eutrophication[2] in the Yellow and South China Seas and in several of China's major freshwater lakes. Agricultural pollution is also evident in Vietnam and the Philippines, though it has tended to be less well documented, more localized, and on average less severe. In Vietnam, for example, certain surface waters are "dramatically degraded" near intensively populated and farmed areas. And livestock and other farms have been the largest contributors of organic matter pollution in the monitored waterbodies of the Philippines.

As a result, changing farming patterns and practices are a growing concern for human and wildlife health and well-being, climate stability, and farm productivity and agroindustry competitiveness. Though evidence linking intensive farming practices to these is incomplete, impacts can be inferred from the levels of pollution observed, together with well-understood impact pathways.

Human, Wildlife, and Ecosystem Health

From a human health perspective, drinking water contamination is a key concern in all three countries, as are food contamination, the development of drug-resistant microbes, and poor air quality. To illustrate:

- *Drinking water contamination*. In China, agriculture bears substantial responsibility for the fact that in 2015, over 61 percent of monitored groundwater sources and nearly 28 percent of monitored rivers were found to be unfit for human contact, and that over 30 percent of major lakes and reservoirs failed to meet drinking or bathing water standards. In the 2000s, agricultural sources became the primary polluter of the Miyun Reservoir, Beijing's most important source of drinking water, after industrial pollution controls were implemented. In Vietnam, livestock farms are reportedly seriously detracting from the quality of drinking water supplies to Ho Chi Minh City; this problem is likely affecting Hanoi and Manila as well, given the intensity of livestock production in these cities' periurban areas. Meanwhile, pesticides used in rice fields and on other crops have been shown to compromise the safety of groundwater extracted from wells and other drinking water sources in Vietnam.[3]

- *Food safety*. Many East Asian consumers worry about the safety of the foods and beverages they consume. One cause for concern is that certain agricultural pollutants regularly find their way into food. Another is that farming practices have caused soils to acidify, a situation that has likely accelerated the uptake of heavy metal pollutants by food crops, thereby creating a human health hazard and leading to the rejection of these crops by markets. In a context of heightened concern over food safety, the contamination of China's soils with pesticides, heavy metals, and other chemical compounds is seen as one of the major pollution problems the country faces.

- *Drug resistance*. Although regional studies are sparse, it is known that drug-resistant microbes have begun to emerge. This development is likely connected to the systematic use of antibiotics and antimicrobial agents in the pig, chicken, and aquaculture operations in all three study countries, including by the majority of small producers. In China, one study estimated that 52 percent of all antibiotics in the country was administered to animals in 2013. Concern about the effects of antibiotic resistance on a global scale led the United Nations in 2016 to declare it a crisis, a status previously applied to the HIV and Ebola viruses.

- *Air quality*. The severity of air pollution in China is well known, as are its effects on the burden of disease—for example, about 78 percent of monitored municipalities failed to meet air quality standards in 2015. Even though the contributions of agriculture to this problem are not well measured, livestock production, open burning of crop residues, and agrochemicals have been implicated. Ammonia releases from agricultural sources—which are the main

sources of ammonia emissions—were recently shown to be detracting from urban air quality in Chinese cities. The open burning of agricultural residues has also been tied to an abundance of fine particulate matter in certain cities on a seasonal basis. Meanwhile, bad odors rising from livestock farms detract from the well-being of nearby communities.

- *Pesticide poisoning.* In Vietnam and the Philippines, farmers and their families are sometimes directly exposed to the pesticides they apply due to a lack of protective gear or to methods such as broadcast spraying that put rural communities at risk. These exposures are in addition to their daily exposure to pesticides in water and food.

As for ecosystem health, several adverse impacts can be noted. For example:

- *Wildlife health and biodiversity.* For wildlife and ecosystems on the front lines of exposure, the health effects of agricultural pollutants can be even severer than for people. Mass fish kills are a common occurrence in aquaculture operations in the Philippines, where over 300 incidents were recorded between 2005 and 2014. In China, some 30 percent of monitored surface waters are polluted to an extent that has been associated with biodiversity losses elsewhere. The disappearance of pollinators, such as seems to have occurred in fruit tree–growing parts of western China, along with recorded instances of fish kills, illustrate how agricultural pollution is threatening the survival of critical populations or species on which humans depend.

Climate Stability

As the primary emitter of nitrous oxide and methane, and as a source of other climate pollutants, East Asia's agriculture is significantly contributing to both long-term and short-term climate warming. China is, by far, the dominant emitter of agricultural greenhouse gas emissions in the region—in part because of its size—and livestock rearing is the largest source of these emissions, followed by synthetic fertilizer use. Meanwhile, farming activities—especially rice irrigation and livestock production—are the second-largest source of greenhouse gas emissions in Vietnam and the Philippines. In Vietnam, manure management and fertilizer were the fastest-growing sources of greenhouse gas emissions between 1994 and 2010. Agriculture's contributions to fine particulate matter or its formation—especially black carbon—and to ground-level ozone are also potential contributors to near-term warming.

Farm Productivity and Agroindustry Competitiveness

The business of agriculture, much like wildlife, is on the front lines when it comes to bearing the brunt of environmental pollution—not only of industrial and urban origins but also of agricultural origin. Soil fertility and crop yields are at risk when fertilizer losses; field burning; and the use of plastic ground covers, irrigation, and other farming activities result in soil acidification, salinization,

soil warming, and other disturbances. In southern China, where a full 65 percent of agricultural soils have become severely acidified, fertilizer use has been both a cause of and response to soil acidification, fueling a vicious cycle of degradation. The loss of pollination and biological control services has already saddled farmers with heavy labor and pesticide costs, notably in China's fruit-growing regions. Drug resistance in confined livestock and aquaculture operations may open new pathways for pandemics that would adversely affect these industries.[4] Finally, food safety concerns also have commercial consequences. The discoveries of excessive levels of veterinary drugs, pesticides, and other contaminants in food products destined for demanding markets have led to trade rejections worth tens of millions of dollars.

Structural and Policy Drivers Have Contributed to Increased Farm Pollution

Several of the pollution problems that the three study countries are facing have been magnified by patterns of structural development, some specific to the region.

Demographic growth and a societal focus on output and yield, shaped in part by policy, have favored development approaches that regard the environment as a resource for exploitation. Direct and indirect fertilizer subsidies (such as those in Indonesia, Vietnam, and China—China's are slated for reform—and formerly in the Philippines), preferential input loans, extension messages, and product advertising have helped cement a widespread belief among farmers that applying more fertilizer always results in higher yields. These factors have contributed to the overuse of fertilizer. Specialization in crop agriculture, the simplification of agroecosystems, and the move to monoculture—favored by investments in irrigation infrastructure and extension messages, and sometimes inflexible land-use policies—have accelerated the loss of natural predators and fertility on farms, increased the susceptibility of crops to pests and disease, and driven farmers' greater reliance on synthetic chemicals to address these problems. The expansion of irrigated agriculture, a centerpiece of public investment in agriculture in several countries, has also unwittingly contributed to agrochemical runoff, soil salinization, and rice-related greenhouse gas emissions.

The agricultural sector's high degree of responsiveness to the emerging demands of urbanizing populations has resulted in a more polluting mix of products and practices, as well as a greater proximity of populations to agricultural sources of pollution. The rise of animal agriculture, including the surge in confined pig and fish farms, in response to the growth in demand for animal products has led to higher levels of pollution. The clustering of agricultural activities and their increasing juxtaposition with dense population centers have increased human exposure to the sector's ever-concentrating set of pollutants. Chinese agriculture's response to the rising demand for fruit and vegetables in a

water-scarce environment has most recently driven plastic, nutrient, and pesticide pollution concerns.

Pollution has, so far, been a major downside of the rapid intensification and expansion of agricultural production. In a region bent on leapfrogging as a development strategy, the uptake of pesticides and other chemicals in farming has happened so fast that it has sometimes outpaced farmers' and regulators' awareness of their dangers, the latter's capacity to regulate them, and the adoption of safe handling techniques. Importing aquaculture species bred for intensive farming has been a quick way to develop a high-output seafood industry—yet one that has increased the risk of genetic contamination, disease, and biodiversity loss. Furthermore, some of East Asia's aquaculture activities have developed around potentially invasive species, which can represent a threat to the health and survival of native species.

Limited space for agriculture and the continued dominance of small farm size have challenged the capacity of producers and regulators to moderate pollution. In some cases, limited space for farming has detracted from sound environmental management. In animal farming, for example, cramped conditions have dissuaded producers from devoting space to waste treatment facilities, especially in light of limited opportunities for market reward and the weak enforcement of waste management regulations. The small size (and limited capacity and resources) of most livestock and aquaculture operations, taken individually, has also possibly dissuaded regulators from imposing more stringent waste management requirements or even just scrutiny of such operations, even though they generate vast amounts of pollution aggregately. Meanwhile, farmers with limited land are increasingly having to seek off-farm income opportunities to make ends meet, and this sometimes leaves them with insufficient time for judicious farm management practices.

That said, the pollution situation is not always improving where consolidation is occurring and industrial farms are emerging. The large, industrial operations that are emerging in the livestock and aquaculture sectors, especially in China and Vietnam, have a mixed record in terms of cleaning up the industry through the use of more sophisticated waste management techniques. Similarly, croplands that have become dominated by large players are not always the most exemplary, perhaps because with market dominance and economic strength come political influence and regulatory capture.

A Range of Priorities Is Clear, and Technical and Policy Solutions Are Available to Address Them

Though incomplete, evidence supports several priority areas in which more and better public sector intervention is needed.

Agricultural pollution and its effects on the East Asia region are characterized by profound data and knowledge gaps. Nonetheless, there is enough evidence to point to specific farming patterns that are contributing to the region's worsening

pollution and to define priorities. Priorities would differ by country, but, overall, attention needs to be given to the following, among other things:

- Improving the *livestock industry's waste management* practices and environmental performance, while being very cautious about stimulating the industry's expansion in view of its relation to human health, its contributions to climate change, and its relative resource inefficiency.
- Cutting back heavily on the prophylactic *veterinary use of antibiotics*, the commercial benefits of which may be far overshadowed by the costs of drug resistance.
- Bringing *farmed aqua-ecosystems* into balance, including through the embrace of improved inputs and various kinds of closed-loop systems.
- Reducing *fertilizer losses* from cereal and specialty crop farming that are contaminating surface waters, harming soil fertility, reducing air quality, and contributing to climate change. In many cases, achieving this will save farmers and governments money without harming yields.
- Professionalizing the *use of pesticides* while promoting prevention and low-toxicity control agents. This process will involve minimizing the use (and preserving the effectiveness) of toxic substances and abandoning the use of banned substances, which harm people and trade.
- Reducing and repurposing the *organic by-products of farming*, including manure and crop residues, to derive value from them and put an end to the open burning and harmful disposal of them as wastes.
- Commercializing more environmentally benign *plastics* and related waste management systems, as well as alternative technologies, especially for use in cold, dry, and other conditions in which plastics have transformed farming.
- Diffusing *rice cultivation* techniques that reduce climate-warming greenhouse emissions from irrigated fields, while saving water and maintaining or improving yields.

A wide range of technical solutions is available to act on these priorities, and this suggests that practices can be guided to evolve in directions that will lessen their environmental footprint. In various parts of the region, for example, nutrient management tools, including ones that bypass soil testing, have proven effective at reducing fertilizer use along with waste and imbalances. Soil testing kits and laboratories, formula fertilizer and slow-release fertilizer, smaller or redesigned chemical containers, fertilizer deep-placement technologies, and micro-irrigation can also improve fertilizer dosing and reduce waste. Although integrated pest management (IPM) has faced challenges scaling up—namely because of small farm sizes—it has empowered some farmers to reduce the use of pesticides, especially the most toxic ones, by using the latter as a last resort and favoring reliance on prevention and biological controls instead. Simple protective gear, when worn, can reduce the exposure of farm workers when chemical spraying is deemed necessary.

Better-quality or biodegradable plastics can help reduce the accumulation of plastic debris in soils, as can the development of specialized waste collection and recycling services and, in some cases, the use of agroecological mulching techniques. Improved water management regimes (including alternate wetting and drying), rice cultivars, and fertilization techniques that utilize rice straw and avert burning can reduce greenhouse gas emissions from irrigated rice while saving water and enhancing yields.

In livestock rearing, improvements in animal housing and sanitation can sometimes achieve benefits similar to those of prophylactic drug use. Manure volatilization can be contained by covered storage facilities and manure-injection technologies; other forms of feces pollution can be attenuated through the selection of different breeds and improvements in feeding, cleaning, water management, water treatment, and other practices. The examples are many.

In many cases, however, farmers need public sector support to adopt technologies and practices that make mitigation possible, at least in the near term. In some cases, public sector intervention may be needed only initially to overcome the hurdles of switching. At times, farmers stand to benefit privately from pollution mitigation—by saving on agrochemical costs, gaining access to premiums and markets reserved for products of higher reputation and quality, or, over time, protecting natural resource and agroecosystem productivity (land fertility, clean water, pollination, natural pest predation, and so forth). In China, for example, nitrogen use was cut by roughly 4–14 percent in maize, rice, and wheat system field trials while boosting yields by 18–35 percent, thanks to a knowledge-intensive approach to farming known as integrated soil-crop system management. In Vietnam, piloting of the "1 Must and 5 Reductions" program has shown that it could save Mekong Delta farmers an estimated 18–25 percent of their production costs per hectare of crop without harming yields.[5]

Governments have a wide range of policy instruments at their disposal to promote greener farming practices (see box ES.1). Many are already being used in the East Asia region, sometimes on an experimental scale. Typically, governments need to develop multipronged programs that use combinations of these instruments to send clear signals to farmers and facilitate effective responses. This is especially the case where smallholders dominate and command-and-control regulations will most likely be too costly to enforce. In parts of the agricultural sector that have become more consolidated (such as for large livestock facilities), command-and-control regulations may be appropriate. Yet experience shows that additional measures are needed to motivate industry to comply and improve program cost-effectiveness. A combination of interventions, sequenced smartly, can be the key to achieving results.

Governments in the East Asia region have begun to utilize several of these policy instruments, although most interventions have been reactive or experimental. China has probably established the most extensive set of agricultural sector–specific laws, regulations, and incentive programs to monitor, prevent, and control pollution. In Vietnam, many government efforts to limit and control

agricultural pollution are also under way as its effects are being felt ever more widely. In the Philippines, where agricultural pollution is less severe overall, or rather more localized, the government has put in place fewer agriculture-specific laws and programs. In all three countries, meanwhile, laws to prevent and control agricultural pollution have often been ignored, and incentive programs have yet to be mainstreamed. In Vietnam, for example, this situation applies to both laws and incentive programs intended to improve the management of livestock waste. In addition, various successful incentive and demonstration programs have yet to surmount the challenges of sustainability and scale-up.

Most recently, China and Vietnam have started to embrace more balanced agricultural policies that not only place greater emphasis on environmental sustainability, but also link it to emerging and long-standing priorities of agricultural policy, such as food quality, competitiveness, yield performance, and food security. In fact, judging from the Sustainable Agricultural Development Plan it adopted in 2015, China may now be turning a corner in starting to address the issue more strategically, with greater attention to prevention and to taking successful approaches to scale. This approach has not been the norm in China, Vietnam, or the Philippines, however, and socializing this way of thinking to see it through will likely be challenging. This points to the need not only for efforts on the legal, technical, and economic fronts, but also for institutional reforms encompassing the incentives, culture, and priorities of regulators. Adequate public sector funding, as well as market participation, will also help mobilize and sustain the resources needed for such things as monitoring, enforcement, and various forms of subsidies for sustainable agriculture.

Box ES.1 Examples of Public Sector Instruments That Can Be Used to Address Agricultural Pollution

Rules Linked to Farm Licensing, Operation, and Input Use

- Zoning rules, including restrictions on livestock rearing within a certain radius of sensitive areas, such as residential and water source protection areas, and restrictions on farming crops on sloped and ecologically sensitive land
- Livestock farm size restrictions expressed in terms of animal or manure limitations
- Specifications for animal housing, waste storage, waste treatment facilities, or proximity to cropland
- Requirements that farms draw fresh water from sources downstream of them
- Mandatory reporting requirements for waste and wastewater discharges
- Bans on the marketing and use of certain pesticides, antibiotics, hormones, and other chemicals
- Limitations on the open burning of agricultural residues (volumes, timing)
- Standards for the treatment and discharge of wastewater.

box continues next page

Box ES.1 Examples of Public Sector Instruments That Can Be Used to Address Agricultural Pollution *(continued)*

Incentives or Disincentives Tied to Improved Farming Practices and Agroindustry Services

- Fines or loss of benefits for noncompliance with mandates
- Preferential credit or grants for straw residue management or manure injection machinery
- Subsidies for formula fertilizer, fertilizer deep-placement products, or soil testing kits
- Payments for adopting practices that reduce farm runoff
- Public procurement requirement that food purchases meet given certification standards
- Fast-track licensing for operations meeting high environmental management standards
- Loans to enterprises offering input application and soil testing services, as well as improved drugs, inputs, and gear
- Grants for demonstration farms and farmer-led movements modeling and supporting best practices
- Grants to enterprises increasing access to and the appeal of plant-based or low-footprint foods.

Research, Surveillance, and Information

- Research programs on precision and cellular agriculture and other potentially disruptive solutions
- Grants for research on noninvasive aquaculture species, recyclable or biodegradable plastics and alternative materials and processes, alternative therapeutics, plant proteins, and the socioeconomic impacts of pollution
- Satellite surveillance of burning and other relevant activity
- Monitoring of more pollutants in more places, with a focus on hotspots
- Training of scientists and technical experts to strengthen extension and pollution-monitoring capacity
- Information and behavior change campaigns promoting better farming practices and diets
- Development of green certification standards
- Dietary guidelines bridging health and environmental perspectives
- Branding efforts to raise the profile of an ecological farming region or product, in a public-private partnership.

Strategic Directions for Effective Pollution Prevention and Control

Curbing agricultural pollution will require the public sector to direct adequate resources to priorities, compel and motivate farmers, shape the agricultural sector's structure and growth trajectory, and back innovation and learning.

What follows are four strategic directions in which the public sector can pursue agricultural pollution prevention and control and achieve results, drawing on a range of policy instruments.

1. Break Silos to Mobilize and Align Resources with Priorities

What: Harmonize and coordinate policy across policy silos, levels of government, and geographic boundaries to breathe life into an agricultural pollution agenda.
Why: To draw attention to agricultural pollution and help its abatement become a better-defined policy objective, a higher priority of ministries, and one with more resources directed to it.
How: Bridge jurisdictional boundaries.

- At the highest, strategic level: harmonize agricultural, environmental, and health policy goals, strategies, and resources, removing any conflicts among them.
- At more operational levels: coordinate efforts across levels of government, sectors, and geopolitical boundaries.

At the highest, strategic level, tackling agricultural pollution calls for harmonizing agricultural, environmental, and health policy, and for setting top priorities. More systematic data collection and evidence will help this exercise, but enough is already known to take steps in this direction. This process of integration is needed to remove any conflicts among these policy areas and to ensure that adequate resources are directed to farm pollution priorities. This approach means that the measurement of agricultural performance needs a rethink. In turn, this reframing will lead to a redeployment of public agricultural spending. Public investment in research may be rebalanced to focus more on protecting resources, building agroecosystem resilience, and optimizing nutrition with respect to environmental impacts. Conversely, public investments biased toward heavily input-reliant, single-species farming systems and technologies may have lower returns than previously thought once their performance is assessed with a less strict focus on yield, output, or protein-energy. Health and environmental policy efforts will also be strengthened by bringing agriculture more fully into their fold and devoting more resources to farming. At more operational levels, efforts will also benefit from breaking silos and achieving coordination across levels of government, sectors, and geopolitical boundaries. This way, policy efforts will better align with agricultural pollution, recognizing its disregard for jurisdictional boundaries.

2. Combine Instruments to Compel, Motivate, and Enable Farmers to "Green" Their Farming Practices

What: Develop mixed-instrument programs to compel, motivate, and enable farmers to adopt less-polluting farming practices.
Why: To achieve pollution abatement across all kinds of farms, acknowledging the limitations of command-and-control approaches that rely on top-down surveillance and enforcement.

How: Strive to bring different players into the fold by using combinations of instruments.

- Combine "sticks," "carrots," and behavioral interventions to compel and motivate farmers in all their diversity.
- Make supportive investments in physical infrastructure, public services, data, and science to enable farm-level change and overcome constraints.

Multipronged government programs that send clear signals and yet offer farmers a range of choices are needed. Specifically, combinations of sticks, carrots, and behavioral interventions are needed to compel and motivate farmers in all their diversity, given the limitations of top-down surveillance and enforcement to change behavior on millions of small (and larger) farms. While stronger enforcement of mandates is broadly needed, expectations need to be aligned with farmers' capacities; flexible, market-based mechanisms and economic incentives are sometimes appropriate to bring farms of differing sizes and capacities under one compliance regime. In some instances, removing or modifying unhelpful incentives, even if they act indirectly on pollution, may prove to be more productive and cost-effective than instituting new incentive programs that target pollution directly. In parallel, supportive investments in physical infrastructure, public services, data, and science are needed to overcome constraints to farm-level change. For example, certain investments in information technology can be game-changing when it comes to monitoring, and specialized waste collection and management services would give farmers more options when disposing of plastic waste.

3. Influence Levers of Structural Change, including Consumption, to Keep Pollution in Check

What: Anticipate and influence the agricultural sector's structural trajectory, intervening from farm to table, to avoid the worst effects of pollution and keep abatement options open.
Why: To avoid structural developments and path dependencies that will overwhelm technical solutions, outpace innovation, reduce technical abatement options, or make it cost-prohibitive to reduce pollution—in short, limiting choices.
How: Seek to directly and indirectly influence structural aspects of the farm sector that have a major bearing on pollution.

- Proactively weigh trade-offs implied by different sector development trajectories.
- Seek to reorient consumption patterns.

To "get ahead" of pollution—to control and prevent it effectively—the public sector needs to guide the agricultural sector to develop differently. Although the existing technical solutions and capacity for innovation have vast potential for

abating pollution, they run the risk of being overwhelmed—depending on how the sector develops structurally—making the desired levels of abatement cost-prohibitive or unattainable in the longer run. The agricultural sector must be guided to develop more sustainably. In general, examining and weighing the trade-offs implied by structural trends will be central to determining preferred trajectories. This points to the need for strengthening the evidence base, broadly involving stakeholders in decision making, and again, involving different levels of government in policy making.

Meanwhile, efforts to influence the agricultural sector's structural trajectory cannot be confined to influencing the farm sector directly. Influencing consumption patterns can also be a powerful and indispensable point of entry going forward. Changes in consumer product and diet choices, as shaped by political, economic, and cultural forces, can play an important role in determining how the sector and its pollution footprint develop. In particular, the promotion of plant-centric diets can have a significant impact on the agricultural sector's development trajectory and environmental footprint, as well as on nutritional health outcomes. Consumer sensitization may be effective if paired with measures to enhance the availability and appeal of more benign food products and thus consumer choice. The choices that product standards allow consumers to make tend to relate to production processes (attributes of food that are not detectable to the senses), and less so to dietary ones, though there can be some overlap. Yet dietary choices—especially choices of what foods to eat and not to eat—aggregated across society have tremendous environmental consequences.

4. Learn and Innovate to Stay a Few Steps Ahead of the Pollution Challenge

What: Invest in data, research, innovation, and entrepreneurship to intervene more effectively over time.
Why: To better set priorities, improve public intervention iteratively, and stay ahead of the pollution challenge both technically and in matters of policy.
How: Invest in data, research, innovation, and entrepreneurship.

- Invest in agricultural pollution monitoring and in research on the physical and socioeconomic impacts of agricultural pollution and the effectiveness of technical and policy instruments.
- Stimulate innovation and entrepreneurship so that abatement solutions can keep up with change and their pursuit can become value addition and job creation opportunities.

Knowledge and knowledge economy investments—in data, research, innovation, and entrepreneurship—are needed to better set priorities, improve public intervention iteratively, and stay ahead of the pollution challenge both technically and in matters of policy. For example, investments in information technology (and training) will lower the costs of monitoring and enforcement,

and increase the scope for product traceability for a better response to market pressures for more sustainable agricultural practices. With focused investment in research and innovation, East Asia can lead the world in developing precision agriculture for smallholders, or in developing "clean meat"—reaping their concomitant economic and environmental benefits.

From Looming Crisis to Opportunity

Looking ahead, tackling East Asia's agricultural pollution challenge is not only within reach, but also a business and leadership opportunity.

Rapid change in the East Asia region bodes well for its ability to redirect farming—and the broader food sector—to a path of more durable, self-serving growth. East Asia's agricultural performance over the past 50–60 years also reflects its inclination toward innovation, its willingness to embrace new technology, and its capacity for transformation. Moreover, the strength, plurality, and dynamism of regional food cultures can help provide the impetus needed to "green" food production and propel these food cultures into the 21st century.

Like every crisis, agricultural pollution can be treated as an opportunity. While farming may be at risk in parts of the region, far more is at stake than farming. Policy actions that enable the public sector to act on agricultural pollution more decisively—consistent with the strategies just outlined—may have benefits that are felt more broadly. The public sector, in particular, can position agriculture to thrive as a business and evolve competitively by being at the service of human and ecosystem health and domestic market opportunities. Building domestically oriented capacity to control and prevent agricultural pollution specifically has the potential to help national food industries remain competitive domestically. Mitigating agricultural pollution can also help lessen what is often one of the root causes of social inequity.

East Asia is in a historic position to show the world how dietary transition can be decoupled from the rise of chronic disease, and tackling agricultural pollution can be one of the region's points of entry in doing so. This may be possible through the embrace of "double dividend" policies that favor both dietary and environmental health simultaneously. Finally, taking steps to mitigate agricultural pollution and enable sustainable food systems and diets to emerge more generally promises to provide significant business opportunities.

Notes

1. *Agricultural intensification* generally refers to a process in which inputs of capital or labor are increased in order to raise productivity per land area or livestock unit. In East Asia, it has rested on irrigation, high-yielding crop varieties, farm machinery, agricultural chemicals and fertilizers, and manufactured feeds.

2. *Eutrophication* refers to the degradation of a body of water (oxygen depletion and reduced sunlight penetration) resulting from an excessive richness of nutrients stimulating dense plant growth.
3. Health risks from water contamination by the remnants of pesticides, fertilizers, drugs, and other compounds related to farming include acute poisoning, irritations, cancers, brain tumors, birth defects, infertility, other disruptions of the endocrine system, cognitive impairment, and other neurodevelopmental effects.
4. The limited evidence available suggests that the economic costs of farm pollution are high. One research team estimated that China's excessive emissions of nitrogen related to the production of staple food cost the country 1.4 percent of annual GDP—close to US$49 billion—from 2001 to 2010. In Indonesia, forest fires tied in large part to the conversion of land to oil palm production cost an estimated US$16.1 billion in 2015, or more than the value added by palm oil production in 2014 (US$12 billion)—see World Bank (2016).
5. Developed by the International Rice Research Institute in collaboration with the An Giang Department of Agriculture and Rural Development in Vietnam, "1 Must and 5 Reductions," or 1M5R, calls for farmers to use certified seeds (the "1 Must"), while reducing the use of four production inputs (seed, water, pesticides, and chemical fertilizers) and postharvest losses (the "5 Reductions").

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Abbreviations

1M5R	"1 Must and 5 Reductions"
ADI	acceptable daily intake
ALS	amyotrophic lateral sclerosis
CBP	Chesapeake Bay Program
DARDs	departments of agriculture and rural development (Vietnam)
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FIRMS	Fire Information Resource Management System
GDP	gross domestic product
GHG	greenhouse gas
GWP	global warming potential
HIV	human immunodeficiency virus
IFA	International Fertilizer Association
IPM	integrated pest management
IRRI	International Rice Research Institute
ISSM	integrated soil-crop system management
MDI	Mekong Delta Development Research Institute (Can Tho University)
MEP	Ministry of Environmental Protection (China)
MoA	Ministry of Agriculture (China)
MRL	maximum residue limit
NASA	National Aeronautics and Space Administration
NUE	nitrogen use efficiency
NVZ	nitrate vulnerable zone
OECD	Organisation for Economic Co-operation and Development
PES	payments for ecosystem services
PM	particulate matter

SAR	special administrative region
SLCP	short-lived climate pollutant
TMDL	total maximum daily load
UNFCCC	United Nations Framework Convention on Climate Change
VOC	volatile organic compound

Chemicals

BC	black carbon
BKC	benzalkonium chloride
CH_4	methane
CO_2	carbon dioxide
HPO_4	hydrogen phosphate
K_2O	potassium oxide or potash
N	nitrogen
NH_3	ammonia
NO_2	nitrogen dioxide
NO_3	nitrate
NO_x	nitrogen oxides
NPK	nitrogen, phosphorus, and potassium
N_2O	nitrous oxide
O_3	ozone
P	phosphorus
P_2O_5	phosphate
SO_2	sulfur dioxide

Introduction

Context, Rationale, and Scope

Emerging East Asia is morphing into an agricultural powerhouse that is maturing and largely rising up to the task of feeding the swelling urban populations in the region and beyond. In this context, agriculture is often portrayed as a victim of industrial and urban pollution,[1] and this is indeed the case. However, agriculture is also taking an alarming and generally growing toll on national resources of all kinds—and this in the region that owes the largest proportion of deaths to the environment.[2] The first national survey of pollution that China released in 2010 was eye-opening. It revealed that, as of 2007, agricultural activities were the country's leading source of surface water pollution with respect to organic pollutants and nutrients.[3] In fact, agriculture is potentially becoming a victim of its own success. Growing recognition that a "pollute now, treat later" approach is unsustainable—from the perspective of both human health and agroindustry—is leading public and private sector actors to try to remedy this situation. The present study rose out of the work being undertaken by the World Bank Group with national governments to correct course. These efforts have revealed the need for a more systematic understanding of agricultural pollution realities in the region to better underpin and guide interventions.

This study, which focuses on three countries—China, Vietnam, and the Philippines—is intended to contribute to a more comprehensive and cross-cutting understanding of the nature and magnitude of the agricultural pollution problems that are deepening at different rates in the region. Agricultural pollution, in the context of this study, is limited to pollution[4] caused by or derived from crop and animal farming activities. It does not include processing, manufacturing, transportation, or other activities. Although they are a serious concern, pollution issues affecting but not caused by farming practices are beyond the scope of this study. By design, the study only explores agricultural pollution within the bounds allowed by the existing literature and highlights critical data and evidence gaps. The study also sheds light on some of the recurring drivers of agricultural pollution, and it touches on ways in which the public sector is intervening—with varying degrees of success—to steer the sector onto a path of

greener growth. Because the East Asia region is in flux, the study set out to specifically examine not only how the structural transformation of the agricultural sector and evolving nature of agricultural production may be shaping agricultural pollution, but also what this process brings in terms of opportunities.

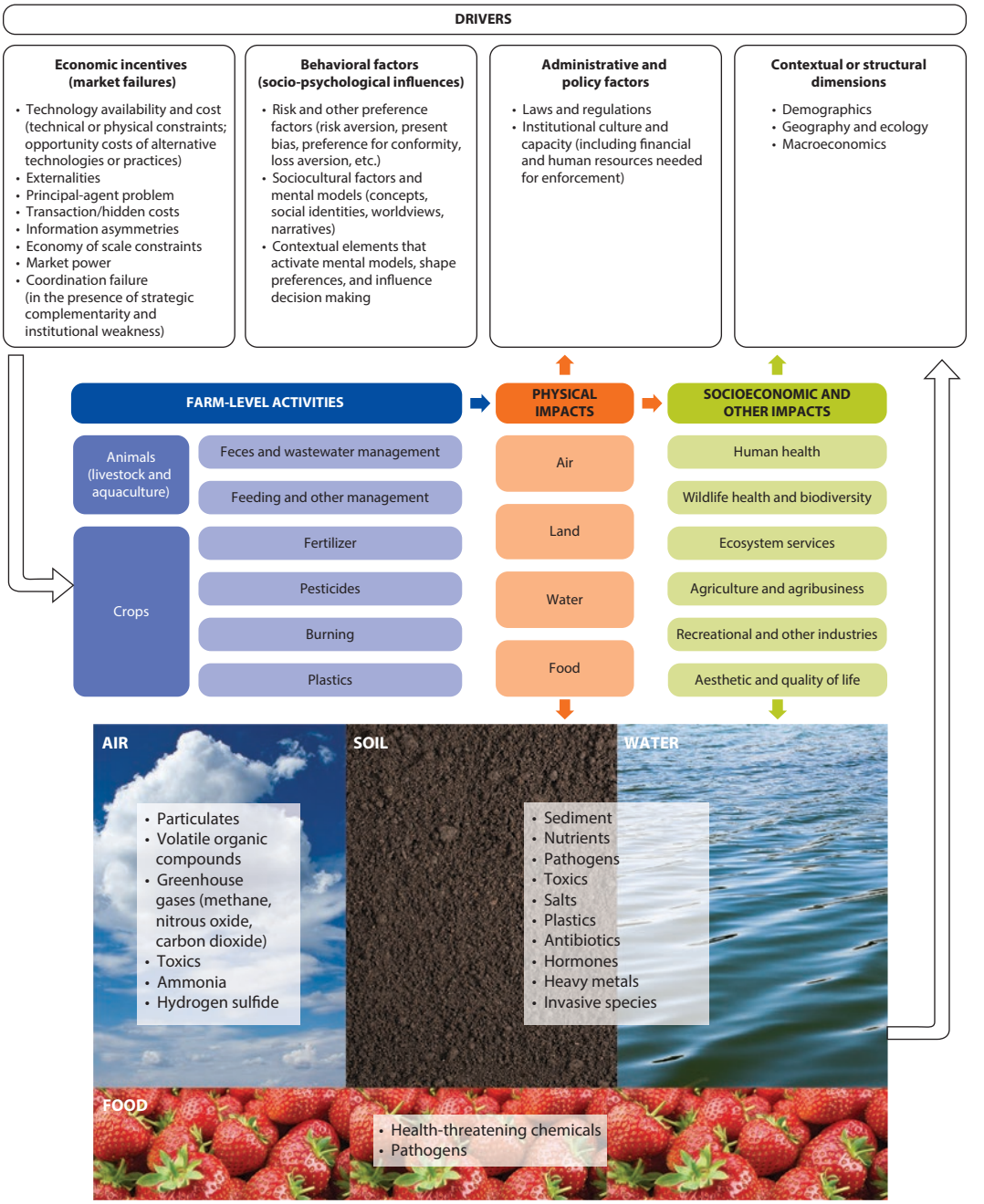
Few studies address the sweeping topic of agricultural pollution, in part for reasons that the limitations of this report confirm: the topic is in many ways too vast and too disparate to aggregate. To delve into this topic is to understand that agricultural pollution is both plural in nature and spatially diffuse. In a water context, much of agricultural pollution comes from nonpoint sources, in contrast to forms of pollution that can be traced to a specific point in space (compare pollution carried by runoff from multitudes of points in a landscape to that ejected by a spigot or smokestack). Agricultural pollution derives from a range of activities—from the choice and use of inputs to the siting of activities and disposal of wastes—and involves a vast set of pollutants, including nutrients, toxic substances, pathogens, antibiotics, particulates, metals, odors, greenhouse gases, and sediment. These pollutants have a range of physical impacts—on soil, water, ambient air, the climate, food quality, and ecosystem dynamics—and an even broader array of socioeconomic impacts relating notably to human health, wildlife, biodiversity, climate change, agronomy, agribusiness, trade, and other industry and ecosystem outcomes (see figure I.1).

The disparate and diffuse nature of agricultural pollution and its technical complexity have made it difficult to get national policy makers to focus on the issue. As noted, agriculture engenders a broad array of pollutants from a multitude of hard-to-pinpoint sources. For that reason, among others, many agricultural pollutants go undetected and unmeasured. When assessments do occur, they tend to be carried out within technical silos: the study of agricultural pollution is typically the domain of scientists, engineers, and local authorities, many endowed with limited resources or policy influence. Furthermore, the multiplicity of indicators used to capture and convey the extent of pollution and the severity of its health and other effects is both a sign and perpetuator of this field's fragmentation.[5] These aspects are not conducive to seeing agricultural pollution as a unified phenomenon or to comparing its different pieces. For all these reasons, decision makers and the public lack the evidence and tools needed to understand the relative magnitude and severity of pollution problems, including their socioeconomic impacts. This lack of evidence and tools limits the ability of decision makers to prioritize and advocate for interventions in general, or by pollutant, agricultural system, hazard, or geography.

The point of addressing agricultural pollution as a whole, then, is to present the range and breadth of the challenges posed by environmentally damaging farming practices. When agricultural pollution is considered in its entirety, both the significance (breadth, magnitude, and concentration) of its impacts and their relative neglect (in terms of measuring and mitigating them) become clear. This study will have met its primary objective if it helps policy makers in the region recognize the seriousness of the problem and the need to embrace environmental considerations in agricultural development strategies and action plans as an

Figure I.1 Sources and Impacts of Farm Pollution: A Multifaceted and Complex Problem

Farming generates many pollutants that take on different forms as they travel through soil, water, and air and enter the food chain. These pollution risks involve long, complex causal chains incorporating multiple sources, forms, and outcomes of pollution. In addition, these risks manifest themselves at different time scales and levels of severity.



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Note: Under the heading "Socioeconomic and other impacts," "Wildlife health and biodiversity" includes flora and fauna; "Ecosystem services" includes climate stability and climate change.

agricultural development priority. The main purpose of this study is not to offer specific solutions, but to lay out areas deserving greater policy attention, public resources, and further inquiry. The design of specific intervention strategies calls for more in-depth analysis of pollution drivers and the shortcomings of existing interventions in a given context and geography—and thus a return to a narrower scope of inquiry.

In this data-hungry space, this effort should be regarded as a gateway study. If policy makers are to respond to this study's call to action, they will need more comprehensive evidence and data to enable them to assess and prioritize the challenges that they use scarce resources to address. The study offers guidance by highlighting some of the farming systems, physical spaces, and pollution issues that represent key concerns in the region and the three countries of interest here. By reviewing the evidence, it sheds light on what is and is not known about agricultural pollution problems—their nature, magnitude, drivers, and impacts. However, this study should be regarded less as an endpoint and more as a starting point because country-specific data and evidence limitations do not permit it to draw some of the basic empirical conclusions it set out to reach. For example, only limited insights are currently available on the efficacy or cost-effectiveness of multiple technical, fiscal, and market interventions that have been deployed to influence farming practices in the region to date. A central and actionable finding of this study in this respect is the need for cohesive, systematic, and decision-oriented measurement systems that allow national and subnational policy makers to assess the value of intervention and to allocate resources to that purpose judiciously.

Road Map

This study has generated a collection of stand-alone pieces that address different aspects of the vast and complex topic that is pollution (see box I.1). The study's primary audience comprises policy makers and their advisers; ministries of agriculture and environment, including their staff; and a range of readers with varying technical backgrounds and interest in the subject. These include research institutions, industry organizations, nongovernmental organizations, and practitioners with an interest in sustainable agriculture and environmental protection.

This synthesis report has two parts. Chapter 1 describes the origins and consequences of farm-level pollution in emerging East Asia, focusing specifically on China, Vietnam, and the Philippines. The first section discusses some of the major agricultural pollution problems (water, soil, air, and food pollution) through the lens of their socioeconomic impacts. The second section ties these problems to broad categories of farming practices and the reasons for them: waste management practices in the livestock and aquaculture industries; the use of drugs, chemicals, and feed in these industries and in crop farming; the use of fertilizer and pesticides; the use and disposal of plastics; and the burning of agricultural residues. The third section examines how patterns of structural change,

including ones specific to the region, have contributed to certain polluting patterns and practices taking shape. The fourth section discusses the status of agroenvironmental policy in the three countries.

Chapter 2 delves into the policy implications of agricultural pollution, and it offers broad elements of a strategy to better address and prevent such pollution in the future, in the three study countries and the region at large. The first section argues that abatement is technically within reach and that the public sector has a key role to play in realizing the potential of abatement technology. The second section discusses the broad directions of institutional reform and public intervention needed to tackle pollution more effectively. The third section concludes by highlighting why tackling pollution is not only within reach, but also an opportunity to positively shape regional food systems more broadly.

Box I.1 Study Road Map

This "study" constitutes the totality of an effort that has generated multiple written outputs:

- *Synthesis report.* This synthesis report, *The Challenge of Agricultural Pollution*, is based in part on the working papers and other reports described in this box. While it focuses primarily on the three study countries—China, Vietnam, and the Philippines—it also seeks to draw lessons for emerging East Asia as a whole, where possible.
- *National studies of agricultural pollution in the three study countries.* Each country study includes a summary report and more in-depth reports on crops, livestock, and aquaculture pollution. They provide more comprehensive accounts of existing evidence on the nature and magnitude of agricultural pollution problems, including on hotspots and worrisome trends, on the drivers of pollution, and on current public sector responses (China: Gao et al. 2017; Vietnam: Cassou et al. 2017; Dinh 2017; Nguyen, C. V., 2017; Nguyen, T. H., 2017; the Philippines: Calub, Saludes, and Tabing 2016; Cuvin-Aralar, Ricafort, and Salvacion 2016; Magcale-Macandog, Briones, et al. 2016; Magcale-Macandog, Paraiso, et al. 2016).
- *Knowledge Notes.* A series of six notes examines agricultural pollution issues (nonregion-specific), their significance and drivers, and possible public sector responses. The notes cover fertilizers, pesticides, field burning, livestock waste, aquaculture, and agricultural plastics (Cassou 2017).
- *Working paper on livestock waste management approaches and practices in the Netherlands*, which has among the most intensive livestock sectors in the world (Backus 2017).
- *Working paper on aquaculture pollution* with a focus on the region and the three study countries and with multiple international examples of effective aquaculture management (White 2017). This paper was written with the support of the Food and Agriculture Organization of the United Nations.
- *Review of the international literature on agricultural pollution.* This literature review and its references (Crystal Romeo Upperman) offer general background on major agricultural pollution issues, globally and in the region.

Notes

1. See, for example, *Economist* (2017).
2. In 2012 nearly one in four deaths worldwide (23 percent) were related to an unhealthy environment (Prüss-Üstün et al. 2016). That proportion was highest in Southeast Asia, at 28 percent, and in nonmember countries of the Organisation for Economic Co-operation and Development (OECD) in the Western Pacific, at 29 percent.
3. Issued by China's Ministry of Environmental Protection (MEP), National Bureau of Statistics, and Ministry of Agriculture in 2010, the First National Pollution Source Survey Bulletin revealed that in 2007, crop, livestock, and aquatic farming contributed 44 percent of chemical oxygen demand, 57 percent of nitrogen (N) discharges, and 67 percent of phosphorus (P) discharges. Among agricultural sources, crop production accounted for 59 percent and 38 percent of N and P releases, respectively, and livestock production accounted for 38 percent and 56 percent of N and P discharges, respectively. Livestock production also accounted for 96 percent of chemical oxygen demand. Releases of nitrogen and phosphorus are linked to excessive or inappropriate crop fertilization and the discharge of untreated livestock wastes.
4. *Pollution* is commonly defined as the presence in the environment of an agent that is potentially damaging to either the environment or human health. Pollutants include chemicals, organisms, biological materials, and energy in its various forms such as noise, radiation, and heat (Briggs 2003).
5. Agricultural pollution—or conventional pollution more generally, for that matter—is not endowed with the equivalent of the carbon dioxide (CO_2)–equivalent metric. The embrace of this indicator of global warming potential by scientific, policy, advocacy, and finance communities has allowed all kinds of actors and decision makers, across sectors, to assess, compare, talk about, and act on climate pollution with an ease that would not be possible if every climate pollutant and its complex causal pathways were measured, studied, and discussed. The lack of convergence around a restrained and accessible set of such indicators in the field of pollution reflects and perpetuates the perception of the field's complexity. The result is that agricultural pollution is seldom thought of as a unified phenomenon, or at its full scale, and the very breadth of its ramifications helps obscure that fact and the broad significance of the problem.

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CHAPTER 1

Origins and Consequences of Farm-Level Pollution in Emerging East Asia

Adverse Effects of Agricultural Pollution

Pollution from farms has begun to stain East Asia's agricultural success story.

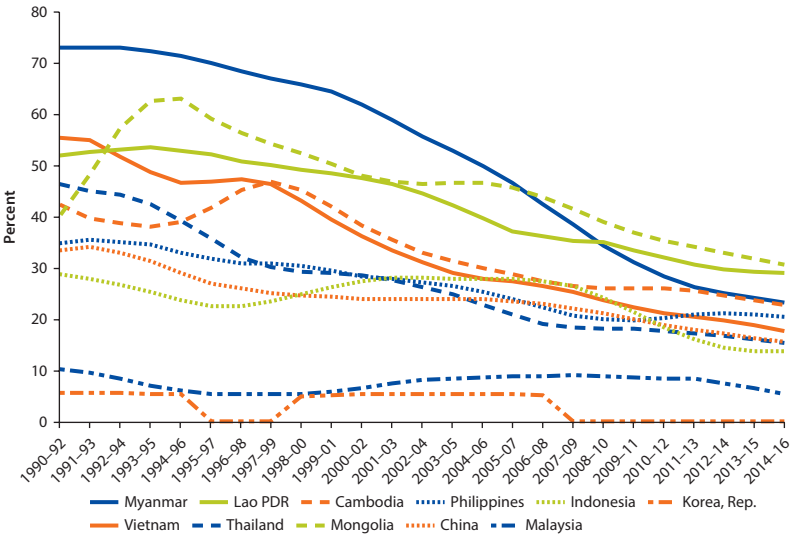
Agricultural intensification and growth have provided a solid footing for East Asia's development over the past three to five decades, but it is now time for the agricultural sector to address its expanding pollution footprint. Regional agriculture has largely succeeded—despite significant intraregional disparities—at feeding some of the world's fastest-developing societies (see box 1.1). More than that, it has proven responsive to rapid changes in people's food preferences and budgets, especially to the surging demand for animal products.[1] The breadth and severity of pollution problems to which agricultural development has given rise, however, may challenge the sector's ability to remain a positive force in the development of emerging East Asian economies. In China, for example, the accumulation of reactive nitrogen[2] in the environment over the past three decades—in large part due to agricultural intensification—has been deemed by scientists to be "extreme and unprecedented globally" (Cui et al. 2013, 4). And though it is pervasive insofar as it affects air, water, and soils, nitrogen is but one agricultural pollutant among many.

Agricultural pollution has progressed at different rates across this vast region, but it has become a concern in every country where farming has taken an intensive turn—indeed, even where very small farms continue to dominate. In that light, the rapid pace of farm industrialization and concentration, together with the continued importance of small yet intensive household farm operations, means that farm pollution could grow far severer in the years ahead—even though the relationship between these phenomena is far from linear and varies by subsector, farming context, and form of pollution.

Box 1.1 The Benefits of Agricultural Intensification in East Asia

Agricultural intensification, which involves technological upgrading and the increased use of inputs, has boosted agricultural productivity in developing East Asia and provided a firm basis for its growth. Across much of the region, agricultural output has expanded somewhat rapidly, even as the share of agriculture in the GDP of these economies has fallen with their structural transformation. For example, from 1990 to 2016, real agricultural value added grew at an annual average rate of 3.9 percent in China and 3.6 percent in Vietnam (it grew at only 2.2 percent in the Philippines). And while serious nutritional challenges remain, regional agriculture has contributed to plummeting rates of hunger (see figure B1.1.1).[a] Since 1990, the prevalence of food inadequacy has more than halved in China and fallen by nearly 70 percent in Vietnam. This achievement has rested primarily on the region's ability to multiply its production of grains despite being land-constrained. In the space of about 50 years, for example, China's grain output increased fivefold—a doubling on a per capita basis—even though land devoted to farming remained remarkably stable (see figure B1.1.2). Greater use of inputs, irrigation, and motorized tools has played a major role in stimulating cereal output growth by helping to improve yields—and often by allowing producers to grow more crops per year on a given plot of farmland.[b]

Figure B1.1.1 Prevalence of Food Inadequacy (Three-Year Average): Selected Countries, 1990–2016

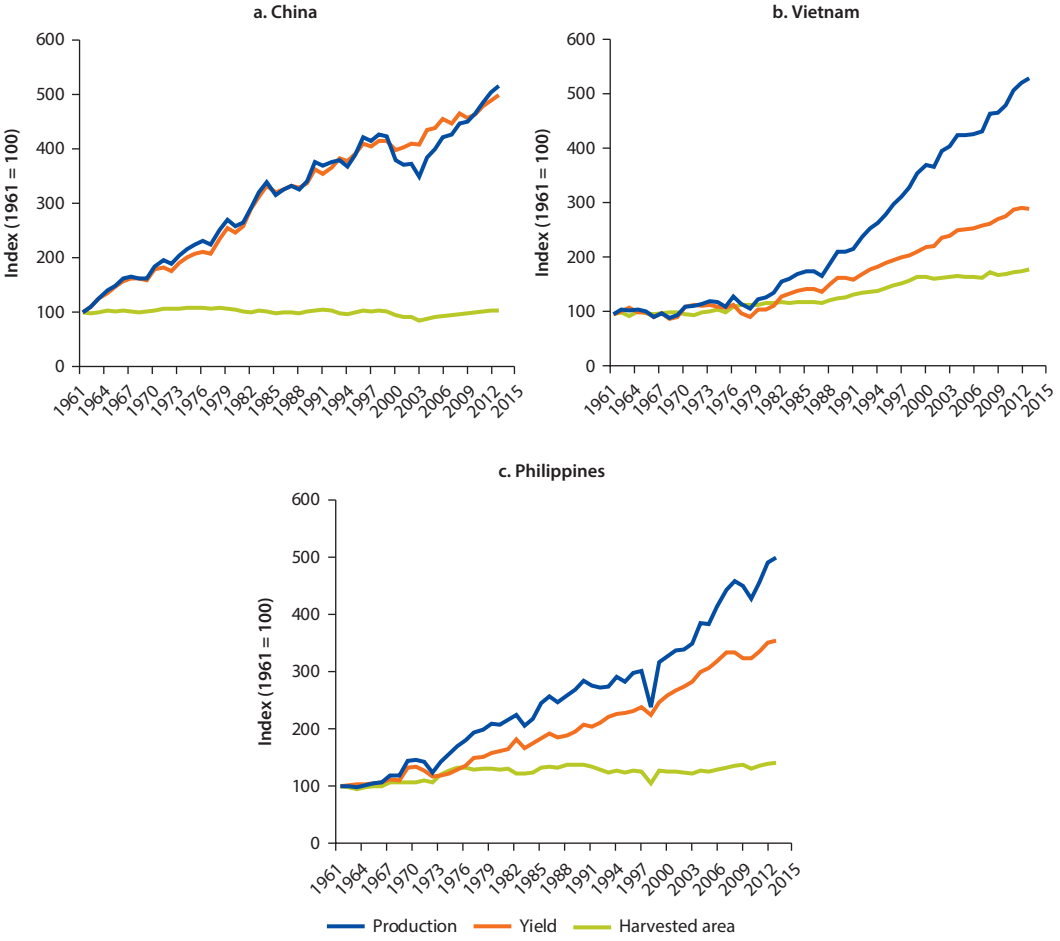


Source: Based on FAOSTAT data.
Note: Food inadequacy captures the proportion of a population at risk of not covering the food requirements associated with "normal" physical activity (http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/IICA_2013/Presentations/Day2_Food_Security_3.pdf).

box continues next page

Box 1.1 The Benefits of Agricultural Intensification in East Asia *(continued)*

Figure B1.1.2 Trends in Cereal Production, Yield, and Harvested Area: China, Vietnam, and the Philippines, 1961–2013



Source: Based on FAOSTAT data.

Note: Agricultural intensification generally refers to a process in which inputs of capital or labor are increased in order to raise productivity per land area or livestock unit (FAO Term Portal, http://www.fao.org/faoterm/en/). In East Asia, agricultural intensification has depended on irrigation, high-yielding crop varieties, power tools, and synthetic pesticides, nitrogen, and other fertilizers.

a. Also see Wang (2016).

b. See Li, Zhang, et al. (2014) on the intensification of grain production in China and Jaffee et al. (2012) on the intensification of rice production in Vietnam.

Intensive farming operations have already become a major source of water pollution in China and certain parts of Vietnam and the Philippines, and they are an underrecognized contributor to soil and air quality impairment. Many agricultural pollutants enter the environment from multiple and spatially diffuse sources, the cumulative effect of which can be tremendous. Evidence is often the clearest in China, where pollution levels also serve as a warning to other countries in the region.

In China, agriculture[3] was the leading source of surface water pollution in 2007, accounting for upward of 43 percent of organic matter discharges, 57 percent of nitrogen discharges, and 67 percent of phosphorus discharges (China MEP, National Bureau of Statistics, and Ministry of Agriculture 2010).[4] Agriculture is the leading cause of eutrophication[5] in the Yellow and South China Seas (Strokal et al. 2014), and in several of China's major freshwater lakes.

In Vietnam, agricultural pollution is a growing concern in the intensively farmed Mekong Delta and Red River Delta regions, even though limited monitoring data indicate that acute surface water pollution may remain a localized phenomenon, and agriculture's contributions have not been estimated precisely (Chea, Grenouillet, and Lek 2016; MRC 2014).[6] In the Mekong Delta, although monitored surface waters are broadly considered safe for humans and aquatic life by Mekong River Commission standards, measures also indicate that certain surface waters are "dramatically degraded" near intensively populated and farmed areas (Chea, Grenouillet, and Lek 2016; MRC 2014).

In the Philippines, although agriculture is not the leading water polluter overall, it was responsible for the largest share of organic pollution in monitored inland waters in 2013, with large livestock farms, which are concentrated around Metro Manila, accounting for an estimated 45 percent of biological oxygen demand from point sources, and other farms accounting for an estimated 61 percent of nonpoint sources (EMB 2014).

Agricultural pollution in these East Asian countries is likely harming human, animal, and ecosystem health; climate stability; farm productivity and agroindustry competitiveness; as well as other commercial interests and quality of life. Even when they are not directly measured, levels of pollution attributable to agriculture (such as soil and air pollution) can be inferred from farming practices. Similarly, the intensity of agricultural pollution observed in the three study countries—even where it is more localized such as in the Philippines—strongly suggests that it is having adverse socioeconomic effects. (See table 1.2 later in this chapter for an overview of possible agricultural pollution hotspots in the three countries.) Evidence suggests that the economic costs of farm pollution are high. To illustrate this point, box 1.2 points out the broad costs of "runaway" nitrogen, one of agriculture's key pollutants.

Human, Animal, and Ecosystem Health

Agricultural pollutants pose a multifaceted and sometimes underrecognized threat to human health in affected parts of the three countries. This is supported by evidence on the impact pathways that are discussed next.

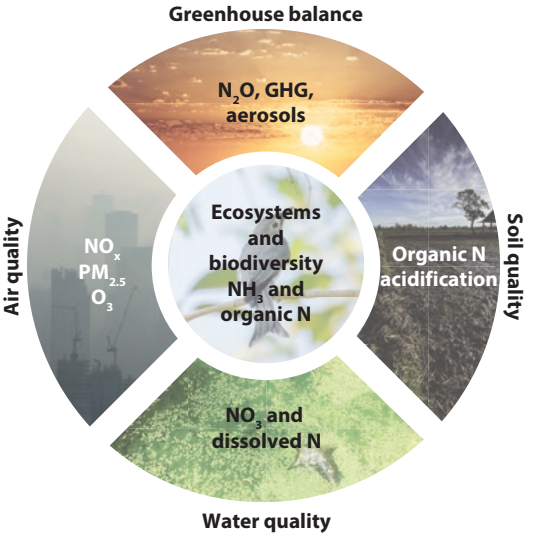
Drinking Water Contamination

Agriculture's contamination of drinking water—as well as water used for bathing and other household activities—is a key concern for urban and rural populations alike. This concern can be gleaned from the large body of evidence available on water pollution in the three countries, and particularly on surface water pollution in China. For example, at the national level in China over 61 percent of

Box 1.2 Valuing the Costs of "Runaway" Nitrogen

"Runaway" nitrogen—reactive nitrogen lost to the environment—has generally been associated with very high costs in the European Union: US$93–$428 billion a year, or 70–320 billion euros, according to the *European Nitrogen Assessment*. (Figure B1.2.1 depicts the major cost centers that are accounted for—see Sutton et al. 2011.) In the United States, the cost was running US$81–$441 billion a year in the early 2000s, according to Sobota et al. (2015)—also see Compton et al. (2011). In China, the 1998 algal bloom in the Lake Taihu catchment area was estimated to cost about US$6.5 billion (46.5 billion yuan), or 5.9 percent of the area's GDP (Le et al. 2010). Agricultural activities and households have been the leading source of water pollution in the area (Zhang, W. L., et al. 2004). A 2016 study of this intensively farmed region estimated that the cost of reactive nitrogen and greenhouse gas emissions from rice production amounted to 13.5 percent of farmers' economic returns from this crop (Xia, Xia, et al. 2016).[a] Another study by the same lead author estimated that during 2001–10, the greenhouse gases and reactive nitrogen emitted by staple food production cost the Chinese economy US$49 billion (325 billion yuan) a year, or nearly 1.44 percent of GDP.[b] Moreover, the damage costs combined with input costs accounted for 66–80 percent of the gross economic benefit generated from food production (Xia, Ti, et al. 2016).

Figure B1.2.1 Five Key Societal Threats of Reactive Nitrogen



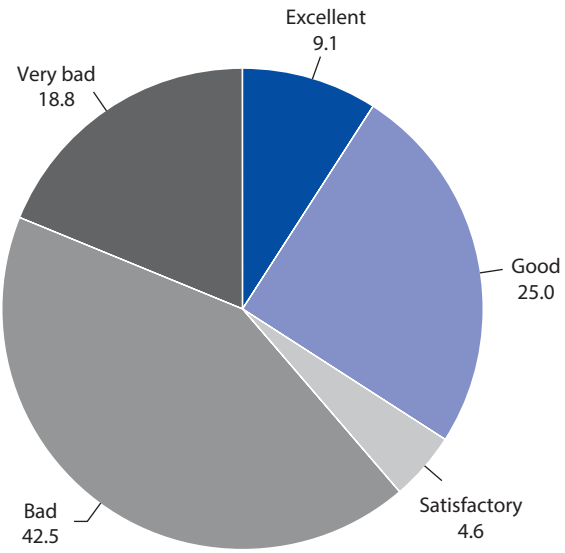
Sources: Based on Sutton et al. (2011). *Clockwise from top:* sky with sun: © Grisha Bruev/Shutterstock.com; plowed rice land: © Asian Images/Shutterstock.com; algae on water: © Siyanight/Shutterstock.com; city in fog: © Wantanee Chantasilp/Shutterstock.com. *Center:* bird on branch: © Tanawat Phensrisirikul/Shutterstock.com. All images used with permission of Shutterstock.com; further permission required for reuse.
Note: GHG = greenhouse gas; N = nitrogen; NH_3 = ammonia; NO_3 = nitrate; NO_x = nitrogen oxides; N_2O = nitrous oxide; O_3 = ozone; $PM_{2.5}$ = particulate matter 2.5.

a. There are no official data on the costs of runaway nitrogen in China.
b. The estimate takes into account the damage costs of multiple forms of pollution (ammonia volatilization, nitrogen oxides [NO_x] emissions, nitrous oxide [N_2O] emissions, nitrogen leaching and runoff, and greenhouse gas emissions) on ecosystems, human health, and climate warming. Per unit costs and sources of them are given in Xia, Ti, et al. (2016).

monitored groundwater sources (see "bad" and "very bad" in figure 1.1) and nearly 28 percent of monitored rivers were found to be unfit for human contact, and over 30 percent of major lakes and reservoirs failed to meet drinking or bathing water standards in 2015 (China MEP 2016a).[7] At the subnational level, in the 2000s, agricultural nonpoint sources became the primary polluter of the Miyun Reservoir, Beijing's most important source of drinking water, after fairly stringent measures reined in industrial pollution (Wang et al. 2003 in Zhou et al. 2010).[8] When massive algal blooms in China's once-scenic Lake Taihu, the country's third-largest freshwater lake,[9] threatened the drinking water of millions in 2007 (Stone 2011), local authorities had to start pumping drinking water from the Yangtze while taking measures to address point and nonpoint sources of pollution (see map 1.1). With respect to groundwater, there is evidence of serious nitrate pollution, especially in the north, where land has been given over to intensive cultivation of vegetables.[10]

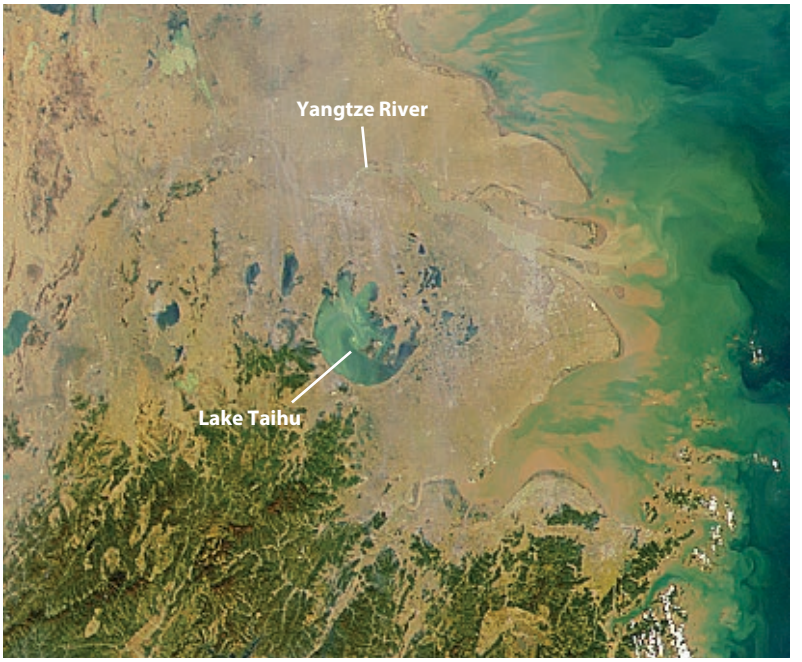
Water quality monitoring is more limited in Vietnam and the Philippines. Nonetheless, livestock farms are thought to be seriously reducing the quality of Ho Chi Minh City's drinking water supplies in Vietnam, and a similar situation likely exists in Metro Manila in the Philippines.[11] In Vietnam, most of the Mekong Delta's surface waters still broadly meet the thresholds for nutrients, organic waste, and acidity that are laid out in the Mekong River Commission Guidelines for the Protection of Human Health and Aquatic Life (MRC 2014),

Figure 1.1 Quality of Monitored Groundwater Sources: China, 2015
percent



Source: China MEP 2016a.
Note: The majority of China's monitored groundwater sources are unfit for drinking or bathing, and the quality of groundwater has been deteriorating in recent years. Surface water quality, however, has improved by Ministry of Environmental Protection standards. In 2001, for example, the water in 70 percent of monitored rivers failed to meet drinking or bathing water standards, compared with 28 percent in 2015.

Map 1.1 Aerial View of Eutrophication in China's Lake Taihu and Yangtze River



Sources: SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE (NASA Earth Observatory 1998) (http://visibleearth.nasa.gov/view.php?id=52738).
Note: Along with sewage and industrial waste, agricultural point and nonpoint sources are major causes of nutrient pollution in China's major freshwater lakes, and in some cases the leading ones (Le et al. 2010).

but local studies have pointed to unsafe levels of agricultural pesticides in drinking and domestic water from a range of groundwater and surface water sources (Lamers et al. 2011; Nguyen, C. G. D., et al. 2015; Schumacher 2011; Toan et al. 2013).[12] In the Philippines, aquaculture operations have been associated with mass fish kills, suggesting instances of acute local water contamination.

Health risks from water contamination include acute poisoning, irritations, cancers, brain tumors, birth defects, infertility, other disruptions of the endocrine system, cognitive impairment, and other neurodevelopmental effects that can stem from chronic exposure. Toxic algae and less visible contaminants, ranging from nitrates (especially in groundwater) and ammonia, to pesticides, fecal pathogens, heavy metals, and plastic leachates, can leave households with water that is unsafe for drinking or other uses. In drinking water, for example, high concentrations of nitrates left behind by animal feces and fertilizer are thought to cause methemoglobinemia (blue baby syndrome), with chronic exposure to lower doses potentially increasing the risk of cancer and other health problems (Naidenko, Cox, and Bruzelius 2012; WHO 2016, 2017).

Compromised Food Safety

Many East Asian consumers worry about the quality and safety of the foods and beverages they consume, and agriculture is implicated. One cause for concern is that certain agricultural pollutants find their way into food, either through direct deposition and adsorption (adhesion), or through bioaccumulation in the food chain via the tissues of animal flesh. In this respect, the contamination of China's soils with pesticides, heavy metals, and other chemical compounds is viewed as one of the major pollution problems the country faces. Studies of local food markets in Vietnam and the Philippines have also raised concerns about food safety, although these studies tend to have narrow geographic and temporal focuses. For example, one study of products from two communes in the Red River Basin in northern Vietnam found worrisome levels of pesticides in vegetable and fish samples (Pham et al. 2011).

Consumer sensitization to food safety risks has risen rapidly in China and is taking off in other countries in the region as well. Evidence on the nature and extent of food contamination originating in agricultural practices is thin, however, leaving the press to report on food safety "scares." Meanwhile, a large body of evidence has generally tied both acute and chronic pesticide exposure—whether through the ingestion of food and water or other means—to elevated rates of chronic diseases such as different types of cancers and diabetes; neurodegenerative disorders such as Parkinson's, Alzheimer's, and amyotrophic lateral sclerosis (ALS); birth defects; and reproductive disorders (Mostafalou and Abdollahi 2013). Exposure to chemicals in plastics, an issue of particular relevance in China, may also have some of these endocrine-disrupting and carcinogenic effects (Colborn, vom Saal, and Soto 1993; multiple sources in He et al. 2015).

Drug-Resistant Microbes

The systematic use of antibiotics and antimicrobial agents in pig, chicken, and aquaculture operations in the three countries, including by the majority of small producers, has potentially begun to give rise to drug-resistant microbes. These microbes spread through animal flesh, but also through drinking water and the air, and this phenomenon threatens to diminish the efficacy of drugs in preventing or treating diseases (see box 1.3). In China, an estimated 52 percent of antibiotics was administered to animals in 2013 (Zhang, Q. Q., et al. 2015).[13]

Box 1.3 Drug Resistance Related to the Use of Antibiotics and Other Antimicrobials: A Global Health Crisis

The systematic, mostly prophylactic (nontherapeutic) use of antimicrobial agents in overcrowded livestock and aquaculture farms, among others—even when they are administered at low doses—is giving rise to significant concerns about the emergence of drug-resistant microbes. Over time, the consumption of antimicrobials and their presence in the environment can exert selective pressure on microbial populations in aquatic environments or

box continues next page

Box 1.3 Drug Resistance Related to the Use of Antibiotics and Other Antimicrobials: A Global Health Crisis *(continued)*

in the guts of animals and lead microbes to develop resistance to treatment. Studies in the United States are now documenting the presence of bacteria resistant to five or more drugs used by the meat industry (FDA 2012). In Vietnam, studies have found that a large proportion of pathogens[a] sampled in aquaculture products and waters, in livestock, and in children living in rural areas have developed resistance to multiple—sometimes three or more—antibiotics used by the industry (Dyar et al. 2012; Huynh, Tran, and Nguyen 2015 in Nguyen, C. V., 2017; Khanh 2010; Phương et al. 2008 in Dinh 2017; Thi, Dung, and Hiep 2014).

This is a concern for animals as well as for humans who are exposed to drug-resistant bacteria (Sapkota et al. 2008; Watterson et al. 2012; WHO 2006). Human exposure to drug-resistant bacteria can occur through the consumption of animal products, but also through airborne dispersal in the vicinity of farms (Friese et al. 2013; Schulz et al. 2012) and through the consumption of "tainted" water. In addition, even when wastewater undergoes treatment, antibiotics and disinfectants can remain in trace amounts. Indigenous aquatic life is also vulnerable to transmission through translocated aquaculture species.

The effects of drug resistance on East Asian populations have not been adequately studied. Meanwhile, each year in the United States at least 2 million people become infected with bacteria that are resistant to antibiotics, and at least 23,000 people die as a direct result of these infections, while many more die from other conditions complicated by antibiotic-resistant infection (CDC 2013). In 2016, concern about the effects of antibiotic resistance on a global scale led the United Nations to declare it a "crisis," a status previously used for HIV and Ebola. Based on projections that antimicrobial resistance could cost the world economy between 1.1 percent and 3.8 percent of GDP by 2050, a 2017 World Bank report on the topic highlights the need to phase out the nontherapeutic use of antibiotics in agriculture (World Bank 2017).[b]

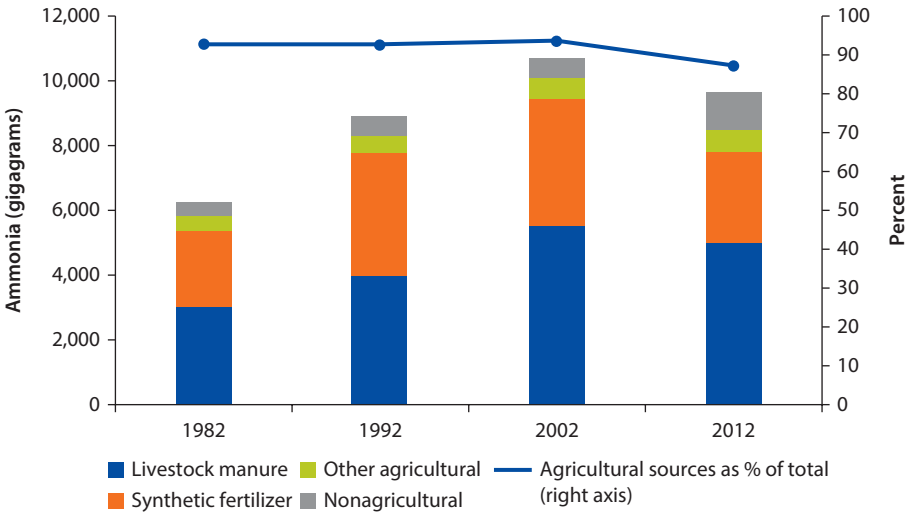
a. That is, 33–80 percent of isolates in the cited studies.
b. Conversely, interventions to prevent antimicrobial resistance are estimated to have exceptionally high economic rates of return of 31–88 percent.

Air Quality Impairment

Air quality impairment is a major concern in many of East Asia's densely populated metropolitan areas. In China, it is particularly severe: in 2013 average fine particulate matter ($PM_{2.5}$) levels were about three times the global population-weighted average (Zhang and Cao 2015), and in 2015 nearly 87 percent of monitored cities failed to meet air quality standards (China MEP 2016b).[14] Agriculture is implicated, even though its contributions to air pollution have been inadequately quantified. Fine particle and other emissions from agricultural burning, improper manure storage, and fertilizer and pesticide use contribute to air pollution and related disease. Nitrogen emissions in China—the sources of which include fertilizer use, manure, and biomass burning—are thought to be a major contributor to health-threatening smog (Liu et al. 2013; multiple sources in

Wang, Y., et al. 2013).[15] Nitrogen releases from agricultural sources in the form of ammonia, for example, were recently shown to be detracting from urban air quality in Chinese cities (Gu et al. 2014).[16] In 2012 agricultural sources accounted for 88 percent of China's ammonia emissions, with livestock manure alone emitting over half the national total—see figure 1.2 (Kang et al. 2016). Agricultural burning also drives air pollution to seasonal peaks in parts of the region after harvest or before planting (see map 1.2, showing fires and smoke in the Indochina Peninsula, and maps 1.3 and 1.4 showing fires and smoke in China).[17] In China, agricultural contributions to haze are particularly acute in southeastern China in the autumn and in western China in the spring (Zhang and Cao 2015). One study from the mid-2000s found that up to 19 percent of total $PM_{2.5}$ in the city of Guangzhou was due to biomass burning (Wang, Q., et al. 2007 in Liu, X., et al. 2013).

Figure 1.2 Ammonia Emissions from Agricultural and Other Sources: China, 1982–2012

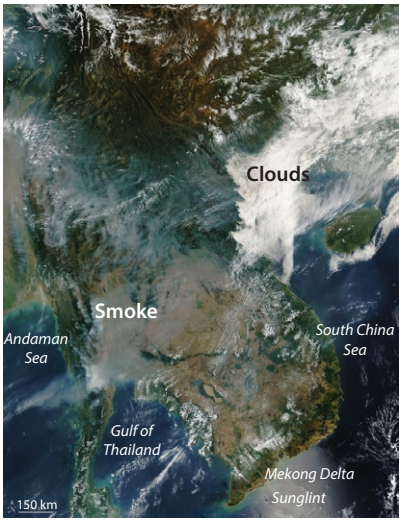


Source: Based on Kang et al. 2016.

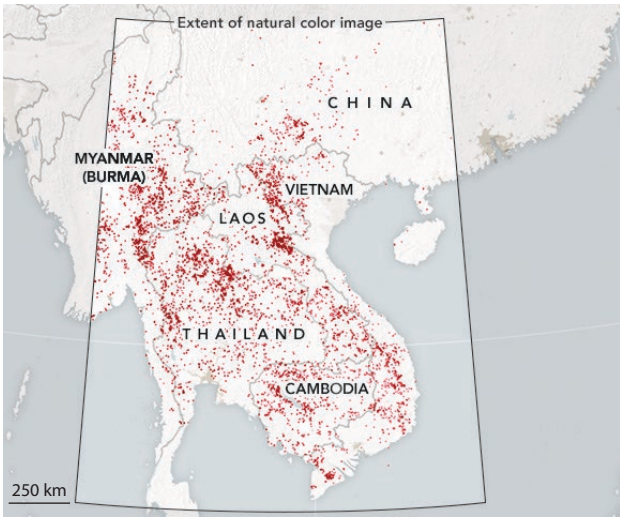
Regarding the health impacts of agricultural pollution, including air pollution, a number of studies from the East Asia region suggest that farm workers and rural populations are the most exposed. For example, farmers and rural communities are the most exposed to the smoke generated by agricultural burning, although urban populations are also affected, sometimes across national boundaries.[18] In Vietnam and the Philippines, farmers and their families are sometimes directly exposed to the pesticides they apply because they lack or do not use protective gear, or because they use methods such as broadcast spraying that

Map 1.2 Fires and Smoke in the Indochina Peninsula

a. Smoke

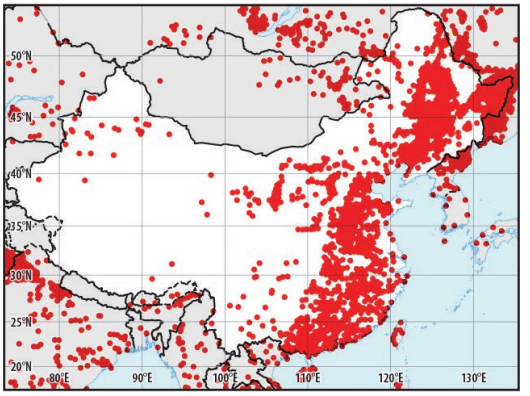


b. Heat from fires



Sources: Panel a: NASA image courtesy of Jeff Schmaltz, LANCE/EOSDIS Rapid Response, http://earthobservatory.nasa.gov/IOTD/view.php?id=87758. Panel b: NASA Earth Observatory map courtesy of Joshua Stevens. Original caption by Adam Voiland.
Note: In panel a, a thick cloud of smoke obscures much of western Thailand and eastern Myanmar. Panel b shows where heat from the fires was detected (red). Large numbers of small fires were burning throughout the Indochina peninsula on March 19, 2016. Labeling retained per original.

Map 1.3 Fire Counts in China, October 2014



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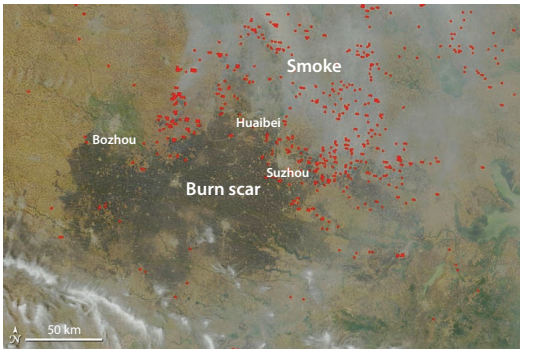
Source: Based on NASA Fire Information Resource Management System (FIRMS) data and published in Zhang and Cao (2015), October 2014. © Nature (CC BY 4.0).

Map 1.4 Wheat Fires in the North China Plain, June 2012



Source: NASA image courtesy of Jeff Schmaltz, LANCE MODIS Rapid Response, June 13, 2012, https://earthobservatory.nasa.gov/IOTD/view.php?id=78256. Original caption by Adam Voiland.
Note: Smoke and actively burning fires (red), and a large burn scar, are visible in this area of the North China Plain where wheat and maize are generally grown in rotation.

expose entire rural communities. In Vietnam, one study found that among surveyed Mekong Delta rice farmers who were medically tested, 35 percent showed signs of poisoning by organophosphates and carbamates, and 21 percent had symptoms of chronic poisoning (Dasgupta et al. 2007). Almost all the farmers who participated in a 2007 Mekong Delta survey (in Can Tho and Tien Giang Provinces) reported that they had experienced negative health effects from using pesticides (Nguyen 2016). Rural populations are also particularly exposed to water pollutants because of their reliance on canal and other waters that are laden with agricultural runoff, including livestock waste—a matter of concern in Vietnam.

Meanwhile, some of the most significant health risks of agricultural pollution likely fail to receive attention because of their slow onset, their chronicity, and the challenges of observing them. Even acute health impacts are probably underreported when they affect agricultural worker populations that are weakly organized or lack political representation. In fact, the broader literature on the health impacts of pollution sometimes points out that youth, the elderly, and other populations with lower immunity are among the most vulnerable.

For wildlife and ecosystems on the front lines of exposure, the health effects of agricultural pollutants may be even severer than for people. Intensively farmed areas of China are giving off emissions of reactive nitrogen that are depositing into and fertilizing nonagricultural ecosystems at high rates, with observable impacts on nonagricultural ecosystems.[19] This phenomenon is known to come at a high cost to biodiversity (see box 1.4) and multiple ecosystem functions

Box 1.4 When Biodiversity Suffers from Pollution

Agricultural pollution, in both its acute and chronic forms, is a major threat to crop and animal biodiversity, and species losses can be irreversible even after pollution ceases (Clark and Tilman 2008). The fact that some 30 percent of China's monitored surface waters fail to meet national "Grade III" standards may be a serious threat to biodiversity. The ammonium standard for Grade III (1 milligram per liter) is the threshold above which biodiversity losses are thought to occur.[a] Though less studied, rates of terrestrial nitrogen deposition and soil acidification are similarly a concern considering that increases in these rates have been associated with biodiversity losses in other regions of the world (see figure B1.4.1 and Stevens et al. 2010).

The effects pollution can have on species are evident in China's Lake Dianchi, which is heavily affected by livestock and other forms of pollution, and has lost its capacity to self-purify (Liu and Wang 2016). "Large" aquatic plants (macrophytes) have given way to very "small" ones (phytoplankton)—see Jin, Wang, and He (2006).[b] This change has possibly had impacts on broader ecosystem dynamics because macrophytes typically provide food, habitat, and oxygen for aquatic fauna, including species that are fed on by ones higher up the food chain.[c] Similarly, Lake Taihu's macrophyte area coverage and diversity significantly declined in the 2000s and 2010s as the result of eutrophication (Qin et al. 2013).

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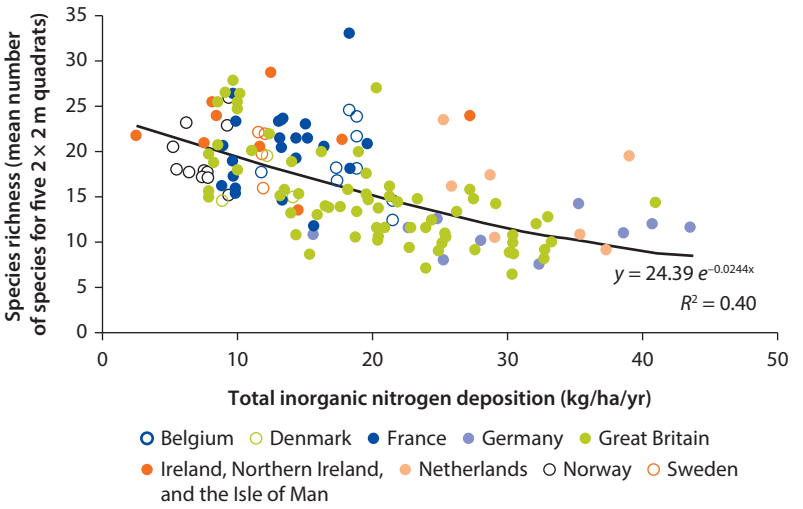
Box 1.4 When Biodiversity Suffers from Pollution *(continued)*

Figure B1.4.1 Nitrogen Deposition and Species Richness in Europe



Source: Stevens et al. 2010. © Elsevier. Used with permission; further permission required for reuse.
Note: kg/ha/yr = kilograms per hectare per year; m = meter.

In Vietnam, some of the pesticides that are in use are listed in the U.S. Environmental Protection Agency's Aquatic Life Benchmarks (U.S. EPA 2014 in Nguyen, C. G. D., et al. 2015). In one study of the Mekong Delta, fipronil concentrations thought to cause acute toxicity to invertebrates were exceeded in half of the samples, while the reference point for chronic toxicity was exceeded in nearly 77 percent of samples (Nguyen, C. G. D., et al. 2015).

Introduced aquatic species have had far-reaching detrimental effects on native populations and aquatic biodiversity in the Philippines. This has notably been the case in Laguna Bay, the Philippines's largest inland body of water, where biodiversity[d] and native species have suffered from the introduction of cultured species such as Nile tilapia, bighead carp, and Tra catfish (Cuvin-Aralar 2014).

a. Ammonium is a form of reactive nitrogen, and biodiversity loss in water is thought to occur from 1.5 to 2 milligrams of reactive nitrogen (N_r) per liter, according to the *European Nitrogen Assessment* (Sutton et al. 2011).
b. The study found macrophytes in less than 2 percent of the lake's surface, compared with 90 percent previously.
c. A Climate Trust 2015 presentation reported that an estimated 55 percent of the lake's fish population was killed. However, such impacts are understudied (http://www.slideshare.net/TheClimateTrust/nitrogen-fertilizer-reduction-in-china-150507mkt).
d. As measured by various biodiversity indexes, including the Shannon-Wiener index, Simpson index, and species evenness.

(Jones et al. 2014; multiple sources in Liu, G., et al. 2013).[20] Amphibians are highly vulnerable to pesticide exposure, for example, and soil biota, insects, aquatic species, and birds, among others, are also at risk from pollution.[21]

In some parts of the region, the survival of a population or species is at stake in a particular location—fish kills and pollinator disappearance being prime examples of this. The eutrophication of waterbodies sometimes leads to mass

fish kills and even to dead zones in which almost no species survive. Mass fish kills have become a common occurrence in the Philippines. In China, most lakes are eutrophic or on their way to being so (Qin et al. 2013),[22] as are three of its seas[23] (Strokal et al. 2014). This problem has altered aquatic life in certain waterbodies (see box 1.4); however, evidence on the specific impacts of (agricultural) pollution on wildlife remains weak.

In all three study countries, the use of pesticides on rice and other crops has likely contributed to harming and sometimes jeopardizing the survival of various species, including the fish, snails, and birds traditionally found in paddy fields and sometimes used by farmers to supplement their diet. In Vietnam's Mekong Delta, for example, snakehead fish, which seek shallow water such as that in rice paddies to reproduce, have reportedly declined dramatically since the 1980s (Nguyen, Nguyen, and Bayley 2008). The life of less visible or charismatic species is also at stake, including that of soil and aquatic microbes, the dynamics of which can be thrown off balance by pollution, including the use of plastic ground covers.

Wildlife and ecosystems are also known to face risks that humans do not face, but country-specific evidence is more limited on these. One is the risk of asphyxiation when the oxygen dissolved in water becomes depleted—as a result of nutrient pollution causing an initial upsurge in biological activity. Organisms and population dynamics are also vulnerable to the "temperature pollution" of soil—specifically, temperature increases brought on by plastic ground covers, even though this effect is deliberately sought to expand the growing season or the range of suitable crops in cold weather contexts. Another risk is the disruption of photosynthesis and the entire aquatic food chain when sunlight is obstructed from filtering into water by plastic debris or an overgrowth of algae. Plastic debris can also cause mechanical harm to wildlife via either ingestion or entanglement. Ground-level ozone can damage plant tissues and slow photosynthesis. Certain chemicals, including disinfectants added to aquaculture waters, can be acutely toxic to aquatic biota. Separately, genetic pollution, and with it the potential for the loss of biodiversity and spread of disease, is a risk associated with the introduction of nonnative or invasive aquatic species.

Climate Stability

As the primary emitter of nitrous oxide (N_2O) and methane (CH_4), as well as a source of other long-lived and short-lived climate pollutants, regional agriculture is contributing significantly to both long-term and short-term climate warming.

Agriculture is the leading regional source of the *long-lived* greenhouse gas nitrous oxide, which has nearly 300 times the global warming potential of carbon dioxide in a 100-year time frame. Its largest single source—in the region and globally—is the use (and afterlife) of nitrogenous fertilizer.[24] Synthetic fertilizer use is the leading source of agricultural greenhouse gases in East Asia

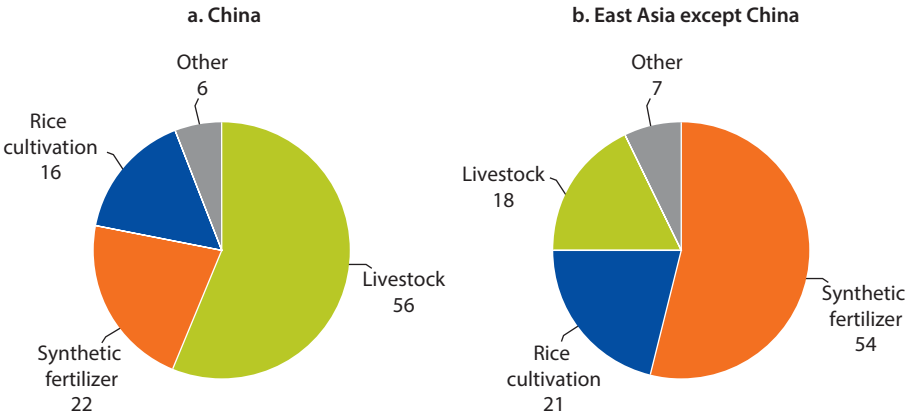
as a whole (based on FAOSTAT data). Manure management is also a significant source of nitrous oxide emissions, as is the burning of biomass (most biomass burning emissions—in particular, those related to land-use conversion—are considered indirect agricultural emissions and are not counted here).

Agricultural activities[25] are also the leading regional source of methane emissions, a *short-lived* climate pollutant (SLCP)[26] that needs to be contained to slow climate change in the near term. Livestock rearing, rice cultivation, and agricultural burning are the major sources of methane.[27] Among them, livestock rearing and rice cultivation were the second- and third-largest sources of agricultural greenhouse gases in the region as of 2014 (based on FAOSTAT data).[28] Agriculture's contributions to fine particulate matter or its formation—especially black carbon (BC)—and to ground-level ozone (O_3) are also potential factors in near-term warming.[29] The main sources of these emissions are agricultural burning (BC, O_3), manure management (O_3), and fertilizer and pesticide use (O_3).[30]

China is by far the dominant emitter of agricultural greenhouse gases in the East Asia region. As of 2014, the livestock sector was the country's largest source of agricultural greenhouse gas emissions (see figure 1.3), not counting its indirect emissions from the intensive growing of feed crops (based on FAOSTAT data). On a lifecycle basis, synthetic fertilizer production and use were estimated to account for fully 7 percent of national greenhouse gas emissions as of 2010 (Zhang, Dou, et al. 2013). At an estimated 6 percent of total emissions in 2014, however, the agricultural sector's direct emissions have been increasingly dwarfed by those of other sectors in China (based on WRI CAIT data). In particular, agricultural emissions were overtaken by industrial process emissions after 2005, putting agricultural emissions in third place (based on WRI CAIT data).[31] Nonetheless, agriculture is the largest source of both methane and nitrous oxide emissions in China.

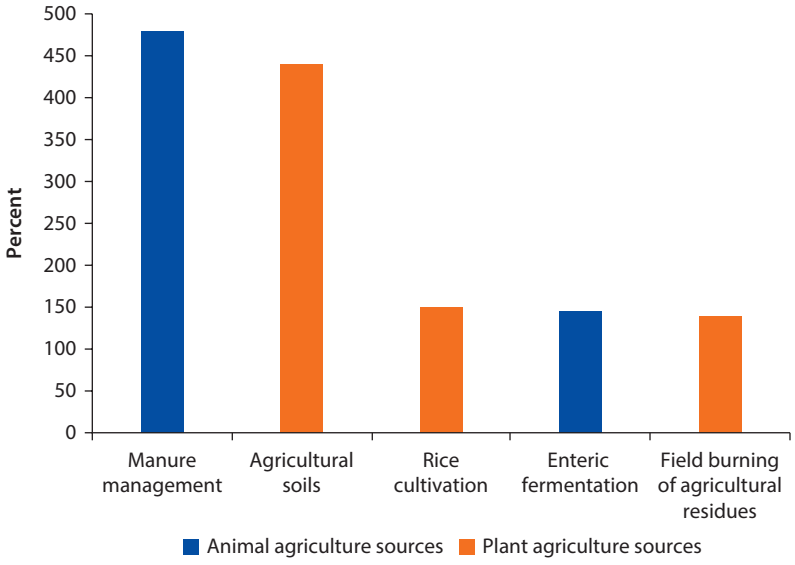
Agriculture is the second-largest source of national greenhouse gas emissions (including short- and long-lived greenhouse gases) in Vietnam and the Philippines, making it of key importance to meeting commitments to mitigate climate change. As of 2014, agricultural activities (narrowly defined) contributed to 29 percent of national greenhouse gas emissions in the Philippines and to 23 percent in Vietnam (based on WRI CAIT data). Also as of 2014, rice cultivation was the leading source of agricultural greenhouse gas emissions in the Philippines and Vietnam, followed closely by the rearing of livestock (based on FAOSTAT data). Emissions from livestock manure management, however, grew at 3.2 times the rate of rice-related emissions between 1994 and 2010 in Vietnam (see figure 1.4), consistent with the industrialization and concentration of livestock rearing under way there (based on data reported to the United Nations Framework Convention on Climate Change [UNFCCC]).[32] Emissions related to the management of agricultural soils increased at a similarly rapid pace, consistent with increases in fertilizer use.

Figure 1.3 Breakdown of Agricultural Greenhouse Gas Emissions: China and Rest of East Asia, 2014 Estimates
percent



Source: Based on FAOSTAT data.
Note: Greenhouse gas emissions are nitrous oxide and methane emissions in this case. Livestock emissions include those from enteric fermentation and manure management. Other emissions include those from crop residue and soil management (nonburning), and burning.

Figure 1.4 Increases in Reported Agricultural Greenhouse Gas Emissions: Vietnam, 1994–2010



Source: Based on greenhouse gas emissions data reported to the United Nations Framework Convention on Climate Change, https://unfccc.int/files/ghg_data/ghg_data_unfccc/ghg_profiles/application/pdf/vnm_ghg_profile.pdf.

Farm Productivity and Agroindustry Competitiveness

In the face of agricultural pollution, many commercial interests are at stake in East Asia, including those of farmers. Agriculture, much like wildlife, is on the front lines when it comes to bearing the brunt of environmental pollution—not only of industrial and urban origin, but also of agricultural origin. Other sectors likely affected, as discussed below, include the real estate, tourism, and utility industries, among others.

In China and Vietnam, farming is already known or suspected to be suffering from the pollution of soils and water, as well as the direct contamination of food products. For that reason, various studies point to the win-win nature of pollution control efforts. In China's intensively farmed and highly polluted Lake Taihu region, for example, one study demonstrated that farmers could improve their income by nearly 4 percent per hectare and help the environment by reducing the amount of nitrogen they apply to their land by 20 percent, compared with the high levels (about 300 kilograms of nitrogen per hectare) typically observed in the area in recent years (Xia, Ti, et al. 2016). The effects of pollution on agroindustry can be traced to several causal pathways.

Soil Disturbance and Acidification (Affecting Fertility)

Soil acidification is a natural process that can be accelerated by farming practices such as irrigation, fertilization, and the removal of crop residues from farmland. In China, the rate at which soils acidified between the 1980s and 2000s would take hundreds of years to materialize under natural conditions (Guo et al. 2010; Zhang, Zhang, et al. 2013). Soil acidification can in turn promote the loss of soil nutrients, as well as crops' absorption of heavy metals.[33] These outcomes sometimes beget the continuation of costly and destructive practices. In southern China, where a full 65 percent of agricultural soils have become severely acidified,[34] fertilizer use has been both a cause of and a response to soil acidification (Zhang, Zhang, et al. 2013). Soil fertility and crop yields are at risk when fertilizer losses; field burning; and the use of plastic ground covers, irrigation, and other farming activities result in soil acidification, salinization, soil warming, and other disturbances.

Crop-Damaging Air Pollution

Ground-level ozone, the formation of which is enhanced by nitrogenous emissions (including from fertilizer and manure management), is known to have a damaging effect on crops—and vegetation more generally, as noted earlier (UNEP 2011). Thus the multiplication of intensive livestock operations and the heavy-handed use of nitrogenous fertilizers that have been so pronounced in China and Vietnam may be having an adverse effect on yields.

Loss of Pollination and Biological Controls

The loss of pollination and biological controls is a risk when species succumb to multiple agricultural stressors, including habitat loss and exposure to pesticides. Hand pollination is used in fruit tree–growing parts of western China, and the substitution of pollinators by manual labor—at least partly due to heavy

pesticide use in fruit orchards—has likely come at a heavy cost to the industry (FAO 2008; Goulson 2012; Partap and Ya 2012; Partap, Partap, and Yonghua 2001). Pollinators play an essential role in the production of many cereal, orchard, horticultural, and forage crops.

Tainted Water and Fishery Yields

Aquaculture yields have been known to suffer from aquaculture and other farm-related pollutants in all three countries (see box 1.5).

Box 1.5 Aquaculture: A Polluted Polluter

- *In the Philippines,* mass fish kills are a common occurrence in aquaculture operations and a source of financial losses for the subsector. Over 300 incidents were recorded between 2005 and 2014, and nearly 40 percent of those cases were attributed to dissolved oxygen depletion and elevated ammonia levels—effects of nutrient pollution and algal blooms (Cuvin-Aralar, Ricafort, and Salvacion 2016). Inland fish kills have been attributed to agricultural runoff into aquaculture operations; other cases have been linked to mariculture practices. One study showed that the pesticides used in vegetable and rice farming within the Pagsanjan-Lumban catchment were negatively affecting tilapia and shrimp farms in the area (Varca 2012).
- *In Vietnam,* the prolonged misuse of pesticides and fertilizers has affected the development of inland fisheries, including pond culture, cage and pen rearing, and brackish water culture. Even though farmers have become more informed about pesticide impacts and selective in their use, the current use of pesticides has harmed fish yields in the Mekong Delta (Nguyen, T. T., 2016). It has notably decreased the growth and survival rates of climbing perch, a native species widely cultivated in rice paddies that is not only an important source of high-quality food fish, but also a natural predator of the brown planthopper, thereby reducing the need for synthetic chemicals to control this pest. In northern Vietnam, significant exposure of fish to toxic levels of pesticides was found after their application (La et al. 2014). Other studies have revealed the long-lasting effects of organophosphate pesticides on fish health (Nguyen, Phuong, and Bayley 2006).
- *In Taiwan, China,* the indiscriminate use of antibiotics is thought to have been among the reasons shrimp farms collapsed in 1988. The drugs increased the survival rate of farmed species in the near term, but they also cultivated drug-resistant pathogens over time (Lin 1989 in Primavera 2006).
- *In China,* nutrient discharges by mariculture have reached noticeable levels in certain regions. As of 2005, those discharged along the Yellow Sea accounted for 2.8 percent of total land-source nitrogen and phosphorus, and along the Bohai Sea, 5.3 percent (Cui, Chen, and Chen 2005). For some observers, how China develops its aquaculture sector is a key question for the future of the world's oceans (Cao et al. 2015).

Vulnerability to Pandemics Due to Drug Resistance

Pandemics such as avian influenza have inflicted devastating losses on the livestock industries in China and Vietnam in recent years.[35] If confined livestock and aquaculture operations breed drug-resistant pathogens, their emergence may

open new pathways for pandemics to rock these industries again. Short of this outcome, the need to develop and switch to new drugs is all but certain to incur additional costs.

Food Safety, Sales, and Trade

Cases of paralytic shellfish poisoning,[36] which are attributable to red tides (algal blooms) in eutrophied waters, are regularly reported in the Philippines and up and down the coasts of East Asia (Ching et al. 2015; Wu, Zheng, and Wang 2005). Food safety concerns such as these have commercial consequences. The discovery of excessive levels of contaminants in food products destined for demanding markets can lead to trade rejections worth tens of millions of dollars (based on UNIDO 2015). In Vietnam, trade rejections linked to the detection of excessive levels of veterinary drugs or pathogens have been persistent in sales to Japan, the European Union (EU), Australia, and the United States, and the aggregate value of Vietnam's fish and fish product rejections by the United States, Japan, the EU, and Australia exceeded that of any other country during 2002–10.[37] One of the most common reasons for the rejection of Chinese food products for export to the United States during 1998–2009 was the "potentially harmful veterinary drug residues in farm-raised fish and shrimp," a problem that arises from farm-level practices (Gale and Buzby 2009, iv).

Corroborated or suspected food safety problems can also be detrimental to the reputation of the agrofood industry, even when they are punctual (confined to one point in time). For example, a 2008 incident in which Japanese consumers were sickened by pesticide residues in dumplings from China contributed to elevating Japan's concerns about the safety of Chinese food imports (Gale and Buzby 2009). Worries about the safety of Chinese seafood raised in waters laced with drugs, pesticides, and other agricultural and nonagricultural contaminants have been described at times as a threat to southern China's booming aquaculture industry (Barboza 2017). In recent years, countries including Japan and Australia have threatened to interrupt certain aquaculture imports from Vietnam because of food safety concerns (Nguyen, C. V., 2017).[38] The potential lowering effect of food safety concerns on the prices commanded by Vietnamese food exports has not been studied empirically, however.

In general, food safety can be jeopardized by the improper application of fertilizer and pesticides to crops, the treatment of farmed animals with antiparasitics and antibiotics, and the pollution of agricultural soil and water with transmittable contaminants (including potentially by plastics chemicals). In crop farming, the risk is amplified by acidified soils because they can promote plants' uptake of these substances.[39] In this light, it is significant that certain surface waters in Vietnam have been rendered unfit for irrigation by agricultural (and other) pollutants.

Other Industries and Quality of Life

Finally, as a sensory, ecosystem, and health pollutant, agriculture is affecting the basic quality of life of many residents of East Asia. It is also affecting several

industries in addition to the agrofood industry. This phenomenon is primarily documented by the media in the three study countries.

Housing Market and Quality of Life

Residents living near pig and other livestock farms endure foul odors and unpleasant sounds, and probably a degradation of the value of their real estate. This problem has notably stirred residents of densely pig-populated zones in Vietnam's Thai Binh, Dong Nai, and Ha Nam Provinces, and on the outskirts of Ho Chi Minh City. In China's Guangdong Province, a stronghold of the national livestock industry, villagers have sought media attention to demand that the province enforce environmental regulations, claiming that their health has suffered from the polluting ways of pig farms (Yao 2015). Separately, smog darkens and corrodes cities and reduces visibility.[40] Visibility has been compromised across China, though nowhere more than in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei region (Zhang and Cao 2015).

Tourism, Utility, and Other Industries

The algal bloom that engulfed China's Olympic stadium in Qingdao in 2008 is emblematic of the kind of visual blemish to which agricultural pollution can contribute (see photo 1.1).[41] Besides being visually polluting, algal blooms can carry toxins that make waters unfit for swimming. The presence of nitrates and other compounds can make waters unsafe for recreational use as well. Meanwhile, plastic debris and aquaculture installations can spoil the safety and beauty of coastal areas. Thus, in addition to jeopardizing human health, agricultural pollutants (and infrastructure) sometimes create visual blemishes in natural landscapes that detract from an area's recreational value.

Photo 1.1 Green Tides along the Coast of Qingdao, China

Source: © Dongyan Liu. Used with permission; further permission required for reuse.
Note: Since 2007, vast algal blooms (covering nearly 29,000 square kilometers in 2013) have blanketed the Yellow Sea, bringing annual green tides to China's coast. In this photo, a green tide is engulfing an Olympic stadium in 2008.

The shutdown of a water treatment plant on China's Lake Dianchi because of algal overgrowth during the 1990s is an extreme example of the potential cost of agricultural pollution to the utility industry.[42] In general, the eutrophication of waterbodies has been known to interfere with the operations of industries that rely on or are in the business of providing clean water.

Farming as a Source of Pollution

A wide range of pollution hazards stem directly from a narrower set of farm-level practices.

These practices relate to the management of both inputs and outputs in crop and animal agriculture.[43] Inputs include fertilizers, pesticides, and other chemical treatments; water used for irrigation; drugs and feed; fuels used for power tools, vehicles, and pumping; and plastics. Outputs include crop residues; water used for aquaculture and the cleaning of livestock farms; plastic containers and films; and animal waste (see table 1.1).

Table 1.1 Farm Activities and Management Practices with Pollution Consequences

Farm management practices		*Farming activities (structural)*
(Mis-)uses of . . .	*(Mis-)management and disposal of . . .*	
Fertilizer	Animal waste	Animal agriculture expansion and intensification
Feed	Water used to clean or flush livestock and aquaculture farms	Cropland expansion, multiple harvests, monoculture
Pesticides	Water used for irrigation[a]	Related forest clearing, peatland draining, mangrove destruction, and other forms of land-use conversion[a]
Other chemical treatments (as in aquaculture)	Crop residues	
Drugs	Plastic containers and films	
Plastics		
Genetic material (especially the introduction of species in aquaculture)		
Fuels for energy[a]		
Soil (tillage)[a]		

a. Energy, tillage, irrigation, and land-use conversion were not a focus of this study.

Livestock and Aquaculture Waste Management

In China, Vietnam, and, to an increasing extent, the Philippines, the dumping of untreated manure and feces-laden wastewater (or dry waste) from livestock and aquaculture operations into the environment is a rampant, often uncontrolled, and expanding problem. It is particularly problematic in the suburbs of certain big cities where small, formal and informal livestock operations have clustered. An estimated 36 percent of animal waste generated in Vietnam is directly dumped into the environment without treatment (Nguyen, T. H., 2017), and, according to more dated surveys, up to 80 percent of animal waste was being disposed of in this manner in some parts of the Philippines (Catelo, Dorado, and Agbisit 2001; Catelo, Narrod, and Tiongco 2008). Once a prized resource,

organic materials, animal and vegetable, have increasingly become a waste stream. In China, the rates of organic waste returned to the field as fertilizer declined from an estimated 95 percent to less than 54 percent between 1949 and 2005 (Gao et al. 2017). The abundant use of water to clean livestock operations (although cleaning practices have reportedly improved in China's larger operations) is also a concern, especially when it is released into the environment without adequate treatment, as it can taint water and food with fecal pathogens, nutrients, heavy metals, and drugs. In aquaculture, similarly polluted water is frequently released, undertreated, from ponds in the process of water exchange. Another source of pollution is the open-air storage of manure in some facilities because this allows its components to volatilize in the air. And even though the uptake of biodigesters (which produce methane from organic matter) has likely lessened the problem in parts of the region, their nutrient-rich slurries are frequently mismanaged and freely discharged into waterbodies.[44]

Drug Use

The prophylactic and growth-enhancing use of drugs in feed is now a standard practice in the three countries' pig, poultry, and aquaculture industries, despite these industries being dominated by smallholders (even in China, where production has significantly shifted to large and midsized farms). In 2015–16, a government investigation in the Mekong Delta found that 83 percent of 139 surveyed *Pangasius* farms were administering antibiotics, including ones that are banned or restricted for use in aquaculture (Whitehead 2016). *Pangasius* and shrimp producers routinely administer antibiotics such as enrofloxacin and amoxicillin, as well as many other drugs.[45] Over 45 antibiotics are widely used in Vietnamese livestock production (Dương and Nguyễn 2015; Kim et al. 2013). In the Philippines and other countries, reproductive hormones such as gonadotropins have been used for years to induce the maturation of captive female broodfish in milkfish, sea bass, bighead carp, catfish, grouper, and many other types of farms. Tilapia are often fed sex-reversing hormones so that more of the fish's energy is channeled into growth and less into reproduction (Chakraborty et al. 2011). In the Philippines, anesthetics are sometimes employed when fish need to be transported or handled because these actions can cause stress and result in immune suppression, physical injury, or death.

Aquaculture Water Treatment (Feed, Fertilizer, and Chemicals)

Most modern fish culture in the three study countries involves the intensive input of nutrients in the form of fertilizer or feed (see box 1.6), yet only a small proportion of these nutrients is actually converted into the target product, and most of the nutrients are lost to bacterial degradation, potentially causing nutrient and methane pollution. To illustrate, only one-third or less of the nitrogen and phosphorus ingested in formulated feeds was retained in fish in a laboratory experiment conducted in the Philippines (Cuvin-Aralar 2003); the rest was lost through excretion. Even more nutrients are lost in the many systems that use low-quality feeds, as these are quick to break down, uneaten, in aquaculture waters. Nutrient pollution is particularly problematic in the open systems that

now dominate the aquaculture subsector because these systems entail the release rather than the recycling of excess nutrients.

Aquaculture operations in the three countries are also treated with large numbers of potentially harmful chemicals, including persistent, toxic compounds. Disinfectants (chlorination and ozonation) are used to reduce pathogens in water, and pesticides are used to control algae, snails, and more. After large numbers of shrimp farms in the Philippines and other countries were devastated by the luminous bacteria *Vibrio*, many farms began disinfecting inflowing water with chlorine or formalin. Water conditioners such as lime are added to promote the volatilization of ammonia (another pollutant that is a byproduct of decomposing feed, feces, and dead organisms). Antifoulants—often copper- or zinc-based paints—are frequently applied to boats and cages to prevent organisms from clinging to them. *Pangasius* and shrimp ponds in Vietnam are treated with dozens of chemicals, including lime, iodine, copper sulfate, benzalkonium chloride (BKC), salt, ivermectin, praziquantel, chlorine, cloramin T, and zeo-yuca for *Pangasius*, and calcium hypochlorite, trichlorfon, formalin/formaldehyde, potassium permanganate, saponin, potassium thiosulfate, benzalkonium chloride, iodophors, copper sulfate, dichlorvos, endosulfan, and humic acid for shrimp. Although the use of dichlorvos and endosulfan is less common—endosulfan is a banned, persistent organochlorine pesticide—they are highly toxic (Nguyễn, T. Q. T., et al. 2015; Tú et al. 2006). These treatments (pigments, stabilizers, pesticides, and others) can result in toxic and sometimes bioaccumulative releases, and they represent a particular threat to aquatic biota. Some end up affecting humans through the contamination of water or animal flesh.

Box 1.6 Nutrient Pollution from Fertilizers, Feces, and Feed in Aquaculture

As East Asian aquaculture has grown and evolved from a traditional practice to a science-based activity over the past 20 years, it has come to rely heavily on the use of inputs. Fertilizers, both synthetic and nonsynthetic, are used to stimulate the growth of natural food (such as plankton), and more often feed is directly added in the form of whole, living organisms or processed products such as pellets.

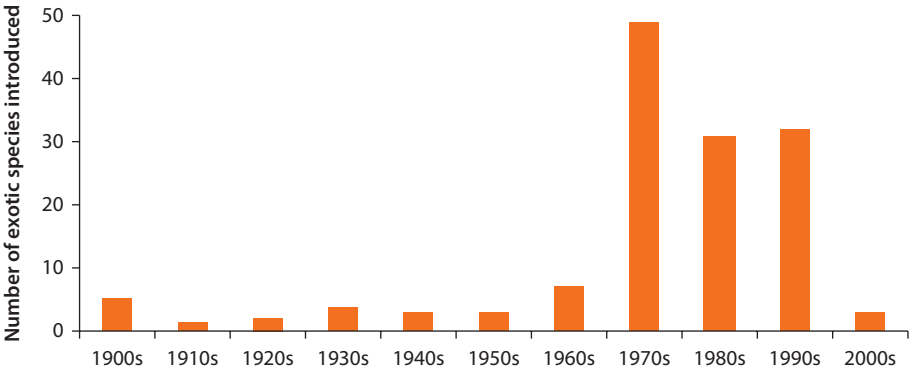
East Asia has a long tradition of fertilizer use in pond culture, and it is used in almost all aquaculture operations, including extensive and semi-intensive ones, even if it is the only input. Although declining, the traditional reliance on nonsynthetic fertilizers, including raw animal and human feces, continues. In the Philippines, chicken manure is a widely used fertilizer as it is readily available and low cost in its uncomposted, unprocessed form. In addition to nutrients, unprocessed fecal matter carries pathogens, which can contaminate aquatic creatures as well as humans.

Overfeeding, along with the use of poor-quality, low-cost feed, are particular concerns in the region. Low-quality feed is prone to crumbling before it is eaten, thus going to waste and contributing to nutrient pollution. The widespread adoption of commercial pellets in Vietnamese fish and shrimp farming has, however, reduced feed losses.

Species Introduction

Some of the three countries' aquaculture activities have developed around the introduction of nonnative and potentially invasive species such as trout, Asian carp, and tilapia, which can threaten the health and survival of native species. Aquatic species are generally introduced into aquaculture systems because they grow quickly, convert feed efficiently, are resistant to disease, or are in demand. Although introductions often involve the adoption of an exotic species, native species are also sometimes translocated into a body of water in which they did not previously breed. The introduction of milkfish, a native Filipino species, into Laguna Bay in the Philippines is one example. When introduced species thrive and develop invasive qualities, their introduction can have irreversible effects. Among the top freshwater species being farmed in the Philippines is the Nile tilapia, an introduced species that, despite its economic benefits, is considered to be invasive (Angienda et al. 2011; Linde-Arias et al. 2008). Another potentially invasive fish that has grown in importance in freshwater aquaculture, especially in Laguna Bay, is the bighead carp, introduced from Taiwan, China, in 1968 (Guerrero 2014). After surging from the 1970s through the 1990s, the introduction of exotic, aquatic animal species into the Philippines slowed at the turn of the 21st century (see figure 1.5).

Figure 1.5 Exotic Aquatic Animal Species Introduced into the Philippines (Recorded Species Only), by Decade



Source: Cagauan 2007.

Fertilizer Use

The East Asia region overall now has some of the heaviest fertilizer users globally in both absolute and relative terms. China is the world's largest consumer and producer of synthetic nitrogenous fertilizer in absolute terms, and among the highest users of synthetic fertilizer on a per hectare basis. In 2014, it used over 490 kilograms of nutrients (nitrogen [N], phosphate [P_2O_5], and potash [K_2O]) per hectare of arable and permanent cropland,[46] according to Food and

Agriculture Organization (FAO) statistics (see box 1.7). Grain cultivation accounts for most fertilizer consumption there, although fertilizer use is more intensive in fruit and vegetable farming. In Vietnam, fertilizer use can be considered high insofar as it is concentrated in the country's grain baskets, especially the Mekong Delta. Approximately two-thirds of fertilizer consumed in Vietnam is used for rice, and other significant uses are for maize, coffee, and rubber. At about 180 kilograms of nutrients per hectare of harvested paddy in 2010–11, the application rate in Vietnam was about 30 percent less than it was in Japan, China, or Malaysia (26–33 percent), but 50 percent higher than in Indonesia and over 200 percent higher than in the Philippines and Thailand.[47] On an annual basis, Vietnam's per hectare application (to paddy) could be comparatively higher considering the country's high embrace of double and triple rice crops. Within the East Asia region and across all crops, only China, the Republic of Korea, and Malaysia had higher uses as of 2014. In comparison, the Philippines used much less fertilizer.

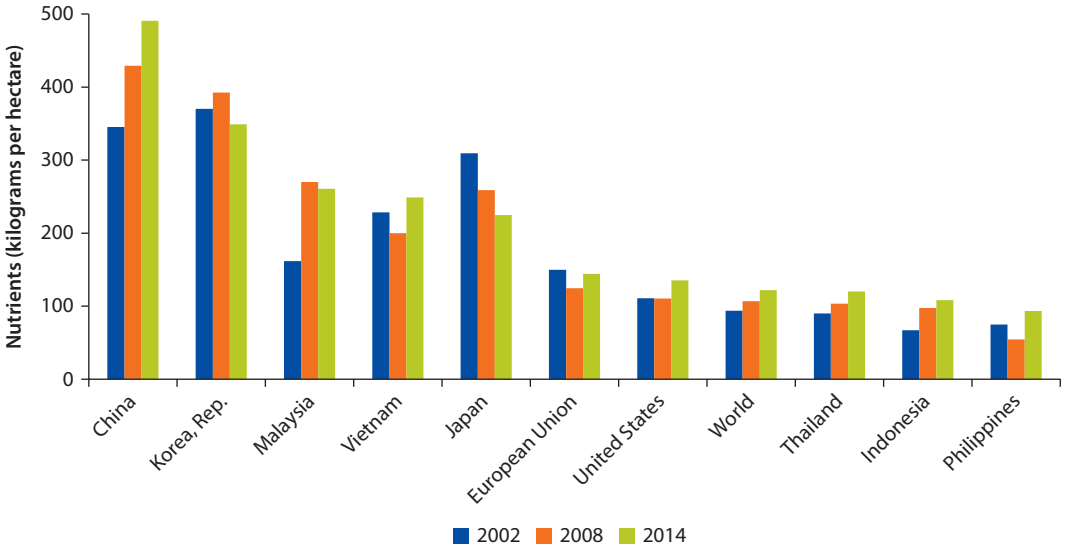
After experiencing steep growth, fertilizer consumption now seems to be stabilizing in China and Vietnam and falling in the Philippines, though accelerating for certain crops. Between 1961 and 2013, total nitrogen, phosphate, and potash fertilizer consumption rose 52-fold in China, 38-fold in Vietnam, and 8.5-fold in the Philippines (based on the International Fertilizer Association's IFADATA). In Vietnam, fertilizer application rates grew rapidly during the 1990s, but they have more or less stabilized since the mid-2000s. Fertilizer use has also flattened in China since the late 2000s, although the fact that it has flattened overall masks its rapid rise in specialty crop production. In the Philippines, where input use was lower to begin with, both fertilizer and pesticide use significantly declined between 2004 and 2013.

Most fertilizer applied to land—as well as to aquaculture waters—goes to waste in the three study countries. It is common for 50–75 percent[48] of the fertilizer applied to cropland to remain unmetabolized by target species and instead to disperse through the air, soil, and water. Although some of these losses are inevitable, they are in large part fueled by excessive, superficial (manual),[49] and untimely applications of what is often quick-dissolving or low-quality[50] fertilizer on fields, especially irrigated ones. In China, notwithstanding possible gains in the efficiency of fertilizer use across many crop systems during the 2000s, the gross (and ongoing) overapplication of fertilizer relative to crop needs has been widely documented, as has the potential to increase fertilizer use efficiency (Gao et al. 2017; Heffer 2016; Ju et al. 2009). In China's intensive grain-producing areas, for example, studies have demonstrated the potential to cut nitrogen applications by 10–60 percent without harming yields (Chen et al. 2014; Huang et al. 2012; Ju et al. 2009; Wu 2014). Fertilizer use is also inefficient in the Philippines, even though fertilizer is applied less heavily there. To illustrate, it has been estimated that in 2010, just over half of the synthetic fertilizer applied to cropland surrounding Manila Bay (mostly to rice and sugarcane) was lost to the watershed (Samar 2012).

Box 1.7 Fertilizer Use in East Asia

Among regions, Eastern Asia[a] was by far the heaviest consumer of fertilizer in 2014, with annual usage averaging around 470 kilograms of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) nutrients per hectare of arable and permanent cropland. This is in comparison to 140–145 kilograms in the European Union and South Asia; 115–125 in South America, North America, and Southeastern Asia; 70–85 kilograms in Western Asia, Central America, and Australia and New Zealand; 30–45 kilograms in Eastern Europe, the Caribbean, and Central Asia; and just over 22 kilograms in Africa. In 2013 China, Indonesia, Vietnam, and Thailand ranked among the world's top 10 fertilizer-using countries in aggregate terms,[b] accounting for close to one-third of the world's total use (see fertilizer use intensities in figure B1.7.1).

Figure B1.7.1 Fertilizer Use per Hectare of Arable and Permanent Cropland: Selected Countries and Years



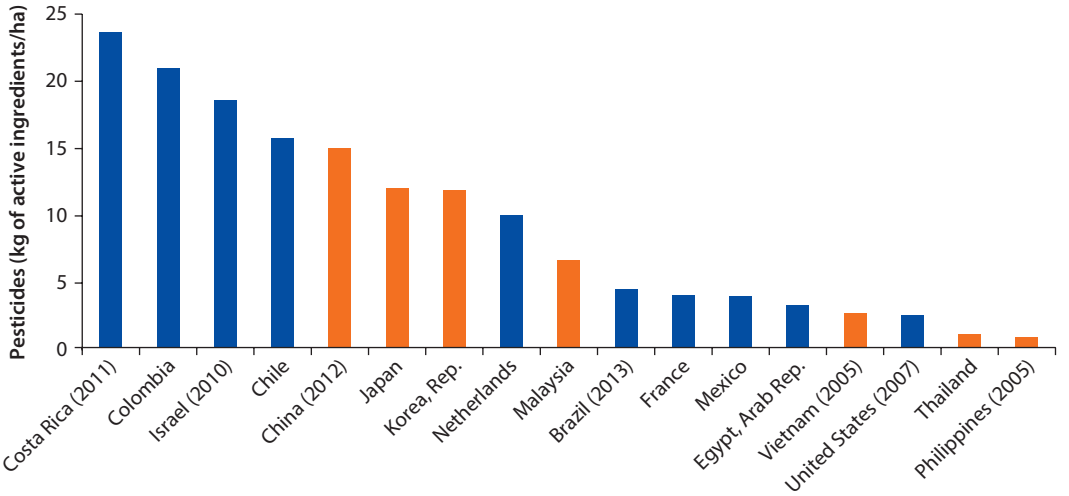
Source: Based on FAOSTAT data.
Note: Fertilizer nutrients are nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Large discrepancies have been noted in Chinese fertilizer use reported by different sources. In 2013 the Food and Agriculture Organization (FAO) estimated the annual consumption of synthetic fertilizer at close to 40 million tons, whereas China's National Bureau of Statistics estimated its use at close to 60 million tons.

a. The FAO divides East Asia into Eastern Asia (China; Hong Kong SAR, China; Macao SAR, China; Taiwan, China; Japan; Democratic People's Republic of Korea; Republic of Korea; and Mongolia) and Southeastern Asia (Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste, and Vietnam).
b. They ranked 1st, 5th, 9th, and 10th, respectively, according to International Fertilizer Association data (IFADATA).

Pesticide Use

Pesticide use similarly soared across much of China during the 1990s and 2000s and parts of Vietnam during the 2000s and 2010s, while also growing sharply but to far more moderate levels in the Philippines. China is the world's largest producer and consumer of pesticides, as well as one of its more intensive users of these chemicals on a per hectare basis (see figure 1.6). It used over 1.8 million tons of active ingredients in 2014 (a 136 percent increase over 1991 levels, or 7.5 percent increase per year), and an estimated 14.8 kilograms per hectare as of 2012,[51] or more than two-and-a-half times the 1991 intensity (based on FAOSTAT data). Vegetables, as a group, accounted for the largest sales of pesticides in China as of 2006, at 24 percent, and rice was the single largest user of pesticides, at 15 percent (Zhang, Jiang, and Ou 2011). China's average pesticide consumption was reportedly two-and-a-half times the world average and still increasing as of 2014, although its growth has slowed in the 2010s, and a number of toxic chemicals have been banned or are being phased out (Gao et al. 2017). Within East Asia, Japan, the Republic of Korea, and Malaysia are the next most intensive users of pesticides. Vietnam's use of pesticides is more moderate, but, as with fertilizer, its geographic concentration in major crop production areas makes it a concern, and changes in cropping patterns and pest resistance may have since driven more intensive use.[52] In the Philippines, overall pesticide use is not only lower, but recently has been falling. That said, the use of pesticides in the country's large-scale, commercial fruit plantations is shrouded in statistical opacity and is abundant by some accounts (Havemann and Rosenthal 2015; Magcale-Macandog, Briones, et al. 2016).[53]

Figure 1.6 Pesticide Use per Hectare of Arable and Permanent Cropland: Selected Countries, 2014 or Latest Year Available



Sources: Based on FAOSTAT data for 2014 or latest year available. Estimates for the Philippines and Vietnam are calculated on the basis of a 2005 FAO survey (FAO 2005) and FAOSTAT data for arable and permanent cropland.
Note: Orange bars indicate countries in the East Asia region. The *China Rural Statistical Yearbook* estimates the average application rate for 2013 at 10.95 kilograms (kg) per hectare (ha).

Highly toxic pesticides remain in use in parts of the East Asia region, and nonnegligible volumes of counterfeit and obsolete pesticides are thought to be in circulation (FAO, n.d.). As of 2012, nearly one in three pesticides used in Vietnam's Red River Delta—the country's second-largest agricultural region—were in the most hazardous category recognized under the World Health Organization system of classification—Class I, "extremely hazardous" or "highly hazardous" (WHO 2010). Fifty-four percent fell into the next most hazardous category—Class II, "moderately hazardous" (Pham, T. T., et al. 2012). In addition, several pesticides that have been banned by the Ministry of Agriculture continue to be in use, although their use seems to be declining (Pham, T. T., et al. 2012). In 2008 the Ministry of Industry and Trade estimated that about 30–35 percent of pesticides used in Vietnam were imported illegally and that many of these were prohibited, according to a press report.[54]

China has taken some of the longest strides toward reducing the toxicity of its pesticide mix: as of 2016, it had banned at least 43 highly toxic and risky pesticides on top of those singled out by the Stockholm Convention on Persistent Organic Pollutants (Guangdong Academy of Agricultural Science et al. 2016). Highly toxic pesticides were recently estimated to account for 2.5 percent of total pesticide production (Gao et al. 2017). However, despite the government's aggressive stance on rooting them out, the Chinese market continues to harbor counterfeits (Gao et al. 2017). Farmers often buy these products unwittingly because they are cheaper. The danger is that they can contain untested, unregulated, and sometimes banned ingredients. The use of banned pesticides is also reportedly an issue in Vietnam, where farmers, according to one Mekong Delta survey, choose pesticides on the basis of how efficacious they perceive them to be in controlling pests, much more so than on the basis of their toxicity, regulatory status, or even price (Nguyen, C. G. D., et al. 2015).

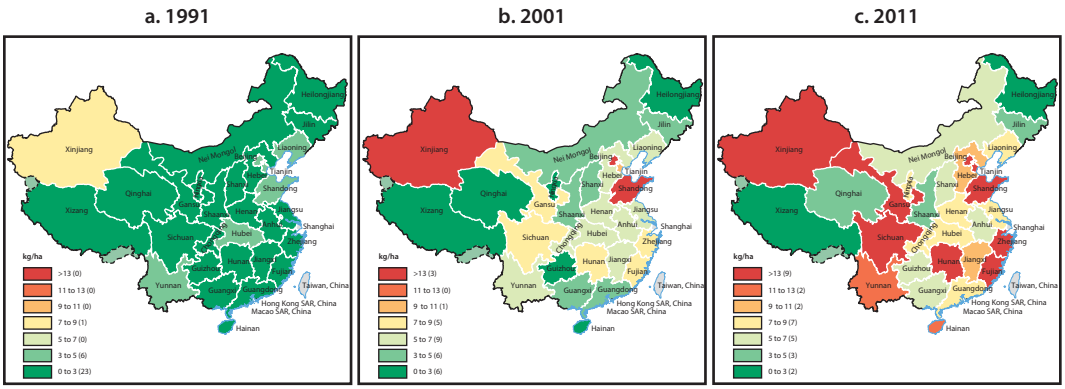
Meanwhile, the improper use of pesticides and pesticide containers remains widespread. In Vietnam and China, farmers commonly ignore extension recommendations and safety instructions for the application of pesticides and the safe disposal of used pesticide containers. Although they are now dated, studies carried out in Vietnam's Mekong Delta during the 2000s found rampant overuse and misuse of pesticides, with most farmers resorting to pesticides as a first line of defense and less than 5 percent of farmers in one survey applying chemicals in accordance with instructions (Huan and Thiet 2002 in Dasgupta et al. 2007; Toan et al. 2013). One study found that more than 70 percent of farmers in the Mekong Delta were dumping pesticide packaging into canals or rice fields, and about 17 percent were collecting the containers to either bury them or sell them for recycling (Toan et al. 2013).[55] Approximately 90 percent of farmers in this study said they washed their sprayers right away in rice fields, canals, ponds, or rivers. These practices are also reportedly an issue in China.

Plastics Use

The use and improper disposal of agricultural plastics, often after being used for just one growing season, are an emerging concern, especially in China.

Plastics offer many unique advantages in farming, and some technologies such as plastic mulches and drip irrigation tubing even offer environmental benefits in terms of water savings. These advantages and benefits help to explain their rapid uptake. It has been particularly pronounced in China's northwestern drylands, where plastic mulches have been transformational, making intensive fruit and vegetable farming possible by increasing soil moisture retention and temperatures, and allowing maize and cotton yields to increase significantly—reportedly by about 30 percent (Gao et al. 2017). Although figures on agricultural plastics use and disposal are scarce, one study found China to have the largest area of agricultural land under plastic films (He et al. 2015). That area grew more than 150-fold between 1982 and 2014, when it reached over 18.14 million hectares, or roughly half the area of the Netherlands; in tonnage terms, plastic film grew 200-fold over this period (*China Rural Statistical Yearbook* 2015; Yan 2015). In the northwestern province of Xinjiang, average plastic film applications increased from 7 kilograms per hectare in 1991 to nearly 35 kilograms per hectare in 2011, a nearly sevenfold increase—see map 1.5 (*China Rural Statistical Yearbooks* 1992, 2002, 2012).

Map 1.5 The Spread of Plastic Mulch in China, 1991, 2001, and 2011



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Sources: *China Rural Statistical Yearbook* for 1992, 2002, 2012.
Note: Red, orange, and yellow shading indicate the most intensive use of agricultural plastics (in kilograms [kg] per hectare [ha]). In the legends, the number in parentheses indicates the number of provinces in that category. SAR = special administrative region.

Of limited durability and recycling value, most plastic films break down quickly, leaving large quantities of residues in soils. This situation is exacerbated by the inefficiency of manual collection and the lack of capacity to gather these wastes mechanically, as well as the lack of collection and recycling options. China's first national census of pollution showed that, as of 2007, some 12.1 million tons of plastic residue had accumulated in agricultural soils. Plastics can be toxic to humans and wildlife alike when they are burned—a practice sometimes observed in China (Gao et al. 2017)—or even left to break down (though not necessarily decompose) in soils. Plastic residues are also physically and chemically harmful to wildlife when they find their way into

marine environments and clog waterways (Rochman et al. 2013; Wilcox, Van Sebille, and Hardesty 2015). China and Indonesia were the leading sources of overall plastic waste leakage as of 2010, reflecting their underdeveloped waste management infrastructure and practices. This makes them the largest contributors to the estimated 4.8–12.7 million tons of plastic waste entering the ocean each year, with lethal consequences (Jambeck et al. 2015).[56]

Burning of Crop Residues

For the sake of expedience, maize, rice, and wheat husks are burned systematically in many parts of the East Asia region, often near cities where their contributions to smog and air pollution are magnified (see box 1.8). In relative terms, the Philippines burns rice husks at one of the highest rates anywhere. Fully 95 percent of these are or were combusted, according to a 2009 estimate (Gadde, Menke, and Wassmann 2009).[57] China burns more crop biomass than any other country, although in relative terms burning has been controlled or abandoned to a significant extent, compared with the extent to which burning has been controlled in neighboring countries. An estimated 24 percent[58] of residue (by mass) was burned or improperly discarded in 2013 (Gao et al. 2017). Burning rates remain much higher, however, in certain grain-growing centers despite bans, and the seasonal and spatial concentration of burning still gives rise to significant ambient air pollution.

Box 1.8 The Practice of Field Burning

In East Asia's farming systems large and small, open burning is a commonly used method for removing crop residues after harvest. It is particularly prevalent following the cultivation of maize, but also of rice, wheat, sugarcane, and other crops (see figure B1.8.1). Burning is also a common way of preparing land for cultivation after it has been fallowed. The decision to burn in certain regions of the world has been found to reflect multiple factors, especially tradition, ease, timing, weather, and location, as well as the practicality of alternatives—the latter being partly determined by access to the appropriate tools or markets for biomass residues.[a]

Across regions, burning is widely seen as a quick and inexpensive way to manage crop residues, while preventing pests and diseases. And burning crop residues can indeed be a rapid way to prepare fields for a second or third crop—an aspect that matters in certain farming contexts in which time and labor constraints factor into farming decisions. In parts of China and Vietnam, for example, there is a short window of typically one to two weeks for the removal of crop residues between harvests. Burning is often the preferred method of land preparation in such cases. In parallel, a lack of awareness (that is, a partial awareness of the costs and benefits of burning and its alternatives) is no doubt part of the explanation for how widely burning is observed. In particular, the initial burst of soil fertility that can be gained from burning may obscure, for some farmers, the downsides of the practice, especially because the downsides can be more drawn out over time or can escape

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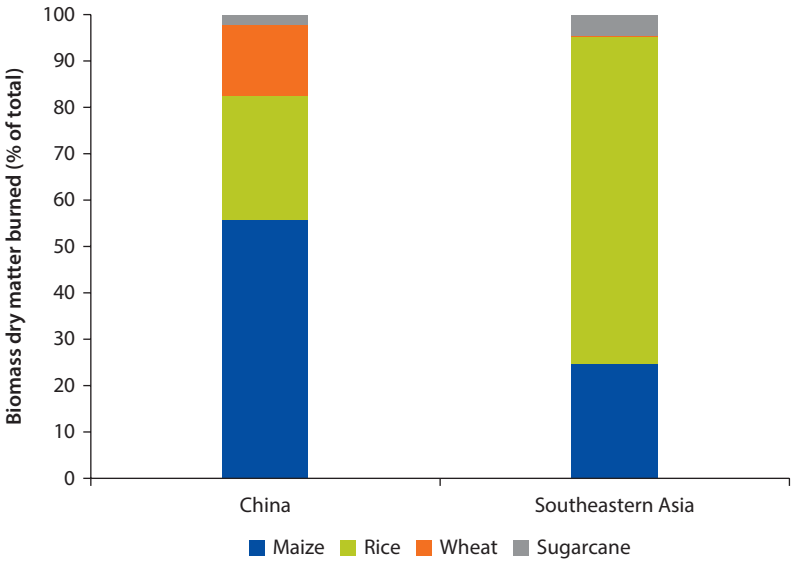
Box 1.8 The Practice of Field Burning *(continued)*

Figure B1.8.1 Burning of Crop Residues in Parts of East Asia, 2012



Source: Based on FAOSTAT data.
Note: Southeastern Asia includes Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste, and Vietnam.

observation entirely. These downsides include a gradual loss of soil fertility and the survival in the soil of insects thought to be eliminated by fire.

Even where farmers perceive net benefits in alternative uses of crop residues, several factors can prevent them from pursuing these alternatives. For example, farmers sometimes lack the ability to pay for (or lack access to) the labor, equipment, or chemicals that would allow them to compost, switch to no-till farming, generate energy, move waste off-field for alternative uses, or manage pests and diseases without burning. Equipment for the production of biogas can require higher upfront investments and only make sense for operations above a certain scale in terms of both feedstock availability and energy needs. The upfront investment can be too high or the payback period too long for farmers, and appropriate financial instruments are sometimes lacking to help them purchase or lease the required equipment or inputs. Investment can be further hampered by insecure land tenure. Farmers also often lack the technical knowledge and know-how to adopt alternatives, and in certain contexts collective action or markets are insufficiently developed to help farmers overcome some of these obstacles. Meanwhile, in contexts in which bans or regulations on burning are in place, weak enforcement means that there is little disincentive for farmers to carry on with the practice. More effective dissuasion in tropical East Asia has typically come from unfavorable weather conditions (too wet or too hot and dry), as illustrated by the situation in Vietnam.

a. One study found these to be the main factors in the Andes and Himalayas (ICCI 2014).

Table 1.2 provides a snapshot of what likely constitutes agricultural pollution "hotspots" in the three study countries, although the quantitative basis for stating or comparing their magnitude, severity, or rate of progression is lacking.

Table 1.2 Major Environmental Pollutants from Agriculture and Potential Hotspots: China, Vietnam, and the Philippines

Pollutant	*China*	*Vietnam*	*Philippines*
		Water and soil	
Nutrients (N and P)	• Livestock waste (esp. in South Central) • Maize fertilizer (esp. in northern and Southwest China) • Rice fertilizer (esp. in East and southern China's double-cropping systems, lower reaches of Yangtze, and North Plain; Northeast; and rising in Southwest) • Wheat fertilizer (esp. in Northeast) • Fruit and vegetable fertilizer • Aquaculture (widely distributed but insufficient data)	• Livestock waste (esp. in Dong Nai near Ho Chi Minh City and Thai Binh near Hanoi) • Rice fertilizer (esp. in Mekong Delta; also Red River Delta) • Fertilizer in coffee (Central Highlands); fertilizer in rubber (Central Highlands, Northwest) and sugarcane (Mekong Delta) • Aquaculture (in Mekong Delta and Red River Delta) • Possibly maize fertilizer (in Northwest, Northeast, Red River Delta, Mekong Delta)	• Livestock waste (insufficient data; widely distributed industry with commercial farms concentrated around Metro Manila known to be affecting Laguna Lake) • Aquaculture feeding (widely distributed, insufficient data) • Fruit and tobacco plantations (insufficient data; noted in Mindanao, Ilocos, and Cagayan) • Vegetable fertilizer (in Cordillera) • Rice-vegetable fertilizer (in Ilocos) • Possibly rice (esp. grown in Nueva Ecija/Central Luzon and Isabela/Cagayan in north, though widely distributed)
Pesticides	• Largest users: East and South Central (esp. Shandong, Henan, and Hubei Provinces) • Largest relative users: East and South Central (esp. in Hainan for fruits and vegetables; Guangdong, Hunan, Jiangxi, Fujian, Hubei, Anhui, Zhejiang, and Shandong Provinces)	• Rice (esp. in Mekong Delta; also Red River Delta) • Maize (esp. in Northwest, Northeast, Central Highlands)	• Fruit and tobacco plantations (in Mindanao, Ilocos, and Isabela) • Possibly rice (as the dominant crop, esp. grown in Nueva Ecija/Central Luzon and Isabela/Cagayan, though widely distributed)
Plastics	• Plastic mulch in fruit and vegetables (esp. in Northwest) • Input containers (no data; likely in East and Northeast)	• Input containers (no data but most likely highest in Mekong Delta rice) • Plastic mulch (no data)	• Input containers (no data but likely highest in rice and plantation crops) • Limited use of plastic mulch in dry season vegetables, melons
Drugs and other chemicals[a]	• Livestock (esp. in South Central) • Aquaculture (no data)	• Livestock (esp. in Dong Nai near Ho Chi Minh City and Thai Binh near Hanoi) • Aquaculture (in Mekong Delta and Red River Delta)	• Livestock (Metro Manila) • Aquaculture (widely distributed)
		Air	
Nitrogenous emissions (→ secondary PM and ozone)	• Livestock manure (esp. in North China Plain/East, East Sichuan/Southwest, Xinjiang/Northwest) • Fertilizer (similar to livestock, with increases in North China Plain; improvements in South Central)	Insufficient data but likely: • Livestock manure (see "Drugs" above) • Fertilizer (see "Nutrients" above) • Crop residue burning (see "PM and gases from burning" on next page)	Insufficient data but likely: • Livestock manure (see "Drugs" above) • Crop residue burning (see "PM and gases from burning" on next page) • Fertilizer (see "Nutrients" above)

table continues next page

Table 1.2 Major Environmental Pollutants from Agriculture and Potential Hotspots: China, Vietnam, and the Philippines *(continued)*

Pollutant	*China*	*Vietnam*	*Philippines*
PM and gases from burning	• Corn, wheat, and rice residues (in that order) • Autumn burning (in southeastern China) • Spring burning (in western China)	• Rice straw (in Mekong Delta, Red River Delta) • Corn husks (esp. in Northwest, Northeast, Central Highlands) • Coffee husks (Central Highlands)	• Corn husks (most grown in Cagayan, Mindanao) • Rice straw (most grown in north—Central Luzon, Cagayan)
GHGs (esp. N_2O and CH_4)	• Livestock rearing (esp. in South Central) • Nitrogen fertilizer (esp. in South Central, Northeast) • Rice irrigation (esp. in South Central)	• Rice irrigation • Livestock rearing • Nitrogen fertilizer	• Rice (most grown in north—Nueva Ecija, Isabela, Pangasinan) • Livestock rearing (especially concentrated around Metro Manila, though small farms widely distributed)

Note: CH_4 = methane; GHGs = greenhouse gases; N = nitrogen; N_2O = nitrous oxide; P = phosphorus; PM = particulate matter.
a. Antibiotics, hormones, other drugs, heavy metals, and other chemicals.

Structural and Policy Drivers of Farm Pollution

Several of the pollution problems that the three study countries are facing have been magnified by patterns of structural development, some specific to the region.

Changes in the organization of agricultural activities are implicated in many of the pollution problems observable in East Asia today. Agriculture's responsiveness to changes in consumption patterns, for example, has been an important structural dynamic in the region and is likely to remain one for decades to come. The expansion of animal rearing and feed crop production is at the forefront of this phenomenon.[59] The consumption of animal products is rising faster in Vietnam, Indonesia, and China than almost anywhere else in the world (based on FAOSTAT data from 2000–11). This and other patterns help explain the magnitude of certain pollution problems, the practices from which they originate, and the hazards they pose. Several patterns have been behind the region's strong agricultural performance in recent decades, although others have resulted from it unintentionally.

Focus on Output and Yield Growth

Demographic growth, and a societal focus on output and yield, shaped in part by policy and limited space for agriculture,[60] have implicitly favored a "grow now, clean up later" approach that regards the environment as a resource for exploitation. Agriculture in the region has been profoundly shaped by the public sector's decades-long focus on output growth through intensification, quantity over quality, and its only distant consideration of the environmental, health, or even longer-run agricultural productivity risks of the methods employed to achieve ever-higher yields (see box 1.9).

Box 1.9 "More Is Better" Orientations of Food and Agricultural Policy

Rapid population growth and urbanization over the past 50 years have generally focused the minds and priorities of Chinese, Vietnamese, and Filipino policy makers on food security, conceived as an output expansion challenge privileging grain. In all three study countries, food security has long been equated with food, and especially rice, self-sufficiency, although this is in the process of evolving. In the Philippines, the Food Staples Sufficiency Program of 2011 sought to achieve 100 percent rice self-sufficiency by 2013 (Philippines Department of Agriculture 2011). And until 2014, China pursued a strict policy of rice self-sufficiency. However, the policy was then relaxed, even though the pursuit of "grain security" has remained enshrined in law and public spending (*China Economic Review* 2015; *Economist* 2015).[a]

Improved access to calories in all three countries over time has progressively raised the profile in food and agricultural policy of nongrain commodities, including meat and aquaculture products, as well as of export-oriented commodities. Various programs in the Philippines have supported the development not only of staple crops (rice, corn), but also of high-value crops and fishery products (including those from aquaculture). The Ginintuang Masaganang Ani for Fisheries Program of 2002–04, for example, aimed to improve capture fishery and aquaculture production. Expanding production of these commodities, however, has often remained the top priority. In Vietnam, the agricultural sector has developed within the context of quantitative targets, both sectorwide and subsector-specific. Only more recently have improving food security and strong trade performance begun to bring added focus to quality—the latter having important environmental dimensions (Jaffee et al. 2016). Agricultural and food policy are gradually embracing nutritional, health, and environmental objectives.

Meanwhile, agricultural output growth has overwhelmingly depended on a push for intensification and only to a smaller extent on extensification, although spatial expansion has played a notable role in some countries.[b] Although this trend has engendered efficiency gains and resource savings, the intensification of agriculture—and its geographic concentration in the case of animal agriculture—have also given rise to sources and types of pollutants that did not exist previously.

a. With notable variations by country and farming system.
b. Although cropland has increased little over the past 60 years in China, increased meat and especially beef consumption has relied on an ever-increasing expanse of farmland. Beef is two-and-a-half to three times more land-intensive than pork or poultry, and a tripling of the land resource devoted to it and other meats is estimated to have been necessary between 1989 and 2009 based on average land requirements (Feely and Machovina 2014).

This selective focus, together with competition for highly constrained land resources, has led the agricultural sector to develop and intensify in ways that have engendered the wide range of pollution problems and impacts described earlier.[61] In particular:

- Direct and indirect fertilizer subsidies in China and Vietnam, preferential input loans, extension messages, and product advertising[62]—consistent with a societal push for higher production and yields—have helped cement a widespread belief among farmers that applying more fertilizer always results in higher yields. The effects of fertilizer prices and (direct or indirect) subsidies on

fertilizer use have generally been understudied. Nonetheless, some studies have found that the maintenance of low and stable fertilizer prices in China has contributed to its overuse in the past to a "moderate" or a "significant" extent (Cheng, Shi, and Wen 2013; multiple sources in Huang and Xiang 2017).

- Specialization in crop agriculture, agroecological simplification, and the move to monoculture in some cases—favored by investment in irrigation infrastructure and extension messages and sometimes inflexible land-use policies—have accelerated farms' loss of natural predators and fertility, increased their susceptibility to pests and disease, and driven a greater reliance on synthetic chemicals to address these problems. Excessive input use is one of the main reasons for the high incidence of pests and disease on Chinese fruit and horticulture farms, where pesticides are frequently applied at two to three times the recommended rates (Li et al. 2006 in Sun et al. 2012; Ma, Mao, and Zhang 2000).

- The expansion of irrigated agriculture, a centerpiece of public investment in agriculture in several countries, has also unwittingly contributed to agrochemical runoff, soil salinization, and rice-related greenhouse gas emissions. Similarly, the Vietnamese government's construction of earthen dikes to protect land from seasonal flooding and allow more farmers to grow more rice crops per year in the Mekong Delta has also prevented the alluvial deposition of nutrients to farmland, reducing its fertility and water-retention capacity. This outcome has increased polluting runoff, even as farmers have had to compensate for this loss with agroinput applications. Meanwhile, less favorable soil conditions have reportedly limited farmers' ability to diversify away from rice, thereby contributing to more widespread input-reliant monocropping (*Economist* 2014).

Shift to a More Polluting Mix of Products

In East Asia, the agricultural sector's responsiveness to the emerging demands of cities and urbanizing populations has resulted in a more polluting mix of products and practices and a greater proximity of populations to agricultural sources of pollution (see box 1.10).

Box 1.10 The Responsiveness of Regional Agriculture to Growing and Shifting Demand: Trends in the Production of Major Agricultural Commodities in East Asia

East Asian agriculture has done a remarkable job over the past decades of keeping pace with the increasing demand for food by the region's growing population. It has also been responsive to the significant qualitative shifts in diet brought on by rapid urbanization, the rise of median incomes, and sociocultural influences. The following changes illustrate how agricultural production has evolved, and figure B1.10.1 visually underscores the pace at which the production of different commodities has grown in the region:

- Regionwide, the domestic supply of all animal products increased more than 10-fold, from 30 million tons in 1961 to nearly 320 million tons in 2011 (see figure B1.10.2).

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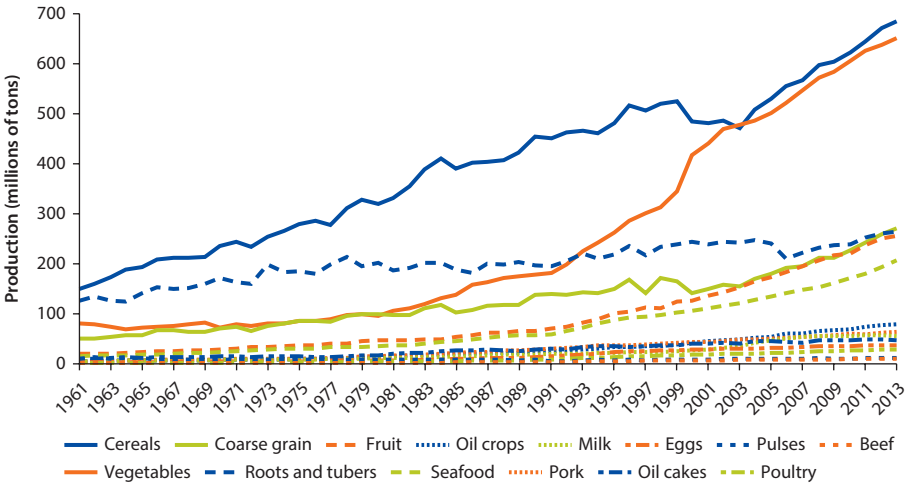
Box 1.10 The Responsiveness of Regional Agriculture to Growing and Shifting Demand: Trends in the Production of Major Agricultural Commodities in East Asia *(continued)*

Meat production grew almost 20-fold, from close to 5.5 million tons in 1961 to over 108.5 million tons in 2013, and went from supplying about 8 percent to 35 percent of global meat over that period. In 2013 China, Vietnam, the Philippines, and Indonesia ranked among the top 20 meat-producing countries—1st, 13th, 19th, and 20th, respectively (based on FAOSTAT data).

- East Asia has become dominant in fish farming. The region produced around 1.5 million tons of farmed fish in 1960 and nearly 93 million tons in 2014. Among all countries, in 2014 China, Indonesia, Vietnam, and the Philippines were ranked 1st, 2nd, 4th, and 5th, respectively, in terms of production, and together accounted for 76 percent of global production (based on FAO Fisheries Global Information System data, FAO FIGIS).
- In East Asia, cereal production rose from over 191 million tons in 1961 to over 834 million tons in 2014 (FAOSTAT).
- China produced just over half the world's vegetables in 2013, making it the largest producer by a very large margin (India, the second largest, produced about 10 percent). Twenty years earlier, China produced 34 percent of these highly perishable crops. The area harvested went from just under 10 million hectares to almost 25 million hectares during this period (based on FAOSTAT data).
- Several countries in the region have also emerged as top producers of various "export crops." For example, Vietnam went from being a minor player to among the top five producers of coffee, tea, cashew, pepper, and rubber. In 2013 the Philippines joined the top six producers of banana, pineapple, coconut, and cashew.

Figure B1.10.1 Agricultural Production, Main Commodities: East Asia, 1961–2013



Sources: Based on FAOSTAT and FAO FIGIS data.
Note: Meat is from indigenous animals only. Seafood includes aquaculture and capture fisheries production. Cereals are in rice milled equivalent. Vegetables include melon. Some categories are not shown: other meats, jute, fiber, tree nuts.

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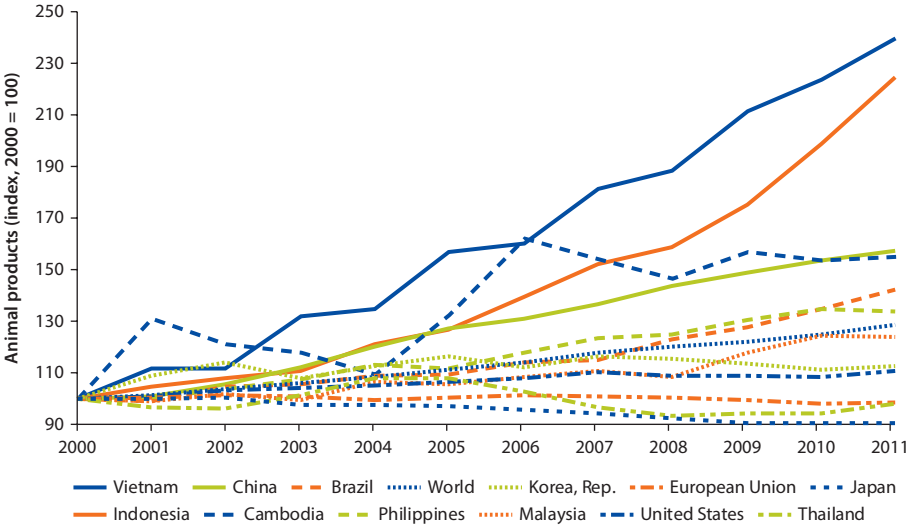
Box 1.10 The Responsiveness of Regional Agriculture to Growing and Shifting Demand: Trends in the Production of Major Agricultural Commodities in East Asia *(continued)*

Figure B1.10.2 Domestic Food Supply of All Animal Products: Selected Countries, 2000–11

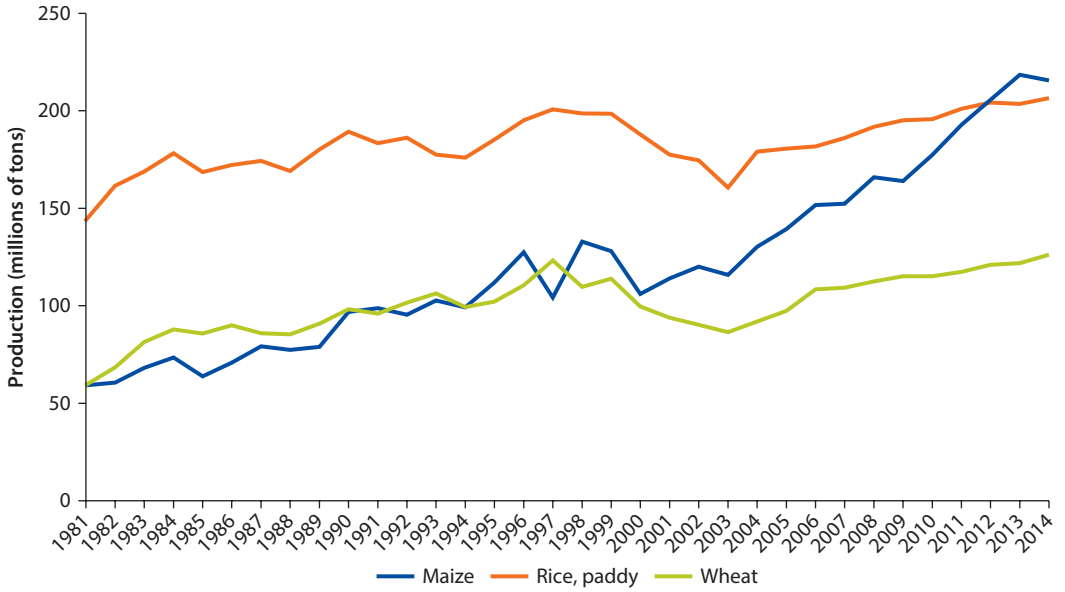


Source: Based on FAOSTAT Food Balance Sheets.
Note: Domestic food supply = production + imports – exports + changes in stocks (decrease or increase).

The rise of animal agriculture (including the surge in confined pig and fish farms) in response to the growth in demand for animal source foods has been consequential from a pollution perspective. Nitrogen recovery is inherently lower in animal farming than in crop farming, for example (Galloway and Cowling 2002; Sutton et al. 2011).[63] And the animal farming industry has often created water pollution hotspots where operations have clustered, undermining biodiversity and threatening human health. The livestock and aquaculture subsectors are also major contributors of climate pollutants—especially short-lived ones.[64]

The pivot to animal source foods has also contributed to the intensification of cereal production, especially maize, for feed production. In China, corn—some two-thirds of which is used to feed animals (Gale, Hansen, and Jewison 2015)—has overtaken rice as the number-one crop—see figure 1.7 (based on FAOSTAT data).[65] The intensification and growth of livestock production have been accompanied by an increasing focus on raising the output and productivity of such feed crops to ensure "feed security." This goal has been pursued by means of intensive monocropping and a heavy reliance on chemical inputs to sustain multiple harvests per year. Furthermore, although the vast majority (more than 80 percent) of fertilizer is used on cropland, the ramp-up of aquaculture that has led East Asia to dominate world production has also resulted in a growing reliance on fertilization and direct feeding, as well as other polluting inputs.

Figure 1.7 Maize, Rice, and Wheat Production: China, 1981–2014



Source: Based on FAOSTAT data.

The clustering of agricultural activities and their increasing juxtaposition with dense population centers have increased human exposure to the agricultural sector's ever-concentrating set of pollutants. In particular, the dense nodes of small pig farms that have cropped up in the outer rings of Hanoi, Manila, and Ho Chi Minh City are fouling the air in nearby communities and contaminating urban water sources. The proximity of agricultural fires to cities has also increased their contribution to smog and poor urban air quality.

The responsiveness of Chinese agriculture to the rising demand for fruit and vegetables in a water-scarce environment[66] has begun to heighten concerns about plastic, nutrient, and pesticide pollution. As noted, the rapid growth in fruit and vegetable production has gone hand in hand with the uptake of plastics and has resulted in China having the largest agricultural area under plastic film in the world (He et al. 2015). And in recent years, the rise of these subsectors has emerged as the main driver of the intensification of fertilizer and (highly toxic) pesticide use.

Rapid Adoption of Technology

Pollution has, so far, been a major downside of the rapid adoption of technology. In a region bent on leapfrogging as a development strategy, for

example, importing aquaculture species bred for and adapted to intensive farming has been a quick way to develop a high-output seafood industry—yet one that has increased the risk of genetic contamination, disease, and loss of biodiversity.

The uptake of pesticides and other chemicals in farming has happened so fast in East Asia that it has sometimes outpaced farmers' and regulators' awareness of their dangers, the latter's capacity to regulate them, and the adoption of safe handling techniques. The use of cheap, toxic chemicals—some counterfeit—has been an issue, as has the lack of precautions in their application (protective equipment and precision application methods, timing, dosing and mixing of chemicals, and disposal).

Continued Dominance of Small Farms

The continued dominance of small farm size has challenged farmers'—and regulators'—capacity to moderate pollution, but it has not prevented farmers from resorting to intensive and polluting farming techniques. In Vietnam, for example, the average rice farmer cultivates a little over half a hectare, and some 90 percent of coffee growers have less than 2 hectares (75 percent have 1 hectare or less, sometimes dispersed among several plots). This structure is common in the region. Even as the livestock sector has been gradually consolidating, farm landholdings have on average been decreasing in size and increasing in fragmentation over time (Rigg, Salamanca, and Thompson 2016).

Small crop farms may be more prone to wasting agrochemicals—applying more fertilizer or pesticides than their crops need at a given time—than are larger or commercial ones, and the waste they generate as a group quickly adds up (see box 1.11). In the context of animal operations, limited space has meant cramped conditions and, together with the limited resources of small operations, explains a reluctance or inability to devote adequate space to waste treatment facilities. Overcrowding has also potentially encouraged farmers' reliance on antibiotics and disinfectants to ward off disease, although these are also used in more spacious conditions to accelerate growth and increase feed conversion efficiency. Limited resources may also help explain reliance on lower-quality inputs such as feed that is more polluting.

Regulatory oversight has likely been hampered by the capacity limitations and large numbers implied by small-farm dominance. For example in Guangdong, one of China's leading pig-producing provinces, there were 180,000 small farms with 500 pigs or fewer, compared with 5,000 with over 500 pigs and 700 with over 3,000 pigs in 2013 (World Bank 2013). The limited resources of small livestock and aquaculture operations, taken individually, along with the multiplicity of these operations, has made it difficult for regulators to impose more stringent waste management requirements or even just scrutiny of them, even though they generate vast amounts of pollution aggregately (see box 1.12).

Box 1.11 Farm Size and Fertilizer Use

Although research has not always found a consistent relationship between farm size and input use efficiency, studies in China and Indonesia have found that larger farms use less fertilizer per hectare compared with smaller farms, suggesting that fertilizer application may be somewhat more calculated and fact-driven in larger operations (Ju et al. 2016; Osorio et al. 2011). This was found to be the case, for example, in China's Chaobai watershed, where fertilizer has been a significant contributor to water pollution and has threatened the supply of safe drinking water: maize farmers there applied less fertilizer on average when they had larger landholdings (Zhou et al. 2010).[a]

There are several possible reasons for this. The amounts of chemicals at stake for small plots of land may be small enough in absolute volume or expenditure terms that farmers neglect the potential savings (where they exist) from using fertilizer in a more calculated way. In some cases, the amounts at stake may defy noticeability, and indeed Chinese and Vietnamese farmers have been observed applying excessive amounts of fertilizer and pesticides just to finish (that is, empty) a container (Arin 2016; Nguyen, T. H., 2017). Yet in Vietnam, fertilizers are rice farmers' largest expenditure category, and still farmers' use of fertilizers remains high and inefficient. An additional explanation may be that small farms are more likely to think in yield-maximizing terms than in profit-maximizing ones (Sun et al. 2012).

Another explanation put forth in the Chinese context is related to the partial exit of many farmers from farming to make ends meet. This is often a necessity in light of small landholdings, but it is also a testament to the development of off-farm economic opportunities. This pattern has given rise to a kind of "absentee farming" and peculiar time constraint. Farmers in this situation sometimes apply a full season's worth of fertilizer at one time, a practice that leads to a great deal of waste and is not favorable from an agronomic, profit-maximization, or environmental perspective. With less time to coax compost out of crop residues or to make other uses of them, part-time farmers (or ones left behind on the farm by their family) may also be more given to open burning, which, as discussed, can also drive greater reliance on chemical fertilizer.

Meanwhile, small farmers often have limited means to invest in soil tests, power tools, and other technologies that would allow them to apply chemicals more precisely, and, with limited landholdings, they generally lack the opportunity to spread their fixed costs. For this reason, a "small farmer, large field" model has been promoted by province-level agricultural authorities in Vietnam to open ways for small farmers to realize economies of scale without giving up the land they hold on to for food and income security.[b]

a. Farmers also applied less when they relied less on irrigation, applied manure (even though its nutrient content is harder to ascertain and can be underestimated), had more fertile soil, were farther from fertilizer points of sale, and had higher levels of education. Another study found that when prices of phosphorus and potassium spiked in 2008, certain rural households in China turned to nitrogen fertilizers as a substitute, reflecting a probable lack of understanding of how these chemicals function (Zhang et al. 2008).

b. Actively promoted by Vietnam's provincial departments of agriculture and rural development (DARDs), the model supports groups of 25–100 neighboring farms in managing their land as though it were a single medium-size farm, without farmers giving up their land rights. Farmers break down the low walls between their plots, prepare the land together, manage water jointly, and plant the same crop varieties. DARDs have intervened by encouraging farmers to form groups, facilitating contracts between such groups and rice millers, and financing or providing land leveling, advisory, and other services.

Box 1.12 Livestock Operations: Small but Clustered and Intensive

In Vietnam, livestock operations remain largely dominated by small, household farms. In 2008, 85 percent of pigs were held by smallholders with fewer than 10 head each; in 2013, 90 percent of poultry bird operations were held by smallholders with no more than 50 birds each; and in 2009, 90 percent of cattle (beef and dairy) were held by smallholders with fewer than four cows on average (Dinh 2017). Overall, producers have been reluctant to grow beyond a certain size (for example, 1,000 pigs, 200–500 cattle), despite generous financial incentives from the government to do so. They recognize that larger facilities require investments in modern waste handling facilities and attract more environmental scrutiny. But Vietnam's livestock farms are growing both in size and particularly in intensity, especially pig and poultry farms.[a] The number of farms raising pigs fell by over 65 percent in the decade preceding 2014, and that year over 65 percent of pork supplied to markets came from farms with at least 10 pigs. Semi-industrial and industrial operations accounted for around 64 percent of the industry by value. Confined cattle operations are emerging to produce beef and dairy, but these still account for a sliver of production. Meanwhile, most pig and poultry farms, large and small, rely on commercial feeds, most of which are rich in nitrogen and phosphorus and contain antibiotics and growth-enhancing heavy metals (since 2014, growth hormones have been banned from feed by Vietnam's veterinary authority)—see Dinh (2017). Livestock farms are also clustering in space, flocking to towns near big cities (for example, in Dong Nai Province near Ho Chi Minh City and Thai Binh Province near Hanoi) that offer the best access to feed and consumer markets.

A similar pattern has been observed in the Philippines, though that country has seen less growth and a more significant shift to commercial pig farms. Although backyard swine production remains dominant, its share of the pig population receded from 82 percent in 1994 to 65 percent in 2014 as commercial farming rose, especially in the Metro Manila area. In China, the livestock industry has moved much further down the path of consolidation, yet it too remains dominated by a plethora of small and backyard operations.[b] Under the country's Sustainable Agricultural Development Plan (2015–30), the government has made it a policy to continue promoting the development of concentrated livestock farms and production zones.

a. Pigs and poultry are more important than ruminants in lowland areas; however, poultry plays an important role in mountainous regions, especially in mixed crop–livestock systems.
b. As of 2015, "above-scale" farms accounted for 69 percent of egg farms, 45 percent of dairy farms, and 42 percent of hog farms. "Above-scale" refers to farms raising 10,000 laying hens or 100 head of dairy cattle or slaughtering 500 or more hogs per year (China Ministry of Agriculture et al. 2015 in Gale, Hansen, and Jewison 2015).

Yet where consolidation is occurring and industrial farms are emerging, the pollution situation is not always improving. The large industrial operations that are in fact emerging in the livestock and aquaculture sectors, especially in China, have a mixed record in terms of cleaning up the industry through the use of more sophisticated waste management techniques.

Similarly, areas of crop farming that are dominated by large players are not always the most exemplary, perhaps because with market dominance and economic strength come political influence and regulatory capture. Large-scale farming operations, whether they involve commercial plantations, contract farming, or outgrower schemes, are sometimes heavy users of fertilizer, plastics, and pesticides. Some plantation crops grown for export in the Philippines, including banana, oil palm, coconut, and pineapple, with multinational involvement, are sprayed with pesticides aerially, putting local populations at risk (Havemann and Rosenthal 2015; Magcale-Macandog, Paraiso, et al. 2016). Perhaps tellingly, even with the cooperation of the government, it was not possible to obtain data on the use of agrochemicals and farming practices (Magcale-Macandog, Briones, et al. 2016). Political influence is not specific to the region. A 2008 report by the Pew Commission on Industrial Farm Animal Production in the United States, based on a review of hundreds of peer-reviewed papers, found "significant influence by the industry at every turn: in academic research, agricultural policy development, and government regulation and enforcement." More broadly, the Pew Commission found that "the present system of producing food animals in the United States is not sustainable and presents an unacceptable level of risk to public health and damage to the environment, as well as unnecessary harm to the animals we raise for food" (Pew Commission 2008, viii).

Public Sector Responses to Date

Many promising public policies and programs are in place, but their results often fall short of expectations.

China, Vietnam, and the Philippines have established laws and regulations for the protection of national air and water resources and food safety, and China was developing a law on soil protection at the time of writing. China has probably gone the furthest in establishing agricultural sector–specific laws and regulations to monitor, prevent, and control pollution, followed by Vietnam. In this respect, the Philippines is lagging, possibly in part because agricultural pollution there remains less severe. Although environmental laws are in place and certain aspects of farming are subject to environmental regulations, a comprehensive agroenvironmental protection strategy and framework are generally lacking.

In China, and to a growing extent in Vietnam, the harmful side effects of agricultural intensification and growth have come to light and begun to drive changes in policy. For example, since 2006 China has built an increasingly comprehensive set of laws, regulations, and standards for the prevention and control of livestock waste pollution at both the national and subnational levels. These documents set forth provisions on farm construction; livestock housing; and waste storage, treatment, and utilization; as well as on the use of antibiotics, hormones, heavy metals, and more. Farmers are barred from evacuating waste that is untreated, encouraged to minimize the use of water for cleaning, and

urged to use manure productively. A 2015 food safety law prohibits the presence of various antibiotics and chemicals in meat (Rousseau 2016).

In addition, various economic incentive programs have been put in place to encourage the adoption of better waste management practices on a voluntary or compliance basis. These programs include economic "sticks," such as fines and fees for excessive or untreated discharge, and economic "carrots," such as concessional finance for investing in treatment facilities, tax breaks on organic fertilizer, and biogas subsidies. In late 2016 China's Ministry of Environmental Protection announced plans to increase and enforce taxes on the population size of large livestock farms and its intent to use the proceeds to protect waterways. Efforts are also under way to shut down unlicensed pig farms and to develop a water quality information system to better track pollution (Godfrey 2017).

In all three countries, however, laws to prevent and control pollution are often ignored, while incentive programs sometimes fail to influence practices as intended. This situation applies, for example, to bans on the burning of agricultural residues, on the use of certain toxic pesticides, and on the dumping of untreated livestock waste into streams. Several factors are at play in the livestock sectors of China and Vietnam, and they have relevance more broadly:

- Economic (dis)incentives are often too small to be motivating. This problem effectively means that, irrespective of their awareness of pollution impacts or the law, farmers are more or less obligated to pollute in order to compete (for example, dumping untreated waste into water streams because it is the cheapest method of disposal). The potential for free-riding in such circumstances adds to farmers' dissuasion.

- The incentive programs that have worked well sometimes face challenges in achieving scale and sustainability. Various pollution prevention and control programs have been implemented successfully in all three countries on a pilot basis, demonstrating that sticks, carrots, and technical training can be combined effectively. In Guangdong Province, a case in point, local authorities have been gradually attempting to scale up a number of incentive schemes that have helped the province start to rein in the untreated dumping of animal feces.[67] Program funding has not been institutionalized, however, and it is premature, if not unrealistic, for program offerings to be carried by markets on their own.

- In some cases, legal principles have not been translated into rules specific enough to hold farmers accountable. For example, even though Chinese law requires farmers to respect the nutrient carrying capacity of the land, specific thresholds have not been defined. In other cases, regulations and standards have not been translated into practical guidance that farmers or others can follow, such as those on the use of manure as fertilizer.

- Yet in other cases, industry requirements are so far removed from on-the-ground realities in terms of stringency that they may as well not be in place.

Vietnam's wastewater discharge standards are reportedly confronting this reality. Because they are more stringent in some respects than those applicable to commercial farms in far more industrialized countries such as Japan, Thailand, and the Republic of Korea, Vietnamese breeders have been dissuaded from even attempting to comply.

- A separate issue in China is that many of the legal dispositions in place target large-scale commercial farms, leaving small and midsized farms to operate in a much more permissive environment. And even though the consolidation and scale-up trends are clear and bringing a growing part of the industry into a regulatory fold, a large swathe of the industry is subject to limited scrutiny.

- In all three countries, a lack of detailed, up-to-date data on farming practices and emissions hampers the government's ability to manage agriculture's various contributions to pollution because they are ultimately not well understood. The first comprehensive survey of pollution in China was conducted in 2007, and it remains the basis for government actions before the second such survey generates data for 2017.[68] Comprehensive surveys of this nature have not been undertaken in either Vietnam or the Philippines.

- Oversight of and assistance to farmers are also a challenge. Extension services are generally underfunded, demonstration programs have been known to stall, and the technical capacity for local supervision is often in short supply. In fact, a lack of funding for extension services has allegedly pushed some agents in China and Vietnam to sell fertilizer and other agro-inputs on the side to cover their operating costs, fueling problems of overuse.[69]

- It has not helped that the development of industrial livestock farms has remained a priority of agricultural policy even though these farms are increasing pollution. This priority has positioned the livestock industry to receive support that is at odds with environmental approaches and objectives, particularly where environmental compliance and pollution control options have received minimal attention (in design and licensing, for example).

Recently, China and Vietnam have begun to embrace a more balanced set of agricultural policies that not only place greater emphasis on environmental sustainability, but also link it to emerging and long-standing priorities of agricultural policy: food quality, competitiveness, yield performance, and food security. Vietnam's Agricultural Restructuring Plan of 2013, for example, marks a shift in thinking by recognizing a link between sector growth and environmental achievement. In China, the Sustainable Agricultural Development Plan of 2015 goes much further in reflecting a desire for the sector to prosper as a result of, rather than in spite of, sound environmental management, while calling for a

stronger hand in protecting agriculture's resource base (see box 1.13). China's strategy directs policies to encourage the comprehensive use of agricultural straw and livestock manure and to recycle plastic films and packaging. It also calls for zero growth in fertilizer and pesticide use by 2020—objectives for which action plans are already in place—and airtight management of livestock waste.

Box 1.13 Highlights from China's Sustainable Agricultural Development Plan

Released by the Ministry of Agriculture in 2015, China's Sustainable Agricultural Development Plan lays out the following principles and calls to action for 2015–30, covering the crop, livestock, and aquaculture industries.

Principles

- Match environmental carrying capacity with agricultural production.
- Promote innovation alongside the enforcement of environmental protection.
- Strengthen short-term pollution control measures while promoting long-term measures for sustainable resource utilization.
- Scale up successful models through piloting and demonstration.
- Use both government guidance and market incentives to promote sustainable production.

Crop Production

- Control cropland contamination as it relates to fertilizer and pesticide utilization and to plastic films and packaging.
- Move toward a science-based and efficient use of inputs.
- Achieve zero growth in fertilizer use by 2020.
- Achieve zero growth in pesticide use by 2020.
- Achieve the full utilization or recycling of agricultural plastics and pesticide packaging wastes by 2030.

Animal Agriculture

- Ensure comprehensive control of pollution from animal production.
- Support the standardization of concentrated livestock farms and production zones.
- Improve the collection, treatment, and utilization of livestock waste.
- Control livestock pollution releases.
- Strengthen control of the production and use of veterinary medicines and feed additives.
- Control the capacity and density of aquaculture production in coastal areas, rivers, lakes, and reservoirs.
- Support the standardization and ecological restoration of aquaculture ponds.

Source: Based on China Ministry of Agriculture et al. (2015).

These and other elements frame pollution control as both a public imperative and a green growth opportunity—a pathway to enhanced innovation, value addition, and farmer prosperity. The strategy also recognizes the need for spatial and structural planning to improve pollution control. Like Vietnam's livestock restructuring strategy, China's strategy calls for controlling the density of aquaculture production, for example.

To date, the logic outlined above has not been the norm in the three study countries, and socializing this way of thinking to see it through is likely to be challenging. This points to the need not only for efforts on the legal, technical, and economic fronts, but also for institutional reforms encompassing the incentives, culture, and priorities of regulators. Adequate public sector funding and market participation will also help produce and sustain adequate resources for such things as monitoring, enforcement, and various forms of subsidy.

Summary

As this chapter has illustrated, agriculture in East Asia is responsible for a wide range and diffuse set of pollutants that are seldom considered as a whole and often escape measurement. Yet considering different forms of agricultural pollution together reveals a problem of significant severity and breadth. The agricultural sector generates a multiplicity of pollutants that assume different forms as they travel through soil, water, and air, and enter the food chain. Many of these pollutants enter the environment from multitudinous or spatially diffuse sources, the cumulative effect of which can be tremendous.

Although agricultural pollution has progressed at very different rates across this vast region, it has become a concern in every country where farming has taken an intensive turn—indeed, even where very small farms continue to dominate. Farming operations have become a leading source of soil and water pollution in the intensively farmed parts of emerging East Asia, and they are a neglected contributor to air quality impairment, preventable disease, and premature death. Agricultural pollution may in fact represent the limits of sector transformations that have been a cornerstone of the region's socioeconomic development over the past three to five decades. In this sense, taking a hard look at agricultural pollution makes the concept of sustainability more tangible and more concrete, and it helps to frame broader questions about the primary sector's role in tomorrow's food systems.

Evidence, though imperfect, supports a number of priority areas in which more and better policy intervention is needed. The data and knowledge gaps surrounding agricultural pollution and its effects on the region are profound, and

limited work has been carried out to valuate, in economic terms, the various impacts of polluting farming practices. Nonetheless, enough is understood to point to a number of farming patterns that are making critical contributions to the East Asia region's pollution woes. Furthermore, a plethora of pollutants—and the complex impacts to which they lead—have the potential to be addressed through the reexamination of a smaller number of agricultural structures and practices. In particular, enough is known for policy makers to recognize that the areas presented in table 1.3 are priorities.

Recognizing these challenges and opportunities, governments have begun to react. China has taken the most steps within the East Asia region to rein in pollution, as the heavy costs of rampant pollution have turned the matter into a simmering public concern. China has also probably gone the furthest in establishing agriculture sector–specific laws, regulations, and incentive programs to monitor, prevent, and control pollution. In fact, it may now be turning a corner in starting to address the issue more strategically, with greater attention to prevention and to taking successful approaches to scale. In Vietnam, many government efforts to limit and control agricultural pollution are also under way because its effects are being felt ever more widely, although they remain more reactive and experimental, and in some cases donor-led. In the Philippines, where agricultural pollution is less severe overall, or rather more localized, the government has yet to tackle agricultural pollution head-on in the sense that it has adopted fewer agriculture-specific laws and programs.

In general, however, agricultural pollution has seemingly yet to become a top priority or a mainstream agricultural policy issue in the East Asia region, and it is not treated as the cross-cutting policy issue that it is. This may explain why even good laws and regulations are underenforced in many cases, and why even well-designed incentive programs sometimes lack the muster they would need to change farming practices on a large scale and in lasting ways. Some programs do not lack resources as much as they face headwinds, some of which stem from the persistence of conflicting policies. This lack of coordination can lead to unhelpful uses of public resources and missed opportunities to use those resources in more supportive ways.

In the future, the success of governments in addressing agricultural pollution will be judged, at the broadest level, by their ability to transition from a reactive and rehabilitative mode to a more proactive one that more effectively prevents damage and leverages the economic opportunity embedded in the act of tackling a challenge of such complexity and magnitude. Looking ahead to solutions, chapter 2 of this report provides general guidance on possible reorientations of policy.

Table 1.3 Agricultural Pollution Priorities

Farming patterns and circumstances associated with critical pollution concerns	*"Pressing opportunities" to enhance the sustainability of farming*
Livestock emissions	
The concentration, improper storage, and release of inadequately treated livestock manure, especially in the vicinity of cities, related primarily to the rise of meat consumption and the development of industrial facilities, and secondarily to facilities' limited capacity, motivation, or compulsion to adopt improved waste management systems or preventive measures upstream.	Improve the livestock industry's waste management practices and environmental performance, while refraining from stimulating the industry's expansion, in recognition of its net detrimental effects on human health even under favorable production circumstances (factoring in zoonosis and food safety risks, environmental pollution, and food-related chronic disease), its fundamental resource inefficiency, and its contributions to climate change.
Drugs in animal agriculture (land and aquatic)	
The systematic use of antibiotics, hormones, and heavy metals in animal agriculture to accelerate growth, enable overcrowding, and enhance profit.	Drastically cut back on the prophylactic, veterinary use of antibiotics, the commercial benefits of which may be far overshadowed by the costs of drug resistance.
Aquaculture waters	
The release into the environment of inadequately treated aquaculture water from intensive, open-loop operations using feed, drugs, and chemicals to cater to the growing demand for animal protein as wild fisheries come under strain and, in some cases, to adapt to climate change.	Bring aqua-ecosystems into balance, including through the embrace of improved inputs and various kinds of closed-loop systems.
Fertilizer	
The intensive and wasteful use of fertilizer, related among other factors to absentee farming; input marketing and pricing; limited soil testing; the low use or availability of adapted blends, higher-quality fertilizers, or precision application tools; farmers' perceptions and beliefs; and a lack of market incentives and opportunities for product differentiation.	Reduce fertilizer losses from cereal and specialty crop farming (as well as feed losses from aquaculture) that are contaminating surface waters, harming soil fertility, reducing air quality, and contributing to climate change. In many cases, this will save farmers and governments money without harming yields.
Pesticides	
The unscientific use of pesticides, reflecting, among other things, a lack of knowledge, understanding, or training; the availability, pricing, and marketing of hazardous products; a lack of coordination in pest control; a lack of standards, testing, and market incentives.	Professionalize the use of pesticides, while promoting prevention and low-toxicity control agents in order to minimize the use (and preserve the efficacy) of toxic substances and abandon the use of banned substances, which, when undetected, harm people and, when detected, harm trade.
Plastics	
The growing reliance on single-use plastic ground covers that break down but do not degrade and are hard to recycle or otherwise manage, related in part to their power to transform farming constraints, to the cost and availability of alternative plastic or nonplastic technologies, to product and manufacturing standards, and to plastic management infrastructure and incentives.	Commercialize more environmentally benign plastics and related waste management systems, as well as alternative technologies, especially for use in cold, dry, and other conditions in which plastics have transformed farming.

table continues next page

Table 1.3 Agricultural Pollution Priorities *(continued)*

Farming patterns and circumstances associated with critical pollution concerns	*"Pressing opportunities" to enhance the sustainability of farming*
Open burning and improper disposal of crop residues	
The persistent seasonal burning of agricultural residues, even where bans are in place, related in part to narrowly spaced crop rotations and, in some cases, to farmers' positive perceptions of burning.	Reduce and repurpose the organic by-products of farming, including manure and crop residues, to derive value from them and put an end to the open burning and harmful disposal of these as wastes.
Rice cultivation	
The permanent flooding of rice paddies, which prevails because of a lack of clear incentives to save water, unreliable water control capacity, and farmers' concerns about yield losses in some cases.	Diffuse rice cultivation techniques that reduce climate-warming greenhouse gas emissions, while saving water and maintaining or improving yields.

Notes

1. See Bonhommeau et al. (2013) on the shifting positions of different countries and regions in the food web.
2. Reactive nitrogen is a highly mobile and bioavailable form of nitrogen that is essential to life but also a major pollutant. Agricultural sources include synthetic fertilizer and animal feces. China is by far the largest emitter of reactive nitrogen globally (Liu, X., et al. 2013).
3. Includes crops, aquaculture, and livestock production.
4. Livestock accounted for the majority of agricultural discharges of organic waste (96 percent) and phosphorus (56 percent—crops accounted for 38 percent and fisheries for 5 percent), as well as of copper and zinc (98 percent each). Crops accounted for the majority of agricultural nitrogen discharges (59 percent—livestock accounted for 38 percent and fisheries for 3 percent).
5. *Eutrophication* refers to the degradation of a body of water (oxygen depletion and reduced sunlight penetration) from an excessive richness of nutrients stimulating dense plant growth.
6. Aquaculture and pesticide use on crops are likely contributors to Mekong Delta water pollution (Nguyen, C. G. D., et al. 2015; Wilbers et al. 2014). One study by C. G. D. Nguyen et al. (2015) found pesticides in every one of its Mekong Delta drinking water samples, sometimes at worrisome levels.
7. Waters assigned grade IV, V, or higher (that is, that meet no grade) are deemed unsafe for drinking (centralized drinking water supply) or for recreational uses involving human contact with water. Above grade IV, waters are considered unsafe for industrial use, and above grade V, for agricultural use (Environmental Quality Standard GB3838-2002 and GB/T 14848-9). Key groundwater pollutants include total dissolved solids, total nitrogen, and total phosphorus, and key surface water pollutants include total phosphorus, chemical oxygen demand, and permanganate (based on China MEP 2016a). Percentages are based on the monitoring of 5,118 groundwater wells, 700 river sections, and 62 lakes and reservoirs.
8. Nonpoint source pollution, including agricultural sources, contributed to 73 percent of chemical oxygen demand, 94 percent of ammonia-nitrogen (NH_3-N), 75 percent

of total nitrogen (N), and 94 percent of hydrogen phosphate (HPO_4) in the Miyun Reservoir's total load.

9. China has faced algal blooms in several of its major lakes, including Chaohu, Taihu, and Dianchi.
10. In a survey of the areas in northern China that have been given over to intensive cultivation of vegetables, the Chinese Academy of Agricultural Sciences found excessive nitrate concentrations in 50 percent of 800 groundwater samples (Zhang, Ma, et al. 2013).
11. According to the city's environmental protection department, as reported in the press; http://www.haisontq.com/tin-tuc-su-kien/tin-tuc/613-nuoc-thai-tu-chan-nuoi-lam-o-nhiem-song.html.
12. In a study of groundwater in northern Vietnam, Schumacher et al. (2011) found five pesticides commonly used in rice production in concentrations exceeding European drinking water thresholds (>0.1 microgram per liter) in 22 percent of spring and 31 percent of summer samples. In a study of multiple drinking water sources in the Mekong Delta, including surface waters, groundwater, harvested rainwater, and purchased bottled water, C. G. D. Nguyen et al. (2015) detected up to 12 pesticides used in rice and other cropping systems in every sample, sometimes at concentrations exceeding the European Commission's parametric guideline values for individual or total pesticides in drinking water (0.1 and 0.5 micrograms per liter, respectively).
13. This is one study's estimate. There are no official data on antibiotics administered to animals in China.
14. According to China Ministry of Environmental Protection (MEP) data, in 2015, 265 of 338 monitored cities (prefecture-level and centrally managed) failed to meet air quality standards (China MEP 2016b). These standards include $PM_{2.5}$, among other pollutants.
15. Nitrogen emissions from agricultural activities play a critical role in the formation of "secondary" air pollutants (see Wang, Y., et al. 2013) that provoke respiratory and cardiovascular problems, as well as cancers in humans (ozone can also diminish crop productivity). Nitrogen oxides (NO_x) and ammonia (NH_3), including from agricultural sources, contribute to the formation of secondary particulate matter (PM), which forms through various reactions among NH_3, NO_x, sulfur dioxide (SO_2), and volatile organic compounds (VOCs), and thus as a result of interactions with urban diesel emissions, among others. Secondary particulate matter is estimated to account for around half of $PM_{2.5}$ in China (Wang, Y., et al. 2013). Emissions of nitrogen oxides (NO_x) also increase levels of nitrogen dioxide (NO_2) and tropospheric (ground-level) ozone (O_3).
16. Agricultural pesticides have also been detected in air samples, and they vary with agricultural seasons. H. Li et al. (2014) found this to be the case in southern China, with concentrations of chlorpyrifos and cypermethrin peaking in the summer and autumn, consistent with their time of application.
17. In Indonesia, fire has also been a prominent means of clearing land to grow oil palm, from which lucrative commodities are derived. The resulting haze has badly affected air quality in both rural and urban areas.
18. Smoke from Indonesian fires has, for example, affected the population of Singapore.
19. In the 2000s, nitrogen deposition rates reached levels similar to those seen in northwestern Europe (the United Kingdom and the Netherlands) in the 1980s before the introduction of mitigation measures. China's nitrogen deposition rates (bulk

deposition, capturing both wet and dry forms) increased by over 60 percent between the 1980s and the 2000s, with the highest and fastest-rising rates observed in the agriculturally intensified northern, southeastern, and southwestern parts of the country (Liu, X., et al. 2013).

20. For example, nitrogen deposition has been associated with declines in (macrophyte) species diversity (Bobbink et al. 2010; Pardo et al. 2011; van der Molen et al. 1998 in Jones et al. 2014). Moreover, restoring lakes to a macrophyte-dominated, clear state can require a return to nutrient levels substantially lower than those at which the collapse of original vegetation occurred (Scheffer et al. 2001 in Zhang, Y., et al. 2016). Gaseous forms of nitrogen can be directly toxic to plants, stunting their growth, and high rates of nitrogen deposition can reduce soil organic matter in multiple types of soil and contribute to soil and water acidification, detracting from nutrient cycling and upsetting flora and fauna productivity and balances (multiple sources in Jones et al. 2014).
21. Exposure to endocrine-disrupting substances, which include pesticides and plastics, has been associated with abnormal thyroid function in birds and fish; decreased fertility in birds, fish, shellfish, and mammals; decreased hatching success in fish, birds, and turtles; the demasculinization and feminization of male fish, birds, amphibians, and mammals; the defeminization and masculinization of female fish, gastropods, and birds; and the alteration of immune function in birds and mammals (multiple sources in Colborn, vom Saal, and Soto 1993).
22. Prior to the 1980s, only a few lakes near urban centers were eutrophied (Le et al. 2010). By 2000, 61 percent of 28 monitored lakes were significantly eutrophied (Sun and Zhang 2000).
23. The Bohai Gulf, the Yellow Sea, and the South China Sea. Agriculture is the dominant source of nitrogen and phosphorus in the Yellow and South China Seas.
24. Most nitrogenous fertilizer is used on cropland—87 percent in China (Zhang, W. F., 2014).
25. Land-use emissions are not counted here, although a large portion of land-use emissions are agriculture-related.
26. SLCPs include but are not limited to greenhouse gas emissions, and they have atmospheric lifetimes spanning a few days to roughly 15 years. Agricultural SLCPs primarily include methane (CH_4), a greenhouse gas of microbial origin and a by-product of the incomplete burning of biomass (which has a 100-year global warming potential [GWP_{100}] of 28–34), and black carbon, a fine particle (a subset of $PM_{2.5}$) also known as soot, that is emitted as a result of incomplete combustion (and has an atmospheric lifespan of less than one month). As noted, agricultural emissions can also contribute to ground-level ozone formation. All three are significant climate forcers, causing warming at different time scales (see Zaelke et al. 2013).
27. Regionwide, methane accounted for 55 percent of agricultural greenhouse gas emissions in 2014 (counting methane and nitrous oxide only) (based on FAOSTAT).
28. As noted, indirect agricultural emissions related to land-use conversion are not counted here.
29. Other pollutants emitted at the same time as black carbon during combustion—especially during the combustion of biomass (as opposed to diesel fuel, for example)—can in some circumstances have a cooling effect that can outweigh the short-run warming effect of black carbon emissions. That said, the net long-term effect of biomass burning is to warm the climate, notably through the production of

methane, with its longer atmospheric lifespan. Furthermore, burning emissions have an unambiguous short-run warming effect when they occur or drift over snow- and ice-covered (that is, highly reflective) areas of the planet (see Cassou et al. 2015).

30. As noted, ozone precursors include nitrogen oxides and volatile organic compounds.
31. Energy emissions are in first place.
32. Emissions from livestock enteric fermentation grew at roughly the same rate as rice emissions over this period.
33. Soil acidification can, among other things, accelerate the loss of nutrients; promote the activation of aluminum, manganese, and heavy metals and other elements; and change the soil microbial population and activity, crop root development, nutrient absorption, and the breeding of plant pests and diseases. At pH (potential of hydrogen) levels of 5.5, rice will show senescence, and dryland crops will become seedless in soils with a pH under 4.5 (Lu 2003).
34. On average, the pH of China's cropland soils is estimated to have declined by 0.5 units from the 1980s to the 2000s (Guo et al. 2010).
35. See, for example, McLeod et al. (2005).
36. Paralytic shellfish poisoning is caused by toxins produced by some species of microscopic algae. When ingested, these toxins affect the nervous system and paralyze muscles, causing illness or death in wildlife and humans.
37. During 2002–10, about 27 percent of Vietnam's cases of agrofood product export rejection stemmed from antibiotic residues and 23 percent from bacterial contamination (based on UNIDO 2015).
38. The presence of pesticide residues exceeding maximum residue limits (MRLs) allowed by trading partners may or may not mean that food is unsafe to consume. MRLs are generally multiple times lower than acceptable daily intake (ADI) levels—that is, the levels considered safe for human consumption. Furthermore, MRLs are set at very low default levels (generally close to zero) for pesticides that have not been specifically preapproved for use on a given crop.
39. As soils acidify, crops' uptake and accumulation of heavy metals such as cadmium can exceed thresholds considered safe for human consumption (Bolan, Adriano, and Curtin 2003; CLRTAP 2016; de Vries et al. 2013).
40. In particular, emissions of nitrogen oxides (NO_x) from fertilizer and manure management are a precursor of tropospheric (ground-level) ozone (O_3), which has a corrosive effect on the built environment.
41. Agriculture is the dominant source of nitrogen and phosphorus in the Yellow and South China Seas, and it is believed to be a prime driver of eutrophication (Strokal et al. 2014).
42. Agriculture and households overtook industry as the leading sources of discharges linked to algal blooms after 2000 (Huang et al. 2014).
43. Pre– and post–farm gate contributions to pollution can also be significant, but they are outside the scope of this study.
44. In China, biodigesters have been heavily promoted and subsidized since the 1980s, and in Vietnam more recently supported by development projects.
45. Drugs commonly used in Vietnamese aquaculture include florfenicol, sulfamethoxazole, trimethoprim, oxytetracyline, ciprofloxacin, norfloxacin, sulfamid,

metronidazole, colistin, gentamicin, sorbitol, ampicillin, and furaltadon (Nguyễn, T. Q. T., et al. 2015; Tú et al. 2006).

46. "Arable and permanent cropland" is the total of "arable land" and "land under permanent crops." Arable land is the land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (for less than five years); and land under permanent crops is the land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest. See http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/land/arable_cropland_area.pdf.
47. Based on nitrogen, phosphate, and potash fertilizer data from the International Fertilizer Association (IFADATA) and FAOSTAT data on paddy harvested area.
48. Based on Yan et al. (2014) and other sources.
49. High proportions of nitrogen fertilizer are applied *manually* to China's major crops—96 percent for rice, 88 percent for wheat, and 36 percent for maize—and 50–60 percent is applied before planting (Zhang, Ma, et al. 2013). Both practices lend themselves to higher losses. Furthermore, nearly all fertilizers on the market are sold in solid form, making them unsuitable for typical mechanical application or fertigation, and little variety is typically available in terms of different blends, limiting farmers' ability to match fertilizer nutrients and minerals to the specific needs of their soils and crops (Gao et al. 2017).
50. The abundance of "low-quality" fertilizers on markets, notably in Vietnam (Phạm and Nguyễn 2013 in Nguyen, T. H., 2017), likely contributes to low fertilizer use efficiency.
51. Per hectare of arable and permanent cropland. The first estimate is calculated by dividing reported levels of pesticide use by the number of hectares of arable and permanent cropland. The second estimate is given by FAOSTAT (both based on FAOSTAT 2016). Li, Zeng, and You (2016) report that pesticides were applied at an average rate of more than 14 kilograms per hectare in 2011.
52. For three rice crops in the Mekong Delta, about 7 kilograms or more were applied per hectare per year according to 2015 Mekong Delta Development Research Institute (MDI) surveys in Kien Giang and An Giang Provinces (Nguyen, T. H., 2017). From August 2013 to March 2014, over 9 kilograms per hectare per cropping season were applied to vegetables in Hanoi's Dong Anh district, an important supplier to Hanoi (Hoi et al. 2016).
53. Nongovernmental organizations have reported the aerial spraying of banana fields with fungicides, herbicides, and insecticides, including the Class Ib ("highly hazardous") pesticide carbofuran and the Class II ("moderately hazardous") pesticides paraquat and chlorpyrifos (CTUHR and NLDF 2013). Carbofuran and paraquat are banned in the EU.
54. Saigon Online, http://www.sggp.org.vn/30-35-luong-thuoc-bao-ve-thuc-vat-nhap-khau-trai-phep-270818.html, October 13, 2008. Counterfeit pesticides remained a noted issue in 2016, even as authorities stepped up inspection efforts (Lexology, http://www.lexology.com/library/detail.aspx?g=2d92ba87-9de0-4718-bd4f-d79227ed7d50, November 21, 2016).
55. In the absence of proper recycling facilities, it is neither legal nor possibly desirable to recycle pesticide containers, which are considered a form of hazardous waste (Cassou et al. 2017).
56. These leakage estimates are not agriculture-specific.

57. Not only does the burning of agricultural residues and plastics release poisonous gases and particles into the atmosphere, but, over time, after a potential initial burst of fertility (from biomass burning), it also detracts from soil fertility. Yet burning is the cheapest and most expedient way to rid fields of residue in preparation for the next planting.
58. The source of 24 percent is the unpublished "12th Five-Year Plan Mid-Term Evaluation Report of Stalk Comprehensive Utilization," cited in the country study by Gao et al. (2017). It does not distinguish between burning and improper disposal. With no official statistics on national stalk output and utilization, it is based on data collected at the provincial level. One 2014 study estimated that China burns around one-quarter of an estimated 600 billion kilograms of straw left behind by crops each year (maize generates the most, at 38 percent, followed by wheat, 22 percent, and rice, 18 percent). These fires emit an estimated 1.6–2.2 billion kilograms of $PM_{2.5}$ and 0.5–0.14 billion kilograms of black carbon (Shi et al. 2014).
59. To put this in perspective, at the global level, livestock production, including feed production, accounts for approximately three-quarters of all agricultural land and nearly one-third of the ice-free land surface of the planet, making it the largest anthropogenic land-use type (Machovina, Feeley, and Ripple 2015; Steinfeld et al. 2006). Livestock constitute one-fifth of the total terrestrial biomass (Krausmann et al. 2008), and they consume a third of global cereal production (Alexandratos and Bruinsma 2012; Foley et al. 2011).
60. The densification in time and space of agricultural activity reflects the increasing competition for scarce land, water, and other resources, and at times has been magnified by spatial patterns of public investment in infrastructure (such as slaughterhouses and roads). Signs of this competition for resources have included a societal focus on agricultural intensification and yield growth to produce more in limited space, the multiplication of growing seasons (made possible by synthetic fertilizer, irrigation, and new varieties), and the crowding of animal operations. Vertical farming has, however, remained incipient.
61. Going forward, urbanization is expected to spread to some of the region's most productive croplands, including those of East China, raising multiple sustainability concerns (d'Amour et al. 2016).
62. On the advertising of agro-inputs in Vietnam, for example, see Normile (2013).
63. An estimated 75–95 percent of reactive nitrogen is lost to the atmosphere and hydrosphere in meat production (50–90 percent not counting feed production), compared with 40–70 percent for cereals across Europe (Sutton et al. 2011).
64. That said, the spatial intensity of these operations has, in some cases, "relieved" certain pressures on natural ecosystems (those pressures that more extensive growth might have generated). Aquaculture has, however, been closely associated with the destruction of mangroves and coral reefs in the region (see Primavera 1995; White 2017), and it continues to depend in large part on capture fisheries for feed.
65. Only 5–10 percent of corn is consumed as food; 60–70 percent is used as feed. The rest is used industrially. Separately, rising demand for feed has driven China to become the world's largest offtaker of Brazilian soybeans (75 percent in 2016, based on UN Comtrade data), the cultivation of which has been one of the major drivers of tropical deforestation.
66. Water is particularly scarce in China, where annual per capita (renewable) freshwater availability is about one-quarter of the world average.

67. At the time of writing, incentives offered under a World Bank–supported agricultural pollution control project in Guangdong had already been scaled up from 2 to 15 municipalities, and authorities were exploring the costs of rolling these out provincewide, spurred by the state's call to "green" agricultural subsidies.
68. Its release is not expected before 2019.
69. Efforts are under way in China to rein in this practice.

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CHAPTER 2

Tackling and Preventing the Problem

Technical Solutions and Policy Instruments

A broad array of technical solutions is within reach, and government has a key role to play in supporting them.

With public health, the environment, and competitiveness at stake, government intervention is needed to guide the private sector onto a path to greener growth. The existing technical solutions already offer significant abatement potential relevant to the agricultural pollution issues discussed in chapter 1. Furthermore, the promise of innovation to address pollution challenges is open-ended.

Well-established technical solutions are already available in almost every domain, cutting across farming practices and forms of pollution. The following are illustrative.

Livestock and Aquaculture Pollution. When it comes to managing emissions from livestock and aquaculture operations, for example, a multitude of techniques have already been tried and tested, and a host of more cutting-edge ones are emerging. In livestock farms, interventions range from upstream ones such as changes in animal breeds, feeds, housing system conditions and design, to more "end of pipe" ones such as changes in how manure and wastewater are handled, treated, and disposed of. Similarly, aquaculture emissions can be reduced by overhauling how aquatic farms are set up—such as by moving from open-loop to recirculating systems—as well as by modifying choices of fish, fish feed, and other pond additions, and by changing farming protocols. In both land and aquatic farms, improvements in sanitation, wastewater treatment, and other interventions can be effective in mitigating several forms of pollution, ranging from nutrients to air pollutants, pathogens, and antibiotics.

Agrochemical Pollution from Crop Farming. In crop farming, different field management protocols have demonstrated their effectiveness in specific contexts. In various parts of the region, nutrient management tools, including ones that bypass soil testing, have proven effective at reducing fertilizer use, along with waste and imbalances. An example of this is the questionnaire-based Rice Nutrient Manager tool developed by the International Rice Research Institute (IRRI) for use by farmers and extension workers via mobile devices (Buresh et al. 2012). Integrated soil-crop system management (ISSM) has also achieved promising results in Chinese maize, rice, and wheat production, as discussed shortly. Although integrated pest management (IPM) has faced challenges scaling up—in part because of small farm size[1]—this approach has empowered some farmers to reduce the use of pesticides, especially the most toxic ones, by using them as a last resort and favoring reliance on prevention, biological controls, and, when necessary, lower-toxicity, lower-residue, and high-efficiency pesticides. During the 1990s, countries such as Sweden, Norway, Denmark, the Netherlands, and Guatemala reportedly reduced their annual pesticide use by one-third without diminishing crop yields (see multiple sources in Hoi, Mol, and Oosterveer 2013). In Vietnam, changes in fertilizer use, together with alternate wetting and drying of rice fields (a technique that uses less water than the more conventional permanent flooding), have in some instances more than halved emissions of carbon dioxide equivalent (CO_2e) while saving water and improving yields (Thu et al. 2016).[2] Methane emissions from rice paddies can also be lessened by the use of improved rice cultivars and fertilization techniques, including ones that use rice straw, thereby averting burning (Adhya et al. 2014; Thu et al. 2016).

Redesigned agro inputs and application gear also hold promise. Although the effectiveness of these technologies depends on affordability and the extent to which they rely on behavior change, among other things, they can make a big difference in protecting the environment and rural communities, even where access to data, analytic tools, or farmer sophistication is limited. Pesticides that can be painted onto seeds, and fertilizers that come in the form of granules intended for deep-soil placement, are straightforward ways to lessen chemical exposure and losses. Soil testing kits and laboratories, formula fertilizer and slow-release fertilizer, smaller or redesigned chemical containers, and microirrigation can also improve fertilizer dosing and reduce waste. Box 2.11 later in this chapter describes experimentation with low-tech precision technologies in China. Simple protective gear, if worn, can reduce farmworkers' exposure when chemical spraying is deemed necessary. Equipment that allows ground-based spraying of pesticides can decrease its volatilization. Biotechnology has shown significant potential for reducing reliance on some of the most toxic pesticides, though the jury is still out when it comes to its long-term effects on pest populations and reliance on pesticides. Looking ahead, scientists are exploring how soil microbes could be used to improve input use efficiency (Wallenstein 2017).

Open Burning and Plastics Pollution. Open burning and plasticss pollution are also technically avoidable. Farmers face a range of technical options when it comes to the use of crop residues, as these can be repurposed to make electricity, fuel, building materials, bioplastics, planting substrates, soil amendments, and more. Plastics pollution has the potential to be averted through the use of plastics substitutes such as green covers, different approaches to farming, and improvements in how plastics themselves are formulated, manufactured, managed, and disposed of.

In many if not most cases, farmers need public sector support to adopt technologies and practices that make mitigation a possibility—at least in the near term. Reducing the use of pesticides and resorting to alternatives to burning in field preparation can involve people spending more time farming. Soil testing and precision application devices to optimize fertilizer applications can be an investment that many farmers, especially small ones (and potentially consumers), are not willing or able to pay for. Upfront research and development (R&D) investments in context-appropriate technologies may not occur in the first place. The incentive to install wastewater treatment facilities, especially when space is lacking, can be nonexistent when contaminated waters can be dumped with impunity, with consumers and regulators all looking the other way. When it comes to plastics use and residue burning, the significant upside of these practices in terms of yield maximization and time savings can make these obvious choices for farmers whether they are actively promoted or merely tolerated by authorities.

In some cases, public sector intervention may be needed only initially to overcome the hurdles of switching to new technologies or practices. There are instances in which farmers stand to benefit privately from pollution mitigation: they can save on agrochemical costs, gain access to premiums and markets reserved for products of higher reputation and quality, or, over time, protect natural resource and agroecosystem productivity (land fertility, clean water, pollination, and so forth).

Field experiments in the region and beyond have shown the potential, for example, to maintain yields while significantly cutting back on the application of fertilizer thanks to better decision making. Better decision making calls for more data and analytics in farm management, along with the skill sets and physical tools required to act on them. In China, for example, nitrogen use was cut by roughly 4–14 percent in maize, rice, and wheat system field trials while boosting yields by 18–35 percent thanks to the knowledge-intensive approach to farming known as integrated soil-crop system management (ISSM), noted above (Chen et al. 2014). In Vietnam, the piloting of a technical package known as "1 Must and 5 Reductions" (1M5R) has shown that it could save Mekong Delta farmers an estimated 18–25 percent of their production costs per hectare of crop without harming yields (Nguyen et al. 2015).[3] Similar "triple win" opportunities for yields, incomes, and the environment have also been identified in relation to the use of fertilizer (and water) to grow coffee in Vietnam's Central Highlands

(Amarasinghe et al. 2015; Technoserve 2013). In such cases, reasons for farmers not adopting the technologies that lead to a "win-win" outcome can include a lack of awareness of the technology or its benefits, action-intention divides, coordination failures,[4] and a lack of access to finance, tools, or training, although these demand context-specific study. Public sector intervention may offer means of overcoming these barriers in certain cases.

With solutions ranging from specific technical ones to ones that are more structural in nature, government is in a position to drive change through its choice of investments, its power to tax and coerce, and its influence over social norms and the incentive environment. Illustrative instruments of government are summarized in box 2.1. The next section of this chapter offers further guidance on the application of these solutions.

Box 2.1 Examples of Public Sector Instruments That Can Be Used to Address Agricultural Pollution

Rules Linked to Farm Licensing, Operation, and Input Use

- Zoning rules, including restrictions on livestock rearing within a certain radius of sensitive areas, such as residential and water source protection areas, and on farming crops on sloped and ecologically sensitive land
- Restrictions on livestock farm size expressed in terms of animal or manure limitations
- Specifications for animal housing, waste storage, waste treatment facilities, or proximity to cropland
- Requirements that farms draw fresh water from sources downstream of them
- Mandatory reporting requirements for waste and wastewater discharges
- Bans on the marketing and use of certain pesticides, antibiotics, hormones, and other chemicals
- Limitations on the open burning of agricultural residues (volumes, timing)
- Standards for the treatment and discharge of wastewater.

Incentives or Disincentives Tied to Improved Farming Practices and Agroindustry Services

- Fines or loss of benefits for noncompliance with mandates
- Preferential credit or grants for straw residue management or manure injection machinery
- Subsidies for formula fertilizer, fertilizer deep-placement products, or soil testing kits
- Payments for adopting practices that reduce farm runoff
- Public procurement requirement that food purchases meet given certification standards
- Fast-track licensing for operations meeting high environmental management standards
- Loans to enterprises offering input application and soil testing services, as well as improved drugs, inputs, and gear
- Grants for demonstration farms and farmer-led movements modeling and supporting best practices
- Grants to enterprises increasing access to and the appeal of plant-based or small-footprint foods.

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Box 2.1 Examples of Public Sector Instruments That Can Be Used to Address Agricultural Pollution *(continued)*

Research, Surveillance, and Information

- Research programs on precision and cellular agriculture and other potentially disruptive solutions
- Grants for research on noninvasive aquaculture species, recyclable or biodegradable plastics and alternative materials and processes, alternative therapeutics, plant proteins, and the socioeconomic impacts of pollution
- Satellite surveillance of burning and other relevant activity
- Monitoring of more pollutants in more places, with a focus on hotspots
- Training of scientists and technical experts to strengthen extension and pollution monitoring capacity
- Information and behavior change campaigns promoting better farming practices and diets
- Development of green certification standards
- Dietary guidelines bridging health and environmental perspectives
- Branding efforts to raise the profile of an ecological farming region or product, in public-private partnership.

Strategic Directions for Effective Pollution Prevention and Control

Curbing agricultural pollution will require the public sector to direct adequate resources to priorities, compel and motivate farmers, shape the agricultural sector's structure and growth trajectory, and back innovation and learning.

Four strategic directions are proposed here for the public sector to pursue more effective agricultural pollution prevention and control—and achieve results. Specifically, it offers ways of using different categories of instruments to (1) break silos to mobilize and align resources with priorities; (2) combine instruments to compel, motivate, and enable farmers to "green" their farming practices; (3) influence consumption and other levers of structural change to keep pollution in check; and (4) learn and innovate to stay a few steps ahead of the pollution challenge.

1. Break Silos to Mobilize and Align Resources with Priorities

What: Harmonize and coordinate policy across policy silos, levels of government, and geographic boundaries to breathe life into an agricultural pollution agenda.
Why: To draw attention to agricultural pollution and help its abatement become a better-defined policy objective, a higher priority of ministries, and one with more resources directed to it.

How: Bridge jurisdictional boundaries.

- At the highest, strategic level: harmonize agricultural, environmental, and health policy goals, strategies, and resources, removing any conflicts among them.
- At more operational levels: coordinate efforts across levels of government, sectors, and geopolitical boundaries.

Harmonize Agricultural, Environmental, and Health Policy Goals, Strategies, and Resources

At the highest, strategic level, tackling agricultural pollution calls for greater harmonization of agricultural, environmental, and health policy goals, strategies, and resources. While the first two (agricultural and environmental goals) have already merged to some degree in high-income countries after decades of evolving separately (as exemplified by the evolution of European Union [EU] policy), their integration with health policy remains at an early stage. Health and environmental outcomes can become a central focus of agricultural agencies, and agricultural productivity goals can be defined without losing sight of them. This may mean taking a long view on yield enhancement that gives more weight to resource conservation. Agriculture's contribution to food security may also come to be as much about its contributions to micronutrient content and diversity as to caloric and protein availability.[5] Concretely, this means that the measurement of agricultural sector performance needs a rethink.[6] Health and environmental agencies can also bring agriculture more fully into their fold. A greater orientation toward agriculture and food production will help ministries of health and environment to more effectively curb the rise of chronic disease and to maintain a productive resource base supportive of food security and industry.

Prioritizing a subset of challenges or opportunities on which to focus can also help shift attention toward agricultural pollution policy and pave the way for action. Ideally, priorities are guided by the best available evidence (see box 2.2). This approach in turn highlights the need for establishing formal processes that regularly feed new evidence generated (see strategy 4) into priority setting, while guarding against institutional capture and biases.

If they are to lead to action, both broad and focused policy goals need to be buttressed by a consistent set of performance indicators, institutional incentives, operational strategies, and resources (budget, human, and other). Certain uses of public resources are fueling rather than mitigating avoidable forms of agricultural pollution in the region, and these can be redeployed if addressing pollution becomes a high enough priority. Examples include subsidies and preferential regulatory dispositions that are directly or indirectly stimulating the development of the livestock industry, as well as direct or indirect fertilizer subsidies. Other uses of resources that have a more neutral or indirect effect on agricultural pollution also represent a missed opportunity in that they could be

leveraged in ways that support greener farming systems. Various forms of farmer income support and investment in farm sector productivity such as in irrigation infrastructure and tree replanting are examples. In addition, measures can be taken to use resources more efficiently, notably by expanding evidence on what constitutes pollution "hotspots" or priorities, on where interventions will have high returns, and on the relative cost-effectiveness of different interventions (under strategy 2).

Box 2.2 Regional Agricultural Pollution Priorities

Though imperfect, evidence supports a number of priority areas in which more and better policy intervention is needed in the East Asia region. As noted, the data and knowledge gaps surrounding agricultural pollution and its effects on the region are profound. Nonetheless, enough is understood to point to a number of farming patterns that are making critical contributions to the region's pollution woes and to define a number of priorities. Although a rank ordering would differ among countries, chapter 1 makes the case that overall priority needs to be given, among other things, to the following (also see figure 1.8):

- Improving the *livestock industry's waste management* practices and environmental performance, while refraining from stimulating the industry's expansion in recognition of its net detrimental effects on human health even under favorable production circumstances (factoring in zoonosis and food safety risks, environmental pollution, and food-related chronic disease), its fundamental resource inefficiency, and its contributions to climate change.
- Drastically cutting back on the prophylactic *veterinary use of antibiotics*, the commercial benefits of which may be far overshadowed by the costs of drug resistance.
- Bringing *farmed aqua-ecosystems* into balance, including through the embrace of improved inputs and various kinds of closed-loop systems.
- Reducing *fertilizer losses* from cereal and specialty crop farming that are contaminating surface waters, harming soil fertility, reducing air quality, and contributing to climate change. In many cases, this will save farmers and governments money without harming yields.
- Professionalizing the *use of pesticides*, while promoting prevention and low-toxicity control agents, in order to minimize the use (and preserve the efficacy) of toxic substances and abandon the use of banned substances, which, when undetected, harm people, and, when detected, harm trade.
- Commercializing more environmentally benign *plastics* and related waste management systems, as well as alternative technologies, especially for use in cold, dry, and other conditions in which plastics have transformed farming.
- Reducing and repurposing the *organic by-products of farming*, including manure and crop residues, to derive value from them and put an end to the open burning and harmful disposal of them as waste.
- Diffusing *rice cultivation* techniques that reduce climate-warming greenhouse gas emissions from paddies, while saving water and maintaining or improving yields.

The steps described above will set the stage for redeploying and leveraging public agricultural spending, and generally bolstering the public resources available to steer agriculture away from polluting practices to cleaner ones (see box 2.3). Public investment in research may be rebalanced to focus more on protecting resources, building agroecosystem resilience, and optimizing nutrition with respect to environmental impacts. Conversely, public investments biased

Box 2.3 Redeploying Public Resources to Support the Production of Clean Food

With adequate policy and institutional reform, a range of public resources can be redeployed more coherently in ways more consistent with reining in agricultural pollution. The public spending and preferential regulatory dispositions currently propelling the development of livestock farms with little regard for their environmental and health consequences, for example, can be redirected to improving livestock as well as crop farming practices. More resources can be devoted to regulatory enforcement; the rewarding of technology adoption and best-in-class facilities; research on improved waste management systems for space- and resource-constrained operations; the development of feeds, breeds, and housing conditions that reduce livestock emissions to begin with; and therapeutics with less harmful side effects. Precautions are needed to avoid dissuading operations from professionalizing in helpful ways because larger and more sophisticated ones are disproportionately targeted by monitoring and enforcement efforts. Singling out large commercial facilities for scrutiny could create this kind of counterproductive trap.

Another way in which pioneering governments can redirect public resources[a] is in support of next-generation meat, seafood, eggs, and dairy made from cell cultures or plant-derived materials, as they could drastically reduce these products' resource use while vastly improving food safety. Vying for leadership in these emerging, potentially disruptive and high-value markets will mean training and attracting chemists, life scientists, food scientists, marketers, nutrition experts, and agribusiness companies to this field. Resources now devoted to livestock production, as well as resources currently used to directly subsidize inputs and support farm incomes, can also be redeployed in ways that help increase the availability, convenience, and affordability—and reduce the footprint—of more benign sources of nutrition such as fruits, vegetables, pulses, grains, and nuts and seeds (the "healthy five"). More resources could be invested not only in improving logistics and marketing, but also in developing precision and agroecological farming systems and related technologies, drawing, for example, on biotechnology, new materials, and information and communication technology. Land-use planning and regulations can also be oriented to ensure the preservation of productive farmland surrounding urban centers in support of vibrant regional "foodsheds."

Along with redeployed livestock sector resources, fertilizer and other inefficient subsidies can be redirected to motivate and equip farmers to profit more from their farming activities, while generating less fertilizer pollution and pesticide contamination. Public funds no longer used for such subsidies can be spent on extension and training and on accelerating the continued emergence of farm service enterprises that offer services such as soil testing, pesticide application, custom fertilizer blending, and even turnkey farming services. In China, as part of an air pollution prevention and control program, the government of Hebei Province has

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Box 2.3 Redeploying Public Resources to Support the Production of Clean Food *(continued)*

started subsidizing less-polluting fertilizer that releases nutrients gradually and is formulated on the basis of soil testing and crop needs. It is also offering livestock farmers concessional loans for investments in covered manure sheds, biogas digesters, and other manure management upgrades (World Bank 2016). In its attempts to realize economies of scale and savings through the consolidation of farming operations and information technology, among other things, this sector is already showing great potential to spur innovation in farming, while creating jobs that could attract youth and talent to this "aging" sector.

a. In general, a rethink on the true socioeconomic costs and benefits of investing in the livestock sector, factoring in environmental, human, and animal health and welfare, is bound to stimulate many more ideas on how public resources can help reconcile consumer safety, nutrition, environmental health, and resource stewardship goals with those of food security and agricultural growth.

toward monoculture farm systems and technologies may have lower returns than previously thought once their performance is assessed with a less strict focus on yield, output, or macronutrient calories.

Develop Multilevel, Multisector, Cross-Boundary Interventions

At more operational levels, developing policy interventions that cut across levels of government, disciplines and sectors, and geopolitical boundaries can be helpful in achieving environmentally significant results. This kind of cross-cutting approach acknowledges the multifaceted nature of agricultural pollution, as well as the fact that it does not necessarily respect jurisdictional boundaries. When abatement efforts are coordinated, compelled, or incentivized within the confines of spatial or sectoral silos (in keeping with jurisdictional responsibilities), they run the risk of failing to see tangible results, even when they can reduce pollution levels significantly.

This is particularly true with respect to improving local water and air quality given that these are often compromised by the activities of multiple sectors that are taking place across political boundaries. Although its results have been mixed,[7] the Chesapeake Bay Program has had decades of experience mobilizing a wide range of actors across sectors, states, and levels of government (see box 2.4). It has also experimented extensively with different combinations of instruments to achieve results, including sticks and carrots, all within a regulatory framework (thereby also making it relevant to strategy 2).

2. Combine Instruments to Compel, Motivate, and Enable Farmers to "Green" Their Farming Practices

What: Develop mixed-instrument programs to compel, motivate, and enable farmers to adopt less-polluting farming practices.
Why: To achieve pollution abatement across all kinds of farms, acknowledging the limitations of command-and-control approaches that rely on top-down surveillance and enforcement.

How: Strive to bring different players into the fold by using combinations of instruments.

- Combine sticks, carrots, and behavioral interventions to compel and motivate farmers in all their diversity.
- Make supportive investments in physical infrastructure, public services, data, and science to enable farm-level change and overcome constraints.

Box 2.4 The Chesapeake Bay Program: Lessons in Cross-Jurisdictional, Multistakeholder Collaboration

The Chesapeake watershed covers a population of some 16 million people across six states in the U.S. Mid-Atlantic region. Pollution from multiple and especially agricultural sources,[a] overexploitation of fisheries, and shoreline development over the past century have left the Chesapeake Bay in a severe state of stress. In the early 1980s, a congressionally funded study exposing the extent and causes of the Bay's degradation set political action in motion, eventually giving rise to the Chesapeake Bay Program (CBP), the cross-jurisdictional, multistakeholder restoration program that remains in place today.

The illustrative relevance of the program here is twofold. First, although the environmental targets that the CBP sets (such as total maximum daily loads, or TMDLs) are regulatory mandates, the program draws on multiple instruments, including sticks and carrots, to influence behavior. Notably, the CBP's emphasis on farmer participation, and on carrots more than sticks, has proven critical to the Chesapeake states' ability (though imperfect) to keep farm-related nutrients, sediments, and pesticides out of the Bay. Second, although the program is under the purview of a federal agency—the U.S. Environmental Protection Agency (EPA), which is mandated to run the program under federal environmental legislation—the program gives roles and responsibilities to multiple subnational, state, and nonstate entities. In fact, their involvement was built into the CBP's DNA, a multiparty agreement that brought the program to life. The CBP thus has had decades of experience experimenting with various combinations of instruments, including ones aimed at changing farmers' behavior, as well as with approaches to collaboration.

Much can be learned from the complex architecture that the CBP has developed to govern multiple subprograms and disparate stakeholders. Stakeholders include about a dozen agencies and 30 subagencies at the federal government level; a similar number of agencies in each of the three core participating states (Delaware, Maryland, and Virginia) and the District of Columbia; additional state-level agencies representing three additional "headwater" states; municipalities; some 20 foundations, watershed organizations, and nongovernmental organizations; over 15 universities; and a number of industry organizations (World Bank 2006). More fundamentally, in its attempt to control both point and nonpoint sources of pollution, the program is designed to involve a myriad of actors across multiple sectors, from farmers and landowners to manufacturers and water utilities.

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Box 2.4 The Chesapeake Bay Program: Lessons in Cross-Jurisdictional, Multistakeholder Collaboration *(continued)*

One source of rich insights into program strengths and shortcomings with respect to stakeholder collaboration is the stakeholder assessment conducted in 2015 in consultation with federal, state, and local governments, and nongovernmental and industry organizations (IEN 2015). Its observations range from the philosophical to the mundane, as the following quotes illustrate:

- "There are vast differences in capability from one jurisdiction and one sector to another. Some urban localities have more staff and capability than does state government. Funding and support need to be targeted to areas that need it the most. Smaller and more rural jurisdictions in particular are overwhelmed with requirements. They do not need punishment; they need more resources, including technical assistance and funding. There will inevitably be concerns that other sectors or other jurisdictions are receiving more favorable treatment, which makes it of paramount importance to be transparent and equitable in how burdens and benefits are shared." (p. 10)
- "Too many localities and sectors do not know what is expected of them. The states have had no comprehensive communication strategy, which leads to uncertainty and other problems with localities and sectors." (p. 11)
- "The [Bay] Program valued science, deliberation, and consensus. That has changed dramatically.... There is no longer an attitude of transparency within the program, which is a big change." (p. 12)
- "Credit has been given for practices without sufficient testing and/or verification.... Too little credit has been given for some jurisdictions or sectors who were good stewards before the Bay TMDL." (p. 15)
- "In the face of noncompliance, efforts need to be made to explore and address the root causes—which typically have to do with insufficient staffing, technical support, or funding—rather than imposing penalties." (p. 5)
- "There is a huge gap between what staff know and what elected officials and residents know. There is too little public understanding about the Bay TMDL, both its requirements and its benefits, including the potential for local water quality improvements." (p. 11)

a. The congressionally funded study that set the CBP in motion in the early 1980s revealed that agricultural runoff was the largest source of nutrients flowing into the Bay. Agriculture is now estimated to contribute about 40 percent of nitrogen runoff and 50 percent of phosphorus runoff (http://www.cbf.org/issues/agriculture/nitrogen-phosphorus.html).

Combine Sticks, Carrots, and Behavioral Interventions

Multipronged programs that send clear signals and yet offer farmers and agroenterprises choices are needed to involve a wide range of producers in abatement efforts. This is especially true where smallholders dominate and command-and-control regulations will mostly be too costly to enforce. In parts of the agricultural sector that have become more consolidated,

command-and-control regulation may be appropriate. This may be the case for large livestock facilities, for example. And yet experience shows that measures are needed to motivate industry to comply and to improve program cost-effectiveness. In this respect, the EU's efforts to tackle nitrate pollution since the 1990s offer an illustration of such an approach (see box 2.5). Dutch manure policy also illustrates how combinations of measures that build in varying degrees of flexibility and that become increasingly stringent over time can be used with some effectiveness (see box 2.6 and below).

Box 2.5 The European Union's Multipronged Approach to Tackling Nitrates, a Pervasive Agricultural Pollutant

While challenges remain to this day, the European Union (EU) achieved notable progress in controlling agricultural nitrates pollution during the 2000s. Between 2004 and 2007, nitrate concentrations in the EU's surface water remained stable or fell at 70 percent of monitored sites, and as of 2010, quality at 66 percent of groundwater monitoring points was stable or improving.[a] These results stemmed in large part from decreases in the application of synthetic nitrogen and livestock manure, although improvements varied substantially among EU member states.

How were these changes achieved? No single measure can be pointed to as the EU took a range of steps to tackle its agricultural nitrates problem. Several were introduced under the Nitrates Directive of 1991, the key legal framework for the protection of surface water and groundwater from agriculture-related nitrate pollution in Europe. Indeed, to control and prevent the problem, the law relies on a combination of mandatory and voluntary standards, together with monitoring and economic incentives.

Specifically, the Nitrates Directive requires member states to monitor nitrate concentrations in surface water and groundwater, and to designate nitrate vulnerable zones (NVZs).[b] Farmers in these zones face limits on the application of fertilizer and manure to their land (170 kilograms of nitrogen per hectare per year), taking into account crop needs and soil nitrogen supply. They must also abide by measures that are recommended on a voluntary basis by the codes of good agricultural practice that the Nitrates Directive calls upon member states to develop. These codes limit the period when nitrogen fertilizers can be applied to land and direct the timing of fertilizer applications to better coincide with crop needs in order to reduce nutrient losses. They limit fertilizer applications on steeply sloping and frozen ground, near water sources, and in other circumstances that promote runoff. They specify how much manure storage capacity livestock farms ought to have, and recommend practices such as crop rotations, the maintenance of ground cover in winter, and the use of "catch crops" to prevent nitrate leaching.[c]

Farmers engaging in such practices on a voluntary basis have had access to financial compensation in the form of agri-environmental incentives, and since 2005, to farm payments subject to cross-compliance under the Common Agricultural Policy. And while some payments

box continues next page

Box 2.5 The European Union's Multipronged Approach to Tackling Nitrates, a Pervasive Agricultural Pollutant *(continued)*

are farmers' to gain if they adopt specific practices on a voluntary basis, others are farmers' to lose if they do not meet minimum requirements under the law.[d]

A study by Velthof et al. (2014) found that between 2000 and 2008, the Nitrates Directive reduced nitrogen leaching losses to groundwater and surface water by 16 percent, as well as gaseous emissions to the atmosphere (ammonia emissions fell by 3 percent and those of nitrous oxide by 6 percent). Meanwhile, the Nitrates Directive is but one of several laws that have addressed agricultural nitrate pollution in Europe. Others include the Air Quality Directive of 2008 and the 2010 Directive on Industrial Emissions, both of which address nitrogenous emissions from livestock systems among other things.

a. European Commission, 2010, http://ec.europa.eu/environment/pubs/pdf/factsheets/nitrates.pdf.
b. Member states can designate as NVZs areas of land that drain into eutrophied or near-eutrophied waters, or waters with nitrate concentrations nearing or above 50 micrograms per liter; they can also designate the entire national territory.
c. http://ec.europa.eu/environment/water/water-nitrates/index_en.html.
d. https://ec.europa.eu/agriculture/direct-support/direct-payments_en.

Box 2.6 Long Sticks and Flexibility: Manure Management in the Netherlands

Since the mid-1980s, the Dutch government has enacted close to 20 measures requiring and helping livestock farmers to improve their manure management practices. These measures make use of educational, command-and-control, and economic instruments and form an integrated regime. For example, the government encouraged farmers to invest in manure storage facilities by restricting how much, when, and how manure could be spread on farmland. Investments in manure storage facilities were subsidized, and for a time a national manure bank operated as the offtaker of last resort.

The requirement that manure be injected into soil (to reduce its volatilization) helped with enforcement because the equipment needed to perform that task is highly visible. Early in the "program," phosphorus excretion quotas (that factored in the extent of farmers' land and its ability to absorb excess nutrients) were enacted, and farmers were encouraged to adopt and report improved feeding practices in order to reduce taxes owed on excess nutrients. Later, these quotas became tradable, within bounds.

Separately, the government has also controlled the production of excess manure by restricting the number of animals per farm or the total amount of manure they can generate, depending on the species. To encourage farmers to take up improved feed that results in less nutrient waste, the government introduced a complementary program that threatened nonadopters with a tightening of their headcount or manure limits.

Though implemented at high cost to industry and the taxpayer, the combination of these and other measures has achieved notable results. Between 1980 and 2010, the average application of nitrogen per hectare decreased by 27 percent and that of phosphorus by 47 percent (Backus 2017).

As the Dutch experience suggests, a combination of interventions, sequenced smartly, can be the key to achieving results. In developing such multipronged programs, the following can be important considerations.

Farm Capacity. Standards, both mandatory and voluntary, need to be based on what is demonstrably possible for farmers to achieve. Whether compliance with voluntary or mandatory standards or qualification for an incentive program or market are at stake, verification can overwhelm the capacity of even the best-endowed authorities. Understanding and cooperation on the part of farmers can go a long way toward reducing cheating. Thus requirements that progress incrementally (see next point) and are derived empirically and transparently are more likely to bring farmers along with policy. The Netherlands has been able to control manure-related pollution with some success using this approach, notably by developing standards with reference to functioning "model farms." Of course, compliance with standards and rules more generally (whether participation is mandated or chosen) requires adequate resources for enforcement and a commitment to stringency.

Measures can be updated over time to keep up with evolving technology. Again, in the Netherlands, as advanced feeds that result in 30 percent less excreted phosphorus became available on the market, regulators gave farmers a choice: either adopt the feed or have your livestock quota reduced by 30 percent. Most opted for the feed, the economically preferable option. Conversely, standards that are out of touch with farm realities or demand technologies that are out of farmers' reach can be dissuasive and are sometimes brushed aside entirely. This has played out in Vietnam's livestock sector, where certain waste management standards are reportedly more stringent than those in place in Thailand, Japan, and the Republic of Korea, and designed for highly industrialized, large-scale commercial operations. The issuance of different standards by different government agencies has added to their counterproductive effect.

Flexible, market-based mechanisms are sometimes appropriate to bring farms of differing sizes and capacities under one compliance regime. Recognizing the range of farm sizes it is regulating and their variable capacities, the Dutch government has made some use of quota trading to involve smaller players with limited investment capacity in complying with environmental regulations. Smaller farms have relied on larger farms, or ones attached to cropland, to carry out more of the physical actions needed to mitigate pollution from livestock waste (for example, using manure on cropland and investing in manure storage and processing facilities, actions that larger farms have a comparative advantage in doing). When the trading of rights is allowed, however, many restrictions apply—something that is needed to preserve the environmental integrity of the system and prevent the destruction of localized ecosystems. Even then, trading systems can have unintended downsides. In the Netherlands, phosphorus trading led to a transfer of resources from younger, more recently established farmers to a generation of retiring farmers, further limiting the younger farmers' capacity to invest in raising animals in more environmentally friendly ways.

Farm Incentives. Removing or modifying unhelpful incentives (even if they act indirectly on pollution) can, as discussed under strategy 1, sometimes be more impactful and cost-effective than instituting new incentive programs that target pollution directly. For example, fertilizer production subsidies (direct ones as well as energy subsidies) remain in place in both China and Vietnam to this day, although China's were slated for ecologically oriented reform in December 2016.[8] These and other forms of support that contribute to agricultural pollution directly or indirectly (for example, support for agricultural incomes, expansion of irrigation, or replanting of aging crops) can be redeployed to motivate and train farmers to produce more cleanly or be tied to pollution control strings. This is the principle on which the EU's "cross-compliance" policy is founded in that it allocates income support to farmers on the basis of farmers demonstrating stewardship of the land and associated ecosystem services. Payments for ecosystem service (PES) programs have already been deployed in East Asia (for example, China's nationwide Ecological Subsidy and Award System for the Ecological Protection of Grassland since 2011, and its "Grain for Green" program since 1999[9]), and PES programs could, in general, be developed further through the redeployment of agrochemical and other subsidies.

If incentive programs created to address pollution directly do not consider the forms of government support that are likely contributing to agricultural pollution directly or indirectly, they may find themselves swimming against strong currents. Moreover, new incentive programs can require years of calibration to become effective. The incentives that Vietnam has put in place to encourage livestock industry consolidation and improve waste management are a case in point: despite the generosity of these incentives, bureaucratic hurdles and economic realities have led most farmers to leave them on the table. Farmers would rather stay small and continue dumping untreated waste with impunity than upgrade and expand their operations and subject themselves to environmental scrutiny and the requirement to invest in wastewater treatment facilities (Dinh 2017). Dismantling counterproductive forms of support may produce results more rapidly. That said, existing incentive programs that are known to contribute to pollution problems may be challenging to dislodge in light of political economy factors and their alignment with broader agricultural policy goals. High-level policy change may be needed in some instances to undo existing incentive programs.

Farmer Motivation. Looking beyond conventional sticks and carrots, social incentives (and behavioral interventions more generally) are sometimes powerful and very low-cost motivators that can coexist with, or sometimes replace, financial and other market-based incentives. Overseas experience suggests that in some contexts, sociopsychological forces—such as the desire to conform to the shifting behavior of peers or to conform to a particular self-image (for example, professional, steward, early adopter, or modern farmer)—can sway farmers as much as payments can.[10] Just as payments have convinced farmers to adopt better management practices in some parts of the world, including the EU and the United States, the grassroots Landcare movement that has spread from Australia to

many other countries has also been effective in changing farmer behavior by empowering farmers to learn from and inspire one another. While it continues to be farmer-governed and farmer-led, this movement has received government backing in several countries.

Separately, interventions that modify "choice architecture"—that is, that modify aspects of a decision-making environment to influence decision outcomes—are another avenue that may hold promise for pollution control. In the context of agricultural inputs, for example, choice architecture interventions could attempt to change how inputs are marketed and sold to farmers, or even change product design, to influence what inputs and how much of them farmers buy, how and when they choose to apply them, and so on.

In a similar vein, the adoption of multiple and various public measures to achieve a given policy objective can favor a shift in social norms among farmers, at which point peer pressure and the desire to conform can alleviate the burden of enforcement that rests on public authorities. This has transpired in the Netherlands, where the government's relative success in controlling manure-related pollution has rested on the emergence of peer pressure effects, the coupling of incentives with mandates, and a certain degree of flexibility (Backus 2017)—see box 2.6.

Make Supportive Investments in Physical Infrastructure, Public Services, Data, and Science

Public sector investments in such things as physical infrastructure, public services, data, and science can contribute to helping farmers overcome constraints to change. For example, without specialized waste collection services and recycling facilities in place, farmers may have limited options for better disposing of the nondegradable plastic films they use. Access to well-functioning agrometeorological data services can be critical to farmers' ability to minimize input waste. Physical infrastructure investments in such things as shipping facilities, slaughterhouses, and physical marketplaces can be geographically directed in such a way as to encourage animal farms to develop in more favorable spatial patterns—encouraging their spatial redistribution, for example. Breakthroughs on low-emission rice systems and livestock breeds rely on public funding of climate-smart agricultural research. The role of public investments in knowledge is further discussed under strategy 4.

3. Influence Levers of Structural Change, including Consumption, to Keep Pollution in Check

What: Anticipate and influence the agricultural sector's structural trajectory, intervening from farm to table, to avoid the worst effects of pollution and keep abatement options open.
Why: To avoid structural developments and path dependencies that will overwhelm technical solutions, outpace innovation, reduce technical

abatement options, or make it cost-prohibitive to abate—in short, limiting choices.

How: Seek to directly and indirectly influence structural aspects of the farm sector that have a major bearing on pollution.

- Proactively weigh trade-offs implied by different sector development trajectories, including by strengthening evidence, broadly involving stakeholders in decision making, and again involving different levels of government in policy making.
- Seek to reorient consumption patterns.

Proactively Weigh Trade-Offs Implied by Different Sector Development Trajectories

Structural change can be critical to "get ahead" of pollution, avert certain path dependencies, effect change at scale, and achieve deeper shades of green. Even if government intervenes effectively to bring about the adoption of mitigation technology, there is a limit to what technical solutions can achieve within existing production systems. In some respects, the public sector will need to guide the farm sector to develop differently—in other words, structural solutions are also needed (see box 2.7).

Box 2.7 Structural Aspects of Farm Sector Development That the Public Sector Can Try to Influence

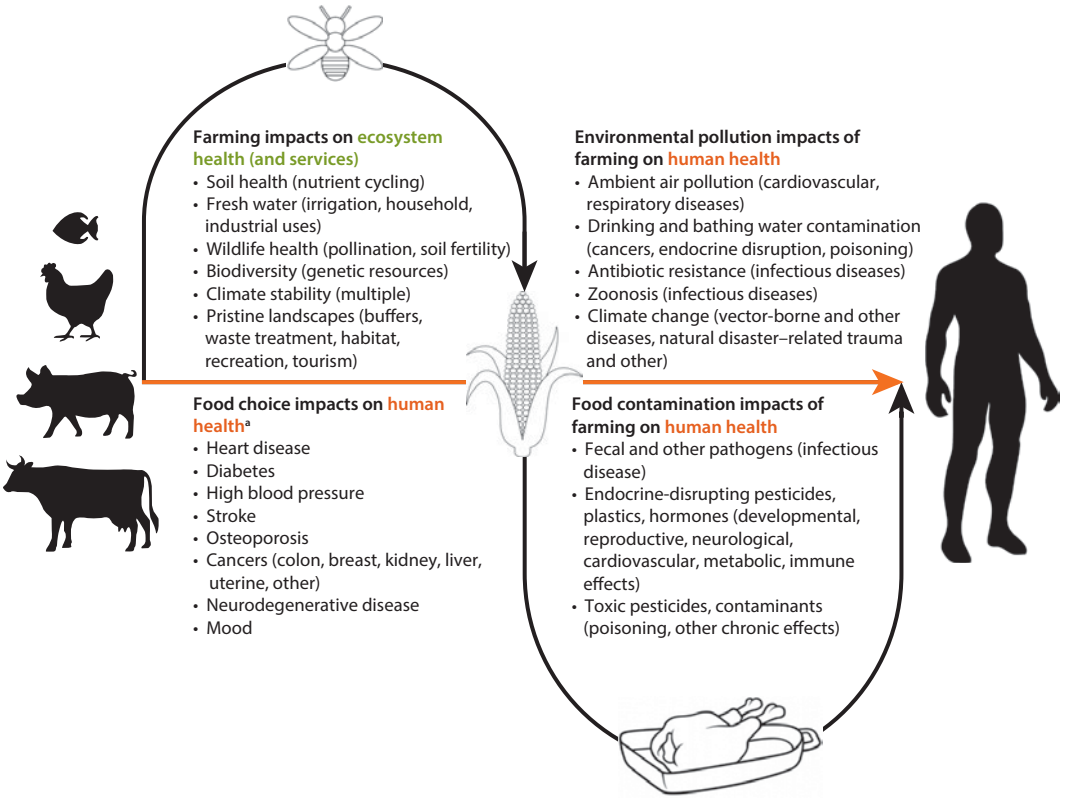
- The number of animals per operation or their spatial density
- The spatial distribution of agricultural activities over the territory and, at the local level, the clustering of operations, especially aquaculture and livestock farms
- Farm consolidation, or the ability of small farms to operate as though they are larger ones
- The extent of farm specialization and the embrace of monoculture versus polyculture
- Land available for agriculture versus other, nonagricultural uses
- The mix of foods and agricultural raw materials produced.

What structural changes offer is the potential to reduce the amount, or the damaging effects, of pollution in the first place and to keep abatement options open. In the Netherlands, for example, the government has attempted to limit the density of its livestock farms—among the densest in the world—recognizing how challenging it is for very large, high-density farms to significantly improve manure management practices. Looking ahead, if the livestock industry grows and overtakes a large share of the economywide greenhouse gas emission "budget" for future years, as several studies have found to be possible under certain global consumption scenarios, then it is probable that abatement solutions, and certainly cost-effective ones, will fall short of abatement needs.[11] Structural changes are sometimes needed to ensure that higher environmental standards

can be achieved economically and thus to keep policy options open. While the forces shaping structural change—demographics, markets, climate, international policy, and so forth—cannot be shaped by a single country's government, the public sector can in fact exert significant influence over how the agricultural sector takes shape on its national territory.

The agroindustry's growth represents a onetime opportunity to develop the food sector more sustainably. Because of the rapid pace of growth and transformation, the East Asia region faces a historic opportunity to forge a greener model for agriculture. The case for this opportunity is especially true in the aquaculture, livestock, and horticulture subsectors given that they are growing with particular rapidity. Patterns of agricultural development—and ultimately changes in food consumption and supply—have and will continue to have significant and long-term impacts on environmental and health outcomes (see figure 2.1).

Figure 2.1 Impacts of Diet on Human and Ecosystem Health



Note: Some of the foods that have the greatest environmental health impacts can also be detrimental to nutritional health. Also see Potter (2017).
a. Related to inflammatory and other effects of, among other things, higher dietary cholesterol, saturated fat, omega-6 to omega-3 fatty acid ratio, heme iron, choline, L-carnitine, lecithin, IGF-1 (insulin-like growth factor 1), and animal protein, as well as lower dietary fiber and phytonutrients.

The pattern of agricultural growth will fundamentally shape national landscapes and partly determine the livability of rural, urban, and periurban environments. In view of the agricultural sector's impact on natural capital, its growth pattern will factor into the national economic development potential. With their high dependency on natural capital, agriculture and agro-industry are among those sectors most likely to be affected, though they are not alone. Most pressingly, a sector that is shaped in the image of sustainability can largely avoid the exorbitant cost of having to mitigate and clean up pollution once highly polluting structures and practices are already entrenched. From this standpoint, government has the power to profoundly influence how the agro-food sector grows, with massive long-run implications for the public's health, productivity, and quality of life.

Weighing trade-offs, and incorporating this process into decision making, are central to steering sector growth onto a more sustainable trajectory. How agricultural industries continue to develop may have not only very real and wide-ranging consequences for the environment and society, as chapter 1 of this report illustrates, but also implications for what approaches to abatement are technically and financially within reach.

To take an example, farm consolidation and industrialization have plusses and minuses with respect to pollution control. Unlike systems in which animals are dispersed in space, large, confined animal facilities that produce high volumes of waste can be considered a point source of pollution. On the one hand, a sector with fewer but more formal players is easier to monitor and regulate. Commercial operations may have more capacity to invest in pollution control. And with more to lose financially, they may have an incentive to meet the standards of more exacting markets, which in turn may or may not overlap with pollution control. Industrial operations may also have more means to invest in pollution controls, or even in achieving efficiency gains that, for example, shorten the time it takes for animals to mature, thereby reducing the waste and emissions they generate over a lifetime.

On the other hand, concentration results in volumes of waste that have the potential to be hugely polluting, and it may or may not be economically viable to manage them in nonpolluting ways. Industrial production, by cutting costs, may also encourage higher per capita consumption of animal products, thereby enlarging the industry's footprint by virtue of its expansion. This result may increase pollution if livestock products are being substituted for plant products with a smaller pollution footprint (for example, per calorie or gram of protein). The indirect environmental impacts of different livestock systems' land-use patterns, as well as other lifecycle impacts linked to the full value chain, are not considered here.

Several other trade-offs implied by patterns of structural change are described in box 2.8. These examples underscore the extent to which the solutions or best approaches to mitigation are not always clear at a structural level. Nonetheless, the starting point for making good decisions is to gain awareness of the trade-offs and path dependencies that are at stake.

Box 2.8 Examples of Trade-Offs Implied by Structural Change

In shaping sector growth, some choices represent win-wins for health, the environment, the economy, and national security; others present difficult trade-offs among nutritional benefits; the intensity of water use, land use, and energy use; emissions footprint; profitability; interpretations of food security; cultural expression; and enjoyment. Some of these trade-offs can be managed away through the adoption of good practices, but that is not always the case. Examples of trade-offs include the following:

- Many consumers show a preference for animal products (meat, fish, eggs, dairy), as evidenced by the boom in their consumption, despite their high land use, water use, energy and emission intensity, and despite the cardiovascular, diabetes, cancer, and other risks these products carry (Chiu et al. 2014; Etemadi et al. 2017; Evans 2013; multiple references in Greger 2015b; Musso et al. 2003; Popkin 2009; Sinha et al. 2009; Tonstad et al. 2013; WHO and IARC 2015).[a] In land-constrained countries, rising meat, seafood, egg, and dairy production also means a greater dependence on imported feed, some of which is sourced at the expense of tropical forest cover. This dependence on imported feed is rising in both China and Vietnam, where the domestic livestock industry is booming (Hansen and Gale 2014; Jaffee et al. 2016).
- High-density, industrial livestock and aquaculture operations produce more protein per unit of space or water than extensive mixed systems or capture fisheries, and can be less carbon-intensive (Garnett et al. 2017), but they also tend to generate more nutrients than their surroundings are capable of absorbing. These operations often resort to pharmaceuticals to manage disease risk and animal anxiety.
- Species and breeds that are highly efficient at converting feed into protein use fewer resources, but sometimes pose genetic pollution risks that can be associated with disease. This is a concern with the farming of *Pangasius* in the Philippines, for example.
- Similarly, growth-accelerating drug use in livestock and aquaculture operations can moderately reduce production costs[b] and mean less excrement generated per gram of protein. However, drug pollution is serious, and there are other (most likely preferable) means of mitigating fecal pollution, as well as significant health and other environmental co-benefits to privileging whole food, plant-centric diets (Katz and Meller 2014; Ornish 2009; Stehfest et al. 2009; Tuso et al. 2013).
- Certain highly nutritious, space-efficient, and lucrative crops also have high water and nutrient demands. The explosion of vegetable production in China has been associated with high levels of agrochemical and disposable plastics use, for example. This dilemma may, however, be resolved by precision farming.
- The siting of farms near cities can offer consumers fresh foods at a lower price, especially where transportation infrastructure is lacking, and it can reduce the pollution associated with transporting them (all else being equal[c]). However, proximity to cities may increase the

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Box 2.8 Examples of Trade-Offs Implied by Structural Change *(continued)*

exposure of farms to pollution from households and industry, and the exposure of urban dwellers to pollution from farming.

- Importing food may shift the environmental burden of food production to source countries, but it may not help its overall footprint and may present economic or food security drawbacks. Vietnam currently enjoys self-sufficiency in rice and substantial income from the export of this and other commodities of which it is a leading producer, but it does so at substantial cost to the land, its farmers, and the population at large.

a. See more references on this topic in the reference section of this study's Knowledge Notes series.
b. The 2008 report of the Pew Commission on Industrial Farm Animal Production found the net bottom-line benefit from the use of antibiotic feed additives to be about US$0.25 per animal in the United States (Pew Commission 2008).
c. Food miles actually correlate poorly with their footprint, and transportation is a small slice of lifecycle footprints for many foods.

There are at least three major avenues for weighing trade-offs implied by structural change, assessing which ones are desirable or needed, and incorporating them into decision making. One involves generating and using more evidence on the implications of different trajectories. Another consists of engaging a multiplicity of stakeholders in planning and other forms of decision making. A third is developing policies and programs at multiple jurisdictional levels, enabling technical and structural remedies to be developed and pursued in tandem. These avenues are complementary in two senses. First, stakeholder interaction and negotiation can be buttressed and facilitated by evidence and by a level playing field. Second, evidence needs (and thus research questions) can be guided by anticipating the implications of decisions through specific stakeholders' eyes. These are discussed in turn.

Evidence Generation. New knowledge needs to be generated to weigh trade-offs and guide how the sector develops. In this endeavor, and consistent with multistakeholder, multilevel approaches, various points of view and dimensions of welfare can be considered: environment, health, well-being—not just output and yield. Lifecycle analysis is one area of research that can help inform trade-offs implied by different development pathways, although its findings tend to be narrow and subject to data constraints. It has the potential to be more powerful if combined with additional analysis and decision tools able to aggregate different findings and draw out structural and policy implications.

Generating new evidence is not enough, however; institutional measures are needed to anticipate and correct for cognitive biases and influences of the political economy. The path from evidence to responses can be long and circuitous, and the use and interpretation of evidence are heavily influenced by such things as prior understanding of a situation and thinking "shortcuts," as well as political calculus, economic interests, and social capital. For a combination of reasons, even the highest levels of government are not immune to the present bias, or "myopia," that leads to the perception or determination that controlling

pollution is too costly. This scenario is all the more likely when evidence on the full, societal costs of pollution (and the upsides of mitigation) is thin—disparate, invisible, and long term, as pollution effects can be. Officials may have concerns about the popularity of costly measures with returns that materialize over the long term and have low visibility. They may also be pressured by organized interests and guided by conflicting policy priorities. These prior assumptions, and even the framing of evidence, are all likely to influence how evidence is received and factored into policy and program design. Institutional precautions therefore need to be taken to anticipate and manage the potentially unwanted influences of cognitive biases and political economy dynamics on the interpretation and use of evidence.

Multistakeholder Processes. Another approach to weighing and incorporating trade-offs into decision making to shape structural change is to involve multiple stakeholders in the process. This so-called landscape approach dovetails with the "breaking of silos" put forth under strategy 1. Bringing stakeholders with different vantage points around a table can also help bring to light apparent development trade-offs within a given landscape. As noted earlier, this can be done on different scales. In fact, the landscape approach concept is of particular relevance in this context, if it is understood to be an interactive way of identifying and acting on trade-offs (which will ideally incorporate research evidence). As defined by Sayer et al. (2013, 8349), landscape approaches "seek to provide tools and concepts for allocating and managing land to achieve social, economic, and environmental objectives in areas where agriculture, mining, and other productive land uses compete with environmental and biodiversity goals." The impetus for landscape approaches, moreover, is sometimes the recognition that agricultural development can be on a "collision course with environmental protection goals."

Multilevel Policies. Finally, when it comes to devising policies and programs to address agricultural pollution, doing so at multiple jurisdictional levels can help to act on both technical and structural opportunities in tandem. Local, focused efforts are needed to address the context-specific complexities of pollution. Yet such efforts may be more likely to achieve mitigation through shifts in technology than to bring about mitigation through structural change, when both are in fact needed. Broader, landscape-level, regional, or national visions and policies are also needed to avert undesirable path dependencies.[12]

Reorient Consumption Patterns

Changes in consumer product and diet choices, as shaped by political, economic, and cultural forces, can play a key role in determining how the agricultural sector and its pollution footprint develop. Consumers are powerful in expressing preferences with their shopping baskets, whether through their choice of food groups or through their choice of production characteristics. Even though agricultural pollution is tied to production systems, consumers can play a role in shaping them. And yet public sector efforts to mitigate and control pollution have only timidly

tried to act on consumption patterns or to enable greater consumer feedback in value chains. Both the opportunity and the failure to act on it point to the need for policies that help shape consumer behavior so that it will better align with health and environmental sustainability.

A range of strategies can be drawn on to influence consumer food choices. Some involve more consumer engagement than others. Changes in product and service design can modify consumer behavior unwittingly (by virtue of changes in what is most available, salient, appealing, or functional to consumers). Investments in the development of cell-cultured meat and eggs and plant protein research supporting the development of palatable meat alternatives are a strategy that relies less on conscious changes on the part of consumers, for example.

Consumer sensitization can be effective if paired with measures to enhance consumer choice. The health implications of agricultural pollution lend themselves to sensitizing consumers to agricultural pollution,[13] but knowledge does not automatically translate directly into purchase decisions that send signals to producers. For this, consumers need alternative buying options supported by trustworthy information about these options, and this is not the norm in the wet markets that dominate Southeast Asia and parts of China (in rural towns and small cities). Raising consumer awareness is likely to generate more fear and frustration than results if consumer choices, or consumer trust in product claims, are lacking. Consumers are also budget- and time-constrained, have a limited ability to sort out complex and incomplete information, and are subject to many influences—conditions that lead them to express preferences in fragmented and often inconsistent ways. Information and educational strategies rely on high levels of consumer engagement and choice availability.

Voluntary food standards and certification systems are one way of expanding consumer choice. They allow consumers to choose among different packages of production technologies. Organic standards are a prime example, as they allow consumers to choose products grown free of (most) synthetic agrochemical inputs. Organic farming standards (and techniques) that do away with the vast majority of synthetic inputs (in both monoculture and mixed farming systems) have progressed rapidly over the past 25–30 years in high-income countries, though they still apply only to a very small slice of overall production. Their adoption has seemingly been facilitated on a large scale in Europe and the Americas by consumer awareness, cultural trends, and disposable income, on the one hand, and power tools and information technology, on the other. Their progress in East Asia has been comparatively slow, although China is rapidly catching up. As of 2014, China had the second-largest area in the world under organic cultivation after Argentina (1.9 million hectares),[14] and it was the third-largest consumer of these products after the United States and the EU (6 percent)—see Willer and Lernoud (2016).

Organic farming can be labor-intensive and reduce yields,[15] and both labor and land scarcity are key constraints in much of East Asia's farm sector. Moreover, the model that has carried organic farming forward in high-income countries is

one based on consumer willingness to pay premiums for certified products, and even in high-income contexts it has shown significant limitations in driving pollution control. Premiums aside, it also rests on consumer trust in product claims and traceability, monitoring and verification systems, and professionalism, all of which generally remain weak in the East Asia region. This situation points to the need to build capacity for voluntary certification, including farmer skill sets and supply chain traceability systems, and to bolster consumer protection institutions along with awareness-raising campaigns.

The example of organic farming standards points to the potential and need to develop agroecological farming protocols and standards adapted to regional realities, especially as relate to farmers' management and "precision" capacity. These protocols and standards can address production methods that are particularly problematic in the region. The latter might include not just fertilizer and pesticide use, but also the use or misuse or disposal of drugs, contaminated irrigation water, crop residue burning, plastics, and feces, and even post–farm gate practices. They could also be updated to improve pollution control in step with evolving regional preferences and capacities: consumer budgets and concerns, farming technologies, and farmers' capacity for precision farming (discussed earlier). At the same time, standards need recognition that is broad enough to enable economies of scale and trade. Meanwhile, voluntary certification systems are only one way of mobilizing consumers, and it is not realistic to rely on consumers' willingness to voluntarily pay premiums to clean up agricultural pollution on a meaningful scale.

Economic incentives for marketers to embrace certified products could bolster these products. Left to the whims of consumers, certified products are likely to remain niche products. Consumer-facing labels have proven to have some effectiveness in spurring more sustainable production practices, but the markets for these labels generally remain small in relative terms, and pollution concerns have not been the main focus. Even those labels that reflect pollution-mitigating production practices, such as organic labels, are not necessarily marketed or appreciated specifically or primarily for pollution-related reasons. The public sector could offer economic incentives to retailers (including in-kind advantages related, for example, to space access or permitting) to offer products that meet given certification requirements. Such an approach could bring larger players into the fold and ultimately send more robust and consistent signals to producers, while reducing the burden on consumers to take on public sector functions while shopping. Economies of scale would push down the associated costs.

Meanwhile, the promotion of plant-centric diets would have a significant impact on the agricultural sector's development trajectory and footprint. The choices that product standards allow consumers to make tend to relate to production processes (attributes of food that are not detectable to the senses) and less so to dietary ones, though there can be some overlap. Yet dietary choices—especially choices of what foods to eat and not to eat—aggregated across society, have tremendous environmental consequences. The multiplication and increasing sophistication of lifecycle analyses performed on food

items have revealed the challenges of comparing products with their many dimensions and effects of interest and the lack of clear answers when it comes to the footprint of individual foods (Roy et al. 2009). However, these and other studies broadly point to the smaller environmental footprint of plant-centric diets compared with those rich in animal foods (de Vries and de Boer 2010; Galloway and Cowling 2002; González, Frostell, and Carlsson-Kanyama 2011; Machovina, Feeley, and Ripple 2015; Nijdam, Rood, and Westhoek 2012; Peters et al. 2016). The convergence of this finding with what is now known about dietary choices that are in the best interest of health (see figure 2.1 in a previous subsection; also Potter 2017; Ranganathan et al. 2016) has led several countries and scientific bodies to recommend diets rich in whole (less processed) plant-based foods and less rich in animal source foods on both accounts.[16]

Although a scientific consensus has yet to form around what constitutes the optimal diet from a health perspective, there is broad scientific support for the association of mostly whole food, plant-based diets with lower health risk (DGAC 2015; Katz and Meller 2014). The dietary guidelines issued by the government of China in 2016 may have an indirect effect on pollution if they are heeded and reverse or even slow the growth in meat consumption.[17] Multiple and sustained efforts to promote healthy diets, not only through dietary guidelines and associated information campaigns, but also through the arts, culture, marketing, and enterprise, may be the key to a sea change in the footprint of food, a motor of innovation, and a boon for industry (see box 2.9).

Box 2.9 Cultivating Sustainable Diets through Food Culture, Business, and Science

East Asia is in a prime position to redefine and lead the development of the arts, science, and marketing of plant-based food, bringing the region's long-standing culinary and agricultural traditions into the 21st century and endowing plant-centric diets with new relevance for youth and emerging consumer classes. China already produces half of the world's vegetables and is a leading consumer and exporter of fresh vegetables as well as fruit. Looking ahead, the public sector can play a role in enticing entrepreneurs, food scientists, marketers, financiers, insurers, and cultural leaders to rebrand plant-based eating, and develop the suite of products and services that will make plant-centric eating accessible and appealing. Major commercial opportunities could be unlocked in the process of thus aligning available food products and consumer choices with health and environmental evidence, whether or not that alignment is incorporated into consumer-facing marketing strategies.

Outside the region, momentum is already building. In the United States, major insurance companies such as Kaiser Permanente have begun to promote plant-based eating among physicians and subscribers (Kaiser Permanente 2013; Tuso et al. 2013), while independent nonprofits are bypassing industry to deliver health evidence to consumers directly.[a] Venture capital is flowing into "food tech" companies catering to time-poor yet image- and health-conscious urbanites in Europe, the United States, and beyond. Recently, leading U.S. meat

box continues next page

Box 2.9 Cultivating Sustainable Diets through Food Culture, Business, and Science *(continued)*

producers and food companies such as Tyson Foods, Maple Leaf Foods, and General Mills have started acquiring or taking stakes in another set of newcomers to the agrofood industry: companies developing and marketing meat alternatives for mainstream consumers.[b]

With their culinary traditions acclaimed worldwide, China, Vietnam, and other East Asian countries are well positioned to foster similar developments on a larger scale in the region and to lead the development of the emerging, high-value plant-centric food industry, just as Thailand has cultivated "gastrodiplomacy" to raise the profile of its agricultural exports and attract investment. Forward-thinking governments in East Asia can also help accelerate the science and commercialization of next-generation meat, seafood, eggs, and dairy made from plant-derived materials or even cell cultures ("clean meat"). Such products could drastically reduce these foods' resource use while improving food safety (Sun, Yu, and Han 2016; Tuomisto and Joost Teixeira de Mattos 2011). Vying for leadership in these emerging and potentially disruptive markets will mean training and attracting chemists, life scientists, food scientists, marketers, nutrition experts, and agribusiness companies to this field, and generally fostering vibrant innovation ecosystems to address food system challenges (see strategy 4).

a. See http://nutritionfacts.org.
b. See coverage of this at, for example, foodtechconnect.com, gfi.org, and new-harvest.org.

4. Learn and Innovate to Stay a Few Steps Ahead of the Pollution Challenge

What: Invest in data, research, innovation, and entrepreneurship to intervene more effectively over time.
Why: To better set priorities, improve public intervention iteratively, and stay ahead of the pollution challenge both technically and in matters of policy.
How: Invest in data, research, innovation, and entrepreneurship.

- Invest in agricultural pollution monitoring and in research on the physical and socioeconomic impacts of agricultural pollution and the effectiveness of technical and policy instruments.
- Stimulate innovation and entrepreneurship so that abatement solutions can keep up with change and their pursuit can become a value addition and job creation opportunity.

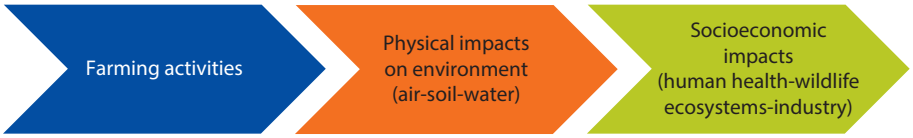
Invest in Agricultural Pollution Monitoring and Research

More systematic data collection and evidence on pollution and its impacts are needed to help guide priority setting and support legal and regulatory action as well as technical interventions. If measurement is the basis for management, and evidence is the basis for policy, significant investments are needed in measurement systems and agricultural pollution research, particularly of the socioeconomic kind. The needs range from investing in hardware all the way to building technical capacity, funding research, developing decision tools, and building consensus among policy, science, and finance communities

around critical indicators. At the policy level, more and more multidisciplinary evidence is needed on the physical and socioeconomic impacts of sector structures and practices, as well as on the effectiveness of different interventions, to both prioritize and manage interventions. Investments in the generation and use of such evidence are needed to learn, adapt, monitor efficacy, and innovate continuously in the course of implementing policies to make the best use of scarce time and resources.

Indeed, in all three study countries, significant data and evidence gaps exist at every step of the causal chain that relates farm management activities to their effects on soil, water, and air, and their many socioeconomic impacts (see figure 2.2). Box 2.10 provides examples of where data and evidence were found to be lacking in the Philippines.

Figure 2.2 Causal Chain from Farm Management to Pollution Impacts



More generally:

- Annual time series on the use of agro-inputs, including pesticides, drugs, chemical treatments, and plastics, and on methods for agricultural residue and manure disposal, are not uniformly available and often are completely missing. This situation sometimes stems from the wielding of political influence (which is likely the case in the large export-oriented plantation areas of the Philippines on which data are unavailable to researchers).
- The measurement of ambient air quality and the detection of pollutants in surface waters and groundwaters are uneven across the East Asia region and within countries, with some cities and bodies of water receiving more attention than others.
- The range of pollutants for which measurements are taken is sometimes incomplete, such as for pesticides in Vietnam.
- Measurements largely remain ad hoc and are not carried out by public authorities on a systematic basis for a full range of pollutants.
- The detection of pollutants in living organisms is even more limited, and evidence on their long- and short-term effects on the health of these organisms, or on population dynamics in the case of wildlife, remains thin, despite the growing number of studies on these topics.[18]
- The effects of agricultural pollution on the economy—whether mediated by its effects on health, labor, the natural resource base, or the quality and safety of food—have been the subject of few national studies. Put differently, little work has been undertaken to translate the impacts of polluting practices and discharges into socioeconomic terms.

Existing data and knowledge gaps, however, should not be used as an excuse to delay investing in abatement today. Knowledge of farm management practices in the East Asia region, combined with an understanding of the general effects of these—observed in other parts of the world or in the laboratory—is enough to infer that agricultural pollution is a serious problem in East Asia.

Box 2.10 Examples of Critical Data and Evidence Gaps in the Philippines

The following examples are related to the ability to describe the nature, magnitude, and impacts of agricultural pollution problems in the Philippines. Further gaps were identified in relation to the drivers of polluting activities and the effectiveness of various pollution control interventions.

Crops

- Lack of available data on what kinds of pesticides are applied in different cropping systems, as well as the amount applied and method of application. No national agency systematically collects and monitors the application of pesticides to crops.
- Lack of data on how much and when fertilizer is applied to crops other than rice and maize
- Inaccessibility of data on fertilizer and pesticide consumption in multinational-owned crop plantations such as those for pineapple and banana
- Lack of systematic monitoring of pesticide residues in domestically marketed vegetables
- Lack of studies on the impacts of agricultural pollution on major waterbodies and river basins besides Manila Bay and Laguna Lake
- Lack of investigations on the impacts of pesticides on humans, wildlife, biodiversity, agroecosystems, and agroindustry.

Livestock

- Lack of institutionalized monitoring of pollution
- Lack of monitoring of air pollutants such as ammonia, hydrogen sulfide, and volatile organic compounds
- Lack of country-specific greenhouse gas emission factors for enteric fermentation and manure management
- Need for continued field validation of detectable antibiotics in meat.

Aquaculture

- Need for more detailed investigation of the subsector's use of regulated and banned drugs and chemicals
- Lack of evidence on human health impacts of consuming fish containing antibiotic and other residues
- Lack of evidence on antimicrobial resistance
- Lack of local studies on trade-offs associated with biological pollution from the introduction of nonnative or invasive aquatic species for culture.

Stimulate Innovation and Entrepreneurship so that Abatement Solutions Keep Up with Change

Support for inclusive research and innovation processes can help bring technical solutions to new contexts and constituencies over time (building on strategy 2). Even where pollution control has proven cost-effective in certain contexts, the transfer of solutions from one context to another does not happen automatically. Although extension and advisory services can play a major role in the dissemination of technology, they become more effective when they are integrated in—or foster—broader innovation ecosystems that facilitate multidirectional flows of information and involve farmers and entrepreneurs in every step of technology creation and service design.

In many instances, investments in science and engineering research will also be needed to solve new or persistent challenges. A likely example is the use of plastics, where the challenge is to ensure the environmental palatability of the unique and multiple functions they offer. Materials and process innovation will probably be needed for fruit and vegetable production to fulfill its green promise.

Investments in information technology (and training) that lower the costs of monitoring and enforcement can help improve program targeting and bring mandatory measures into the mix of policies. For example, advanced monitoring technology based on the analysis of satellite imagery may help to enforce bans on burning. However, results are not guaranteed by the availability of such technology, as China's case illustrates; the country has had a national ban on open burning of agricultural residues in place since 1998. Even if economic incentives are privileged over command-and-control mandates, farm-level monitoring capacity is needed to determine whether farms meet criteria for receiving an incentive.

The potential to develop "clean meat" and other animal food alternatives made from cell cultures or plant-derived materials was already discussed under strategy 3 (see box 2.9). With focused investment in research and innovation, East Asia can also lead the world in developing precision agriculture for smallholders. Precision technology, the marriage of data-intensive analytics with data-guided farming equipment, is sweeping vegetable production and gradually penetrating row crop farming in high-income countries, saving farmers, the environment, and the public some of the costs of agro-inputs of all kinds and improving their commercialization opportunities. Developed by the private sector, the hard and soft tools that make precision farming a reality are a product of public investments in science and education. Moreover, there is room to increasingly steer these kinds of tools toward solving environmental problems. The challenge for East Asia will be to adapt precision agriculture technologies to the region's agroecological and small-farm realities (see box 2.11).

The concept of precision can be interpreted differently and pursued to varying degrees. Cutting-edge precision tools are aimed at determining inputs down to the subfield level to match plant-specific needs, but a wider range of tools allow farmers to improve their level of precision more incrementally. They may

help farmers better determine appropriate levels and mixes of inputs at the field level, or based on a soil type, crop, and climate or time of year. If one accepts this more evolutionary interpretation, precision technologies and services for small farms are already emerging in the region, as some of the previous examples make clear (for example, formula fertilizer in China). And yet significant investments in research and innovation capacity can accelerate the emergence of these technologies and services and ensure that they advance environmental and health objectives in addition to production enhancement or cost-savings objectives. With sufficient investment, the precision technology "revolution" can spread to smallholder-dominated East Asia and restore farming to fulfilling its role as an enhancer of health and ecology.

Box 2.11 Precision Farming for Smallholders: Innovations and Challenges in China

Over the past decade, China's Ministry of Agriculture (MoA) has actively promoted several technologies to help farmers make more sparing and judicious use of chemical inputs. For example, since the early 2000s the MoA has financed soil testing and promoted the diffusion of formula fertilizer based on soil testing results. In theory, this technology allows farmers to use tailor-mixed fertilizers that better align with their specific needs, taking into account local conditions and what they are growing.

A World Bank project has promoted this technology in Guangdong Province by competitively procuring fertilizers specially formulated on the basis of soil testing results and crop needs and creating incentives for farmers to use them. After three years of efforts to promote formula fertilizer, the market seems to have responded positively. As of 2017, multiple brands of formula fertilizer that have *not* been procured under the project have become available in agro-input shops in project areas.

Formula fertilizer is not a panacea, however. In Guangdong Province, for example, various circumstances have limited the technology's effectiveness in pollution control. Government-sponsored soil testing is still limited (at one sample per 10–20 hectares), and soil testing results are not systematically made available to input suppliers. Furthermore, tailor-formulating fertilizers to meet a wide range of smallholder needs remains cost-prohibitive for most suppliers. Meanwhile, formula fertilizer does not address the issue of poor timing, a problem that, as noted, is taking on growing proportions as increasing numbers of farmers seek off-farm employment.

While new technologies and service models hold promise for addressing this major challenge, those that have emerged to date have a long way to go before they reach commercial viability. Since 2007, for example, the market for slow- and controlled-release fertilizers has been growing in China (Heffer 2016). In Guangdong Province, however, adoption of such fertilizers is still limited because of concerns about cost and quality. One limitation of this technology is its current inability to provide a boost of nutrients at the needed point in a crop's growth cycle. In parallel, the development of professional pesticide application services has also faced challenges. Farmers often prefer to manage pests on their own when they do not have off-farm jobs. The development of pesticide application services has also been complicated by

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Box 2.11 Precision Farming for Smallholders: Innovations and Challenges in China *(continued)*

disputes over responsibility for pest outbreaks and partial participation by farmers in a given area. Partial participation on the part of farmers undermines the quality of the service because a pest infestation in a nonparticipating plot can undermine the efficacy of the pesticide application service in the surrounding area.[a]

a. This may be less a free-rider issue than a question of some farmers preferring to cut costs by managing pests on their own.

From Looming Crisis to Opportunity

Looking ahead: tackling emerging East Asia's agricultural pollution challenge is not only within reach, but also a business and leadership opportunity.

Doing more to avoid pollution and the worst of its effects is within reach. Rapid change in the East Asia region bodes well for its ability to redirect farming—and the broader food sector—down a path of more durable and self-serving growth. Farmers in China, several studies show, can exhibit a high level of openness to technical experimentation and change (Arin 2016). In general, East Asia's agricultural performance over the past 50–60 years reflects its inclination toward innovation, its willingness to embrace new technology, and its capacity for transformation. Moreover, the strength, plurality, and dynamism of regional food cultures (Lam et al. 2013) can help provide the impetus needed to "green" food production and propel these food cultures forward.

Furthermore, like every crisis, agricultural pollution can be treated as an opportunity. While farming may be at risk in parts of the region, far more is at stake than farming. And policy actions that enable the public sector to act on agricultural pollution more decisively—consistent with the strategies outlined earlier—may have benefits that are felt more broadly. The following opportunities for spillovers are offered as illustrations.

The public sector can position agriculture to thrive as a business and evolve competitively by being at the service of human and ecosystem health and domestic market opportunities. This is consistent with the "green growth" argument that is upheld for several productive sectors, including agriculture. According to this argument, sustainable management of natural capital is vital for innovation, productivity and efficiency gains, resilience, and increased welfare (World Bank 2012). In addition, mitigating agricultural pollution can help lessen what is often one of the root causes of social inequity.

The agricultural sector can lay the foundations for a circular economy. The EU's Action Plan for a Circular Economy defines a *circular economy* as one in which the value of products, materials, and resources is maintained in the economy for as long as possible and the generation of waste is minimized. That plan recognizes that businesses and consumers are in the driver's seat, but it also underlines the role of local, regional, and national authorities in enabling the transition. As the provider of

primary resources on which the economy is based, agriculture is a cornerstone of the circular economy and an area in which tradition can guide technology to restore the sector's original circularity at a higher level of output and productivity, and with far greater reach into other sectors of the economy.

Building a domestically oriented capacity to tackle agricultural pollution can help the national food sector remain competitive domestically. Ensuring the health and safety of the domestic food supply will be paramount to securing domestic consumers' increasingly choosy dollars. Southeast Asia's growing domestic food market is its own to lose. In this endeavor, opportunities exist to redeploy export agricultural capacity to strengthen and expand the institutions and expertise focused on ensuring the health and safety of foods produced for domestic market consumption.

China and emerging East Asia more broadly are in a historic position to show the world how dietary transition can be decoupled from the rise of chronic disease, and tackling agricultural pollution can be the region's point of entry onto this unblazed trail. The high-stakes linkages between food and chronic disease are steadily gaining recognition, and policy has a role in addressing both the production and consumption sides. Although evidence on pollution impacts could improve dramatically, enough is known to infer that current food production patterns and trends are giving rise to forms and levels of pollution that are contributing to the burden of chronic disease. Moreover, dietary approaches to pollution control, primarily involving less dependence on animal-based products and pesticides, may offer a double dividend because they potentially offer nutritional as well as environmental pathways to better public health.

Mitigating agricultural pollution and enabling sustainable food systems and diets to emerge more generally promise to be big business for both the public and private sectors in East Asia. Organizing markets to deliver all-around healthy diets calls for a policy rethink on several fronts and clear regulatory signaling. It also calls for sustained public and private intervention or investment in such things as science and technology; education, extension, and training; product and service design; innovation processes; voluntary and mandatory standards; monitoring and testing; economic incentives; arts and enterprise; and marketing. Retooling the food sector is the kind of challenge that has the potential to carry the regional economy for decades to come.

Summary

Agricultural pollution has reached alarming proportions in the intensively farmed parts of emerging East Asia, and the rapid pace of farm industrialization and concentration, together with the continued importance of small yet intensive household farming operations, means that farm pollution could grow far severer in the years ahead. The public sector is, however, far from helpless in the face of today's problems and this worrisome trajectory.

Farm pollution can be curbed if governments act on both technical and structural opportunities. Indeed, significant abatement will be possible in the near term by enabling the diffusion of proven and emerging technical solutions. For this, a wide variety of instruments are at the public sector's disposal. However, such efforts may be outdone by continued structural change if it follows a business-as-usual trajectory. Thus parallel efforts are needed to shape how the agrofood sector develops even as it is growing, so that it does not overwhelm countries' ability to mitigate.

In particular, because dietary and consumption patterns will have a profound influence over how the farm sector takes shape, influencing how these patterns evolve may be a key to successful pollution prevention. In general, the starting point for public sector efforts to exert influence over the farm sector's structure will be to weigh the trade-offs implied by different modes of land use (or space use), farming, and consumption. This in turn will mean generating more multidisciplinary evidence on the costs and benefits of different trajectories and involving a wide range of stakeholders in decision making.

All this will require that sufficient resources be devoted to agricultural pollution and that the use of these resources not be outdone by conflicting uses of resources and policies. In this regard, agricultural pollution prevention and management can vastly improve if it is elevated as a mainstream and common objective of agricultural, environmental, and health policy. This will allow agricultural pollution to be integrated into high-level, multisector strategies. And it will enable meaningful incentives to be created from the highest level of government down to the farm and extension worker level. Meanwhile, it will provide impetus to harmonize uses of public resources so they can be redeployed more coherently and effectively. In practice, this will mean a rethink of performance indicators and incentives of all kinds, as well as important investments to generate the evidence needed for better resource allocation and policy implementation.

Box 2.12 summarizes the four strategic directions offered to achieve more effective agricultural pollution prevention and control.

Box 2.12 Four Strategic Directions for Effective Agricultural Pollution Prevention and Control

1. Break policy, geographic, and other silos to mobilize and align resources with priorities.

- Establish strategic priorities that reflect a deeper integration of agricultural, environmental, and health policy and the best available evidence on agricultural pollution impacts.
- Develop new performance indicators, institutional incentives, and budgets that align with strategic priorities. In particular, root out and redirect conflicting uses of resources; better leverage, or "green," resources already devoted to agriculture, environment, and

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Box 2.12 Four Strategic Directions for Effective Agricultural Pollution Prevention and Control *(continued)*

health objectives; and use evaluation to make more efficient use of all resources. Finally, establish processes to update policy on the basis of new evidence, guarding against capture and biases.

- In deploying resources, mobilize stakeholders across levels of government, geographic boundaries, and disciplines to tackle environmental challenges that are not bound by such jurisdictions.

2. Combine sticks, carrots, and behavioral interventions, while investing in supportive infrastructure, to compel, motivate, and enable farmers to "green" their farming practices.

- Strive to bring different players into the fold by, among other things, sending clear signals while offering choices, matching demands on producers with their capacities, and using a variety of instruments in ways that are mutually reinforcing.

3. Influence diets, broader consumer behavior, and other levers of structural change to keep pollution in check.

- Proactively weigh trade-offs implied by different sector development trajectories by, among other things, generating more evidence, engaging multiple stakeholders in planning and policy making (including through stakeholder consultations and "landscape approaches," and developing policies and programs at multiple government levels and spatial scales.
- Indirectly shape consumer preferences and behavior and enable consumers to have a greater influence on production patterns and the farm sector's trajectory.

4. Learn and innovate by investing in pollution monitoring, research, and entrepreneurship in order to stay a few steps ahead of the pollution challenge and use resources effectively.

- Generate better evidence on agricultural pollution to solidify the case for making agricultural pollution a policy priority and thereby directing resources for the greatest near-term and long-term impacts. Evaluate technical and policy interventions and feed evidence into policy making to help improve public (and private) spending iteratively.
- Support knowledge and innovation systems more broadly to enhance the technical and policy toolbox at the disposal of the public and private sectors over time. Such investments can help reduce the cost of the toolbox, widen its application, achieve deeper abatement, and even turn the pollution abatement challenge into a value addition and job creation opportunity.

Notes

1. For this reason, over the past 10 years Vietnam has promoted a "small farmer, large field" model involving more farmer coordination, along with integrated pest management and other ecoagricultural farming principles.
2. Based on a field experiment in the Red River Delta. Greenhouse gas emissions decreased by 53 percent in the group applying mineral fertilizer in combination with straw biochar fertilizer without the intervention harming yields.

3. Developed by the International Rice Research Institute in collaboration with the An Giang Department of Agriculture and Rural Development, "1 Must and 5 Reductions" calls for farmers to use certified seeds (the "1 Must"), while reducing the use of four production inputs (seed, water, pesticides, and chemical fertilizers) and postharvest losses (the "5 Reductions"). This estimate is based on the piloting of the 1M5R package in the Mekong Delta's Kien Giang and An Giang Provinces through nine cropping seasons during 2012–14. Based on this study (Nguyen et al. 2015), Nguyen (2017) estimates that 1M5R could potentially save farmers US$1.4 billion (VND 32,000 billion) a year, assuming 4 million hectares of double-cropped rice.
4. Coordination failures can be particularly problematic when it comes to pest control because pests do not tend to respect field boundaries.
5. The concept of a global protein gap was debunked in the 1970s, and the focus on protein availability as separate from caloric availability in the name of food security is unfounded in most contexts, though protein quality may be relevant to explaining child stunting in highly food-insecure contexts (multiple sources in Greger 2015a; Semba 2016; Uauy et al. 2016). In most of the world except Sub-Saharan Africa, consumption of animal products is already high and exceeds healthy levels (Searchinger et al. 2013).
6. See Jaffee et al. (2016) for a broader view of this in the context of Vietnam.
7. According to the 2016 assessment by the Chesapeake Bay Foundation, after billions of dollars in spending, the Chesapeake Bay's ecosystem remains "dangerously out of balance." However, this situation is turning around, and, overall, progress has seemed to accelerate in the 2010s (Chesapeake Bay Foundation 2017).
8. The Green and Ecology-Oriented Subsidy System Reform Scheme announced by China's Ministries of Finance and Agriculture in April 2016 (Notice to Comprehensively Reform the Three Agricultural Subsidies) aims to "by 2020, establish the green and ecology oriented agricultural subsidy policy system and incentive restriction mechanism promoting the rational use of agricultural resources and ecological and environment production. The scheme will further increase the accuracy, targeting, and effectiveness of the agricultural subsidy, promote the sustainable development of agriculture, increase the agricultural modernization process, and realize the vision of 'strong agriculture, rich farmer and beautiful village'" (China Ministries of Finance and Agriculture 2016).
9. See, for example, Yang et al. (2016) and Shao et al. (2017) on the subsidy and award system and Liu and Wu (2010) on Grain for Green.
10. Whether market-based incentives go so far as to crowd out other, more socially rooted or intrinsic forms of motivation needs to be ascertained on a case-by-case basis and calls for careful program design.
11. On its current trajectory, agriculture could, by midcentury, consume roughly 70 percent of the budget for all greenhouse gas emissions consistent with an increase of two degrees (Celsius) in the global temperature (Searchinger et al. 2013). Unless unprecedented advances in technology occur, studies have found that relative climate stability may be achievable "with a high probability" only if the agricultural sector rallies to curb the production of dairy and ruminant meat, the consumption of which is rising quite rapidly in the region, causing emissions to grow (Bailey, Antony, and Laura 2014; Bajželj et al. 2014; Hedenus, Wirsenius, and Johansson 2014; Searchinger et al. 2013).
12. Path dependencies arise from developments that become a challenge to reverse and that limit options going forward. To take an example from the Netherlands,

pig housing and waste management structures that were encouraged by rules put in place to increase manure storage capacity in the 1980s have made it nearly impossible for a range of farmers to collect slurry and put it to use by, for example, converting the waste to energy using biodigester technology (Backus 2017). From a path dependency perspective, the greatest stakes may lie in the geographic implantation and concentration of animal agriculture going forward.

13. Consumers in the EU choose organic produce primarily for human health reasons—and specifically based on perceptions of food safety risk rather than environmentally mediated risk (Magnusson et al. 2003).
14. And yet organics remained only a sliver of the market, with just 0.6 percent of cereals coming from organic farms, for example (Willer and Lernoud 2016).
15. That said, organic farming is not systematically associated with a yield penalty. A meta-analysis of 115 studies found no significant yield penalty for leguminous and perennial crops, or in developed compared with developing countries. Furthermore, organic farms that practice multicropping and crop rotations suffer a much smaller yield penalty (Ponisio et al. 2015).
16. See, for example, the Brazilian and Dutch dietary guidelines (Health Council of the Netherlands 2015; Ministry of Health of Brazil 2014), as well as the recommendations of the United States Dietary Guidelines Advisory Committee (DGAC 2015), and Nordic Council of Ministers (2012).
17. "The Chinese Dietary Guidelines" (http://dg.cnsoc.org/article/04/8a2389fd5520b4f30155be1475e02741.html). The guidelines call for roughly halving current average meat consumption (Milman and Leavenworth 2016).
18. For example, the use of agricultural films in China has been shown to result in significant increases in phthalate acid esters in the soil (Kong et al. 2012; Wang et al. 2012 in He et al. 2015). However, whether these potential endocrine disruptors appear in humans and how they might affect humans who consume products grown in contaminated substrates are not known.

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In emerging East Asia, agricultural output has expanded dramatically over recent decades, primarily as a result of successful efforts to stimulate yield growth. This achievement has increased the availability of food and raw materials in the region, drastically diminished hunger, and more generally provided solid ground for economic development. The intensification of agriculture that has made this possible, however, has also led to serious pollution problems that have adversely affected human and ecosystem health, as well as the productivity of agriculture itself. In the region that currently owes the largest proportion of deaths to the environment, agriculture is often portrayed as a victim of industrial and urban pollution, and this is indeed the case. Yet agriculture is taking a growing toll on economic resources and sometimes becoming a victim of its own success.

In parts of China, Vietnam, and the Philippines—the countries studied in *The Challenge of Agricultural Pollution*—this pattern of highly productive yet highly polluting agriculture has been unfolding with consequences that remain poorly understood. With large numbers of pollutants and sources, agricultural pollution is often undetected and unmeasured. When assessments do occur, they tend to take place within technical silos, and so the different ecological and socioeconomic risks are seldom considered as a whole, while some escape study entirely. However, when agricultural pollution is considered in its entirety, both the significance of its impacts and the relative neglect of them become clear.

Meanwhile, growing recognition that a "pollute now, treat later" approach is unsustainable—from both a human health and an agroindustry perspective—has led public and private sector actors to seek solutions to this problem. Yet public intervention has tended to be more reactive than preventive and often inadequate in scale. In some instances, the implementation of sound pollution control programs has also been confronted with incentive structures that do not rank environmental outcomes prominently. Significant potential does exist, however, to reduce the footprint of farms through existing technical solutions, and with adequate and well-crafted government support, its realization is well within reach.

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ISBN 978-1-4648-1201-9

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