Global innovation needs assessments

Food system methane synthesis report

April 2023

Supported by:

Global Methane Hub

climateworks FOUNDATION

The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) are a first of a kind platform for assessing the case for low carbon innovation. The GINAs take a system wide perspective, explicitly modelling the impact of innovations across the global economy. Uniquely, the GINAs analysis quantifies the **economic benefits of low carbon innovation and identifies the public investment levels —from research and development to commercialization —needed to unlock these benefits.**

The analyses do not assess all relevant technologies nor do they evaluate all relevant factors for policy judgements. Instead, the work is intended to provide a novel evidence base to better inform policy decisions. The Food System Methane GINAs analysis looks across a broad range of climate mitigation practices, technologies, and behavior change in the food chain to model the economic value of related investment in diffusion, commercialization and research development and demonstration (RD&D). As with all technologies, there are risks and potential downsides to their adoption, and some remain controversial. This analysis does not provide policy recommendations for governments to invest in, accelerate, or otherwise support any specific technologies.

The Global Innovation Needs Assessments Food System Methane project is supported by ClimateWorks Foundation and the Global Methane Hub. It builds upon GINAs work completed in 2021 which examined a broad range of climate mitigation technologies in energy and land-use, adopting a broader lens to look at methane reducing interventions both at the late and early stage of the innovation pipeline, and diffusion of existing technologies.

The findings and views expressed across this project do not reflect the views of ClimateWorks Foundation or the Global Methane Hub.

Food system methane GINAs – Background and context

Methane emissions reductions are critical to limiting global warming in the next decade. The IPCC Sixth Assessment report estimates that methane – a relatively short lived but potent climate forcer with high global warming potential – accounts for almost a third of observed warming to date and is a major determinant of near-term global temperature increases. Emissions budgets estimated by the IPCC call for a 34% decrease in methane emissions by 2030 and 51% by 2050 relative to 2019 among other reductions, in scenarios to limit global warming to 1.5°C with no or limited overshoot.

The Global Methane Pledge, launched at COP26, commits participants to take voluntary actions to reduce global methane emissions by at least 30% from 2020 levels by 2030. Over 150 countries, representing over half of global anthropogenic methane emissions and over two-thirds of global GDP have signed the pledge.

The food system can play a vital role in contributing to methane reduction goals. Agricultural practices account for 50% of human caused methane emissions. The food system contributes additional methane emissions after harvest through transport chains and disposal of waste. In total, the food system accounts for an estimated 60% of global anthropogenic methane emissions.

This GINAs study focuses on methane abatement options in the food system but notes methane innovations can support wider food system decarbonization by reducing other GHG emissions, including CO_2 savings through avoided land use change and increased carbon sequestration potential. Additionally, a broader set of innovations can target wider food system greenhouse gas mitigation including measures focusing on reducing CO_2 and N_2O emissions.

This study quantifies the public and financial benefits from methane reduction actions in the food system. It quantifies the payoffs from innovation in food system methane practices and technologies in terms of public benefits generated and gross value added (GVA) and the jobs supported in each innovation area. The project also estimates the spending required to unlock such benefits with the aim of raising global ambition for innovation commitments.

Contents

The Global Innovation Needs Assessments food system methane outputs are available at: https://www.climateworks.org/ginas-methane.

Executive Summary

Innovation lowers climate transition costs with diverse and substantial co-benefits, but requires increased near-term investment ambition

Methane represents roughly a fifth of GHGs, 60% of which comes from the food system...

- Roughly 10 $GtCO_2e$ of methane are emitted per year
- Food system methane accounts for an estimated 6-7 $GtCO_2e$, driven mainly by **livestock enteric fermentation, food loss and waste, and rice cultivation**

...and rapid reductions in methane by 2030 will be critical to meet a 1.5°C temperature target.

- Under IPCC pathways that limit global warming to 1.5°C with no or limited overshoot, methane emissions must be halved by 2050
- The **Global Methane Pledge** (GMP) **targets global methane reductions of at least 30% from 2020 levels by 2030**

Food system innovations analyzed could reduce methane emissions by up to 75% by 2050...

- This study analyses abatement potential and benefits of innovations across the food system value chain, including **low-cost or cost-saving productivity** measures as well as direct mitigation and diet shift measures
- Analyzed innovations could abate up to 5.6 $GtCO_2e$ in 2050, in line with 1.5˚C and the GMP

...collectively reducing transition costs by roughly $100 billion in 2030 and $1 trillion in 2050...

- Benefits accrue through abatement cost savings and revenues generated relative to high-emissions alternatives
- Demand feedback effects on land use change CO_2 emissions increase benefits to an estimated **$140 billion in 2030** and **$1.1 trillion in 2050**

...and supporting 118 M jobs, $700 B in GVA[1], and multiple food security and nature goals...

- Job contributions dominated by **low-cost productivity innovations** in food loss & waste in the near-term, **alternative proteins** by 2050
- GVA contributions are dominated by **alternative protein investment** throughout study period
- Innovations can have **synergies with sustainable development goals** in low- and middle-income regions while driving sustainable value creation in developed countries

...but this potential is unachievable without a 5X scaling in investment by 2035

- Investment must scale rapidly from current levels ($10-$20 billion per year) to **over $60 billion per year by 2035** to overcome the diffusion barriers faced by existing best practices and commercialize novel technologies, with spending deployed across **agricultural extension/technology transfer, and energy, agricultural, and biotechnologies**
- Investing in food system methane innovations could bring up to **12x larger benefits by 2050** through reducing cost of energy and land transition

1. Measure of contribution to GDP made by an industry or sector.

Note: Throughout this report, monetary values are reported in US$ 2005

Methane abatement innovations in the food system have significant and diverse benefits for the climate, global economy, and populations

GINAs analyzed abatement, co-benefits and investment needs across a broad range of food system methane innovations

Innovations could mitigate up to 75% of food system methane emissions by 2050...

Innovations provide large abatement opportunities across key food system sectors

...while reducing the costs of the climate transition...

Benefits accrue through abatement cost savings, and revenues generated relative to high-emissions alternatives

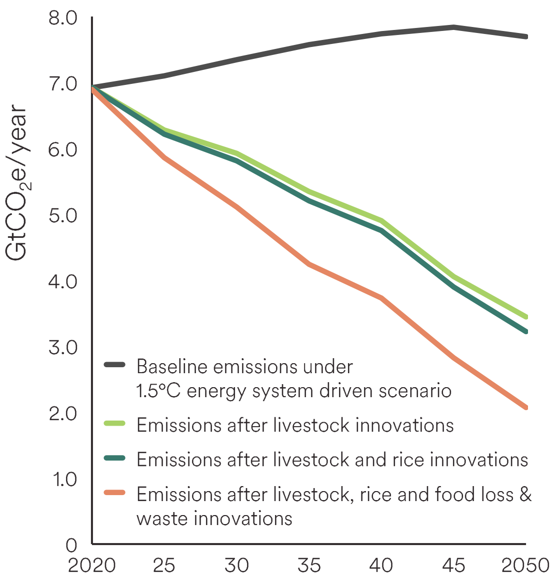
...and driving positive co-benefits...

Innovations can support economic development including jobs, GVA, and a range of food security, nature and health goals

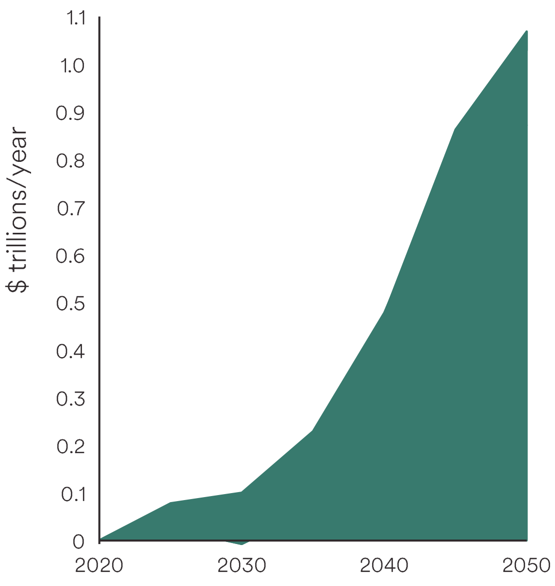
...but require significant near-term investment to facilitate deployment

Innovations require an ~5x increase in annal investment from baseline levels in order to realize their modeled mitigative and economic benefits

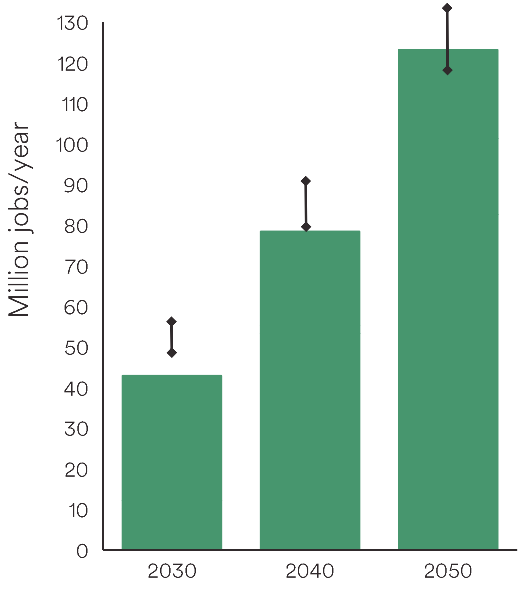
Methane emissions reduction potential across key food system sectors



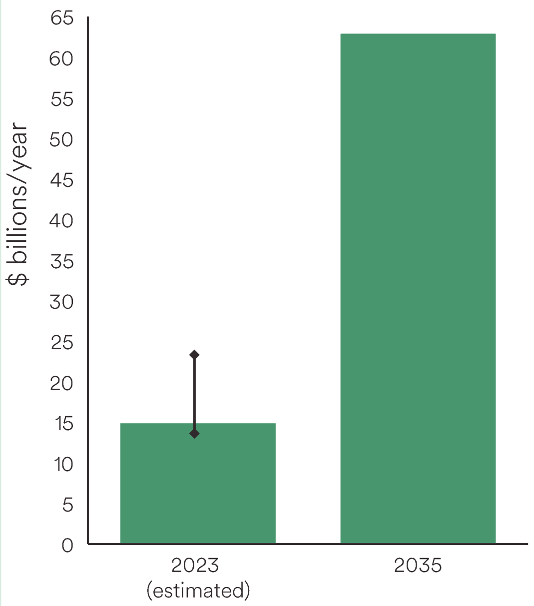
Innovation net benefits



Jobs supported through innovations



Investment in innovations



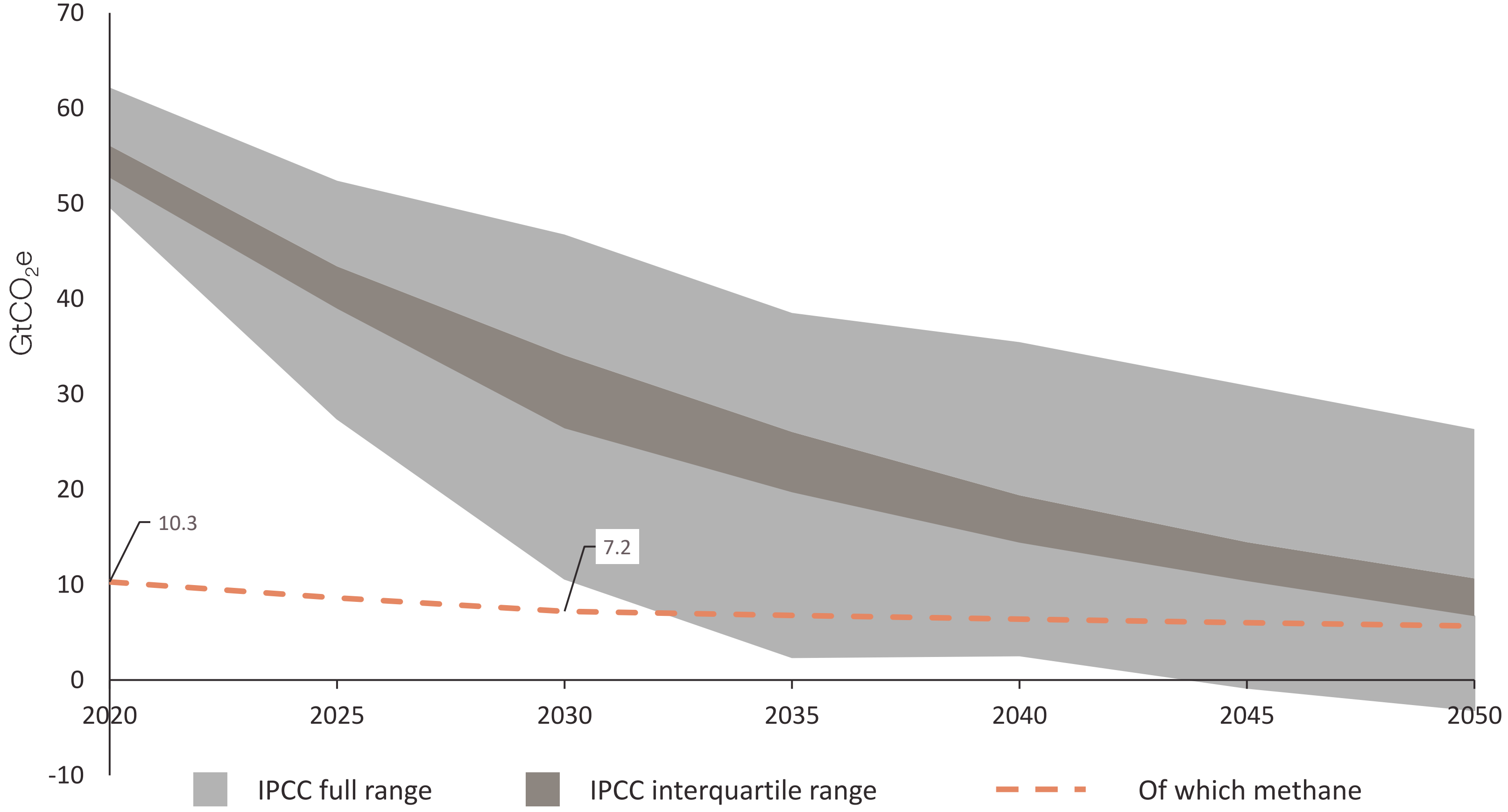
Note: Job estimations subject to +/-12% uncertainty range based on variation in input cost assumptions across innovations. Baseline investment levels estimated based on various public studies.

Part 1 – Methane in the food system

Achieving a 1.5°C climate goal requires sizeable short-term reductions in GHGs, including in anthropogenic methane emissions

IPCC 1.5°C aligned pathways and the Global Methane Pledge require significant reductions in methane emissions by 2030

Global CO_2e emissions trajectories under IPCC SR1.5°C Global Pathways[1]



Under IPCC pathways that limit global warming to 1.5°C with no or limited overshoot, **GHG emissions are required to fall by 43% by 2030 and 84% by 2050**

Within this ambition, and to align with a net zero pathway and the Global Methane Pledge, **human-caused methane emissions** (spanning fossil fuel, agriculture and waste sources) **need to be reduced by a third by 2030** from current levels

Deep reductions, particularly for methane, are likely to **lower peak warming and lead to less reliance on negative emissions** during the second half of the century

1. Total emissions trajectories comprise all Kyoto gasses, including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Ranges reflect modelled and estimated emissions pathways.

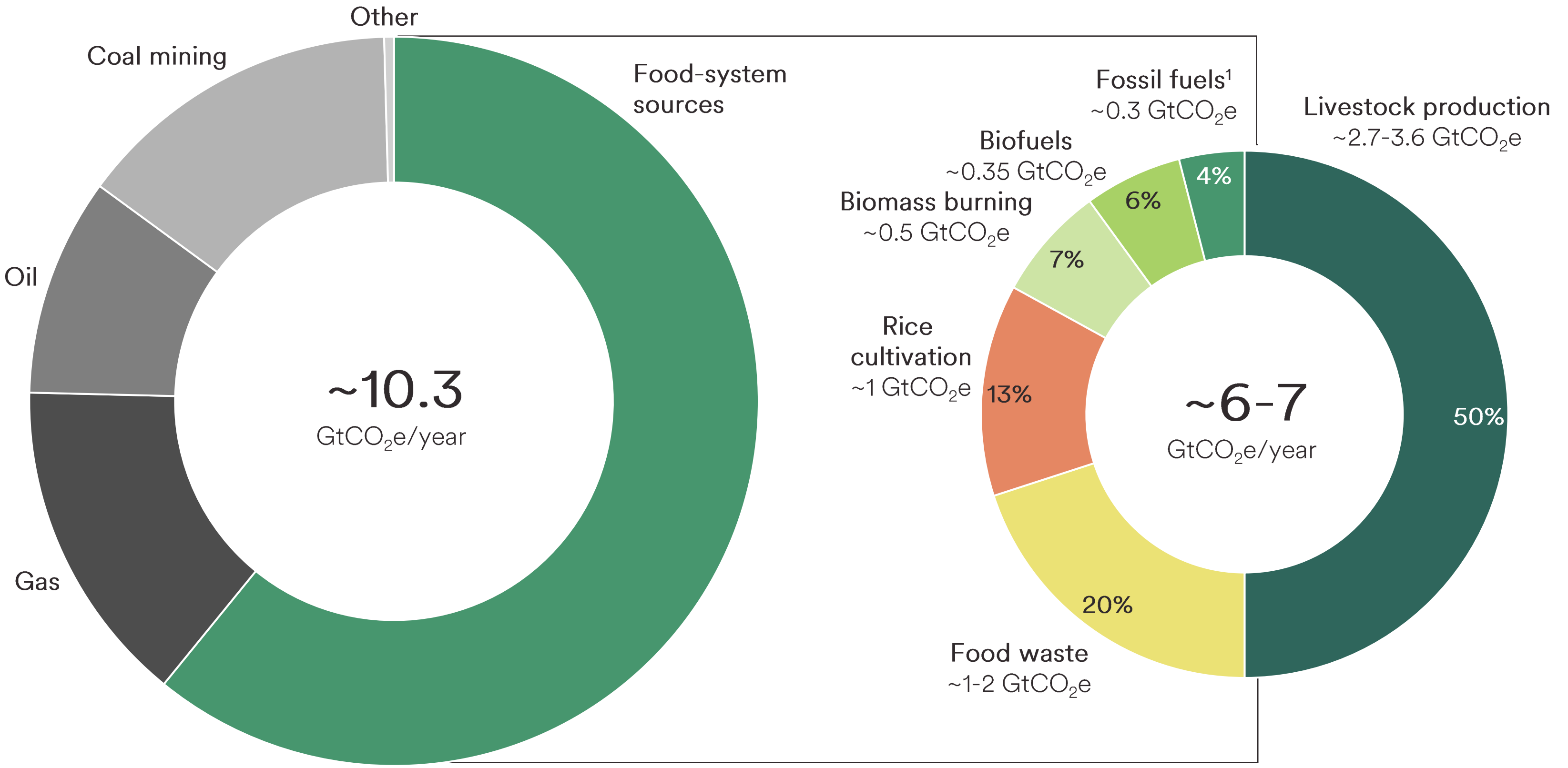
Source: IPCC AR6 (2022). Available at: https://www.ipcc.ch/report/ar6/.|

Total anthropogenic methane emissions are 380 MtCH4 with a range of 359-407 MtCH4/year based on bottom-up estimates, which are presented in CO2e using GWP-100. 2030 and 2050 methane reductions reflect IPCC AR6 projections for methane to be reduced by 34% (21-57%) in 2030 and 45% (25-70%) in 2050, compared to 2019 levels, in pathways limiting warming to 1.5°C with no or limited overshoot.

The food system accounts for an estimated 60% of global methane, and is dominated by emissions from livestock, waste and rice cultivation

Global anthropogenic methane emissions, 2017

Estimated food system methane emissions



Food system methane emissions currently account for an estimated **6-7 $GtCO_2e$** per year, arising primarily from **livestock, food loss and waste**, and **rice cultivation** - which make up **roughly three quarters of food system methane**

- ~45% due to **enteric fermentation**, the natural digestive process in ruminant animals such as cattle, sheep, goals and buffalo; 5% arising from animal manure
- ~20% attributed to **food waste** of which some is avoidable, decomposing in the absence of oxygen (e.g., in landfills)
- ~13% produced in **rice cultivation** due to methane-emitting bacteria in flooded rice paddies
- The reminder of food-system methane arise from **biomass burning, fossil fuel extraction** and the **fertilizer value chain** related to agricultural inputs

1. Methane associated with fossil fuel extraction and the fertilizer value chain related to agricultural inputs.

Notes: Total anthropogenic emission range is 380 Mt CH4 with a range 359-407 Mt/year based on bottom-up estimates which are presented in CO2e using GWP-100.

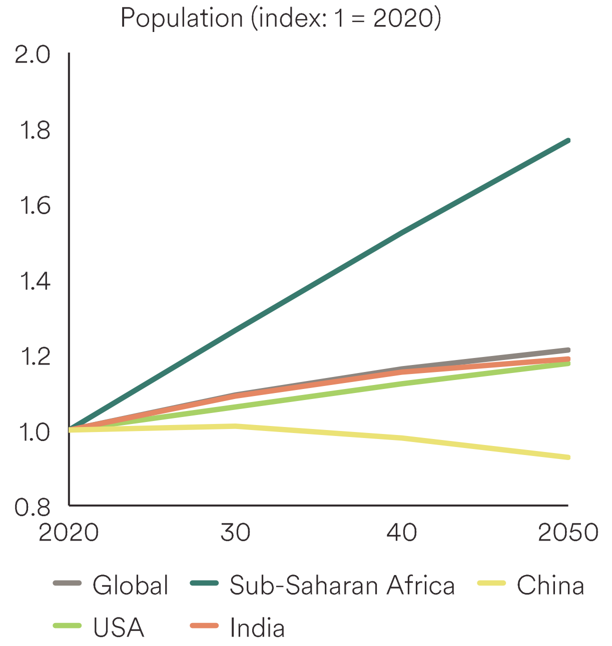
Sources: Saunois et. al 2020: IPCC AR6 WGIII (2022). Available at: https://www.ipcc.ch/report/ar6/

The global food system faces multiple challenges over coming decades, including growing demand, shifting income, and climate change impacts

The food sector will face significant and evolving challenges over coming decades, including…

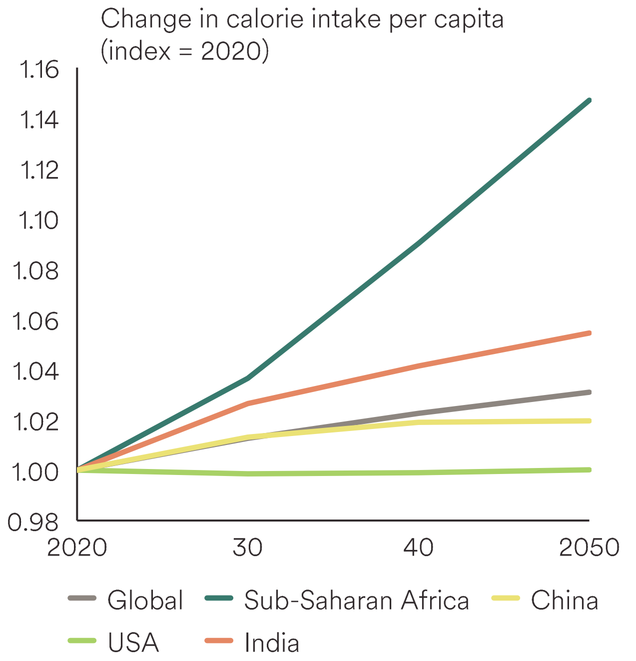
…meeting the nutritional needs of a growing population…

The global population is expected to grow over 20% to ~9.4 billion by 2050, driven by growth in lower- and middle-income countries



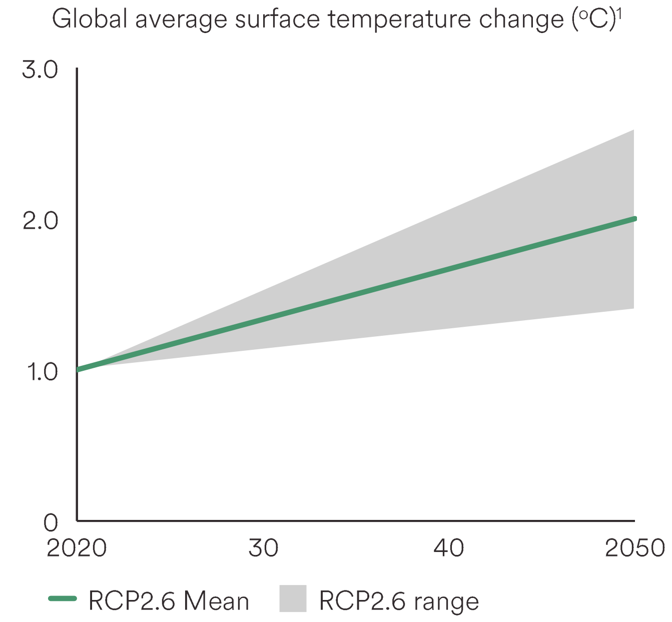
…with increasing demand in developing regions…

Calorie intake per capita is likely to grow significantly over the period to 2050, particularly in lower- and middle-income countries



…against a backdrop of climatic change and heightened physical risks

Temperature and climate changes will drive physical risks in agriculture, including reductions in water availability, extension of liveable ranges of pests/diseases and increased flooding/sea level rise



1. Relative to 1986-2005 levels, IPCC (2023). Available at: https://ar5-syr.ipcc.ch/topic_futurechanges.php

Part 2 – Methane abatement in the food system through innovation

This study considers food system methane innovations across three categories and major contributors of emissions

Modelled innovations span low-cost best practices to nascent technological interventions in three high-emitting sectors

	Livestock	Food loss & waste	Rice cultivation
Productivity/best practices Improve yields/efficiencies, reducing methane on an input/output basis	Management practices including: • Improvements in animal breeding • Improvements in animal health and reproduction • Improved herd management/feeding practices	Reducing food loss across the supply chain: • Cold chain technologies including on-grid and off-grid cold storage units[1], transit and routing innovations, pallet-level temperature monitoring devices, hyperspectral imaging • Waste tracking and analytics: real-time tracking of food stocks and surpluses using monitors, sensors	Productivity and improvement in rice management practices, including: • Rice paddy water management • Straw management • Direct dry seeding
Direct mitigation Directly reduce methane emissions at their source	Mitigation innovations including: • Novel feeding additives • Immunization against methanogens	Organic waste diversion with: • Composting • Mechanical and biological treatment	Mitigation innovations including: • Low-methane varietal rice selection • Methane inhibiting fertilizers
Diet shift	Diet shift away away from ruminant meat and dairy products and towards alternative proteins. This includes a shift towards conventional non-ruminant livestock and fish protein as well as towards newly emerging alternative protein products.		

1. On- and off-grid solutions analyzed to ensure consideration of local innovation suitability. This GINAs study focuses on the costs and feasibility of deploying low-carbon cold storage solutions (e.g. solar PV-based) but notes absent interventions, cold chain emissions in developing countries could increase if delivered via conventional fossil-fuel based technologies (UNEP and FAO (2022). Sustainable food cold chains: Opportunities, challenges and the way forward. Available at: https://www.unep.org/resources/report/sustainable-food-cold-chains-opportunities-challenges-and-way-forward

This study prioritized food system methane innovations based on climate, economic and co-benefit impacts

Areas of focus for the Food System Methane GINAs

Productivity/best practices

Improve yields/efficiencies reducing methane emissions per unit of food produced. Many are existing best practices that leverage existing technologies and can be cost-saving or low cost, but face diffusion barriers due to lack of awareness/incentives.

Direct mitigation

Directly target methane production at its source, e.g., vaccines that target methane-producing bacteria in ruminant livestock

Diet shift

away from ruminant meat and dairy products and towards alternative proteins. This includes a shift towards conventional plant-based, non-ruminant livestock and fish protein as well as towards newly emerging alternative protein products.

Filters applied for selection

Innovations play a material role in 1.5°C scenarios

Innovations highlighted by established research institutes that can drive substantial abatement across diverse geographies and production systems

Innovations span the food system chain and across production processes

Innovations have holistic potential, tackling production, distribution and disposal

Innovations have substantial diffusion potential while yielding co-benefits

Technologies and practices exhibit plausible diffusion, innovation and cost reductions; yielding co-benefits and not being likely to have adverse effects on other social or environmental goals

Selected innovations highlight the potential scale of benefits of innovation in the food system

The chosen areas of focus do not imply practices and technologies selected will necessarily play major roles in achieving net zero globally. This will depend on political choices and inherently uncertain innovation processes

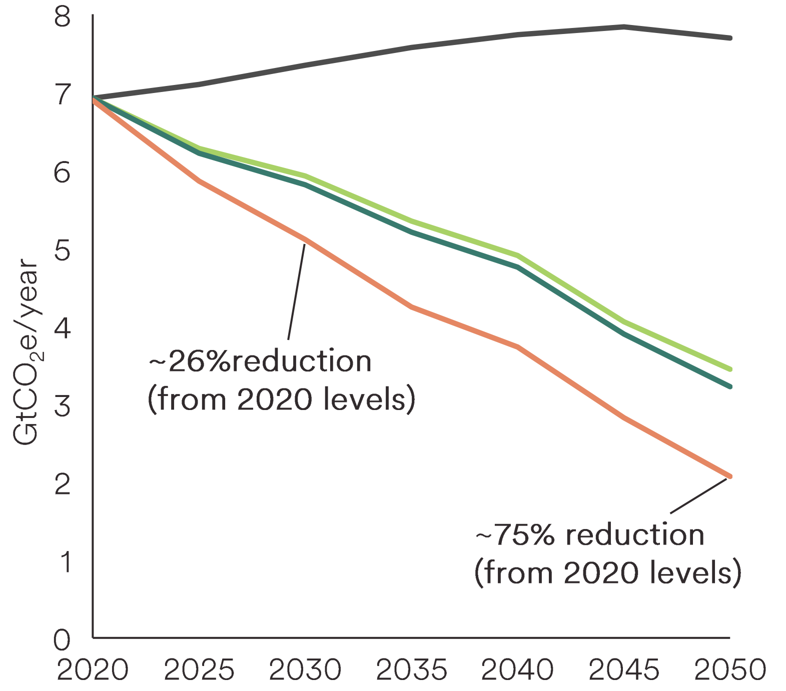
Nor do they imply that technologies and innovation which are not within the GINAs selection cannot play a major role in achieving the Global Methane Pledge and net zero

Indeed, many omitted food system methane abatement innovations are technically and financially feasible today and could offer abatement potential and benefits

Note: Today's evidence base on the potential of decarbonization technologies can help decisionmakers guide innovation. However, innovation is inherently uncertain and not fully predictable. Unexpected breakthroughs will occur, as well as disappointments in development. Our understanding of the potential benefits will change, and the GINA methodology can be applied to map innovation potential and benefits of new technologies, or technologies for which expectations have substantially changed. Further detail on how GINA's areas of focus were selected is set out in the Technical Report available online.
This GINAs study focuses on methane abatement options in the food system but notes methane innovations can support wider food system decarbonization by reducing other GHG emissions, including CO2 savings through avoided land use change and increased carbon sequestration potential. Additionally, a broader set of innovations can target wider food system greenhouse gas mitigation including measures focusing on reducing CO2 and N2O emissions.

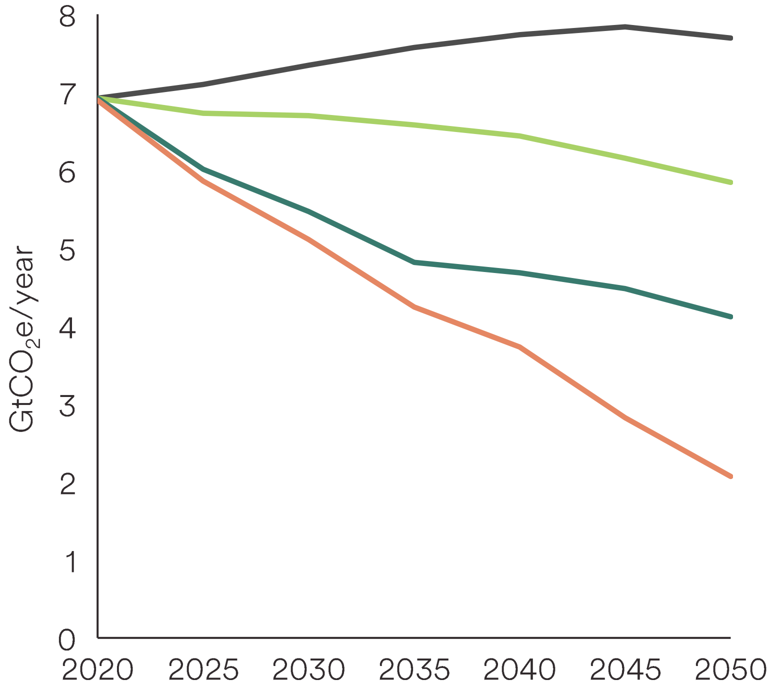
Food system innovations can help meet climate targets by reducing food system methane in line with Global Methane Pledge

Contributions by sector



- Baseline emissions under 1.5°C energy system-driven scenario
- Emissions after livestock innovations
- Emissions after livestock and rice innovations
- Emissions after livestock, rice and waste innovations

Contributions by technology family



- Baseline emissions under 1.5°C energy system-driven scenario
- Emissions after diet shift
- Emissions after diet shift and productivity measures
- Emissions after diet shift, productivity and direct mitigation measures

Notes: Methane emissions savings from food system innovations are sensitive to account methods which can influence the scale of impacts. This GINAs study leverages the IPCC's AR6 recommended global warming potential of methane GWP100, where 1tCH4 is assumed to have a warming impact equivalent to roughly 27.2tCO2. Please see technical report for sensitivity analysis of emissions savings by GWP.

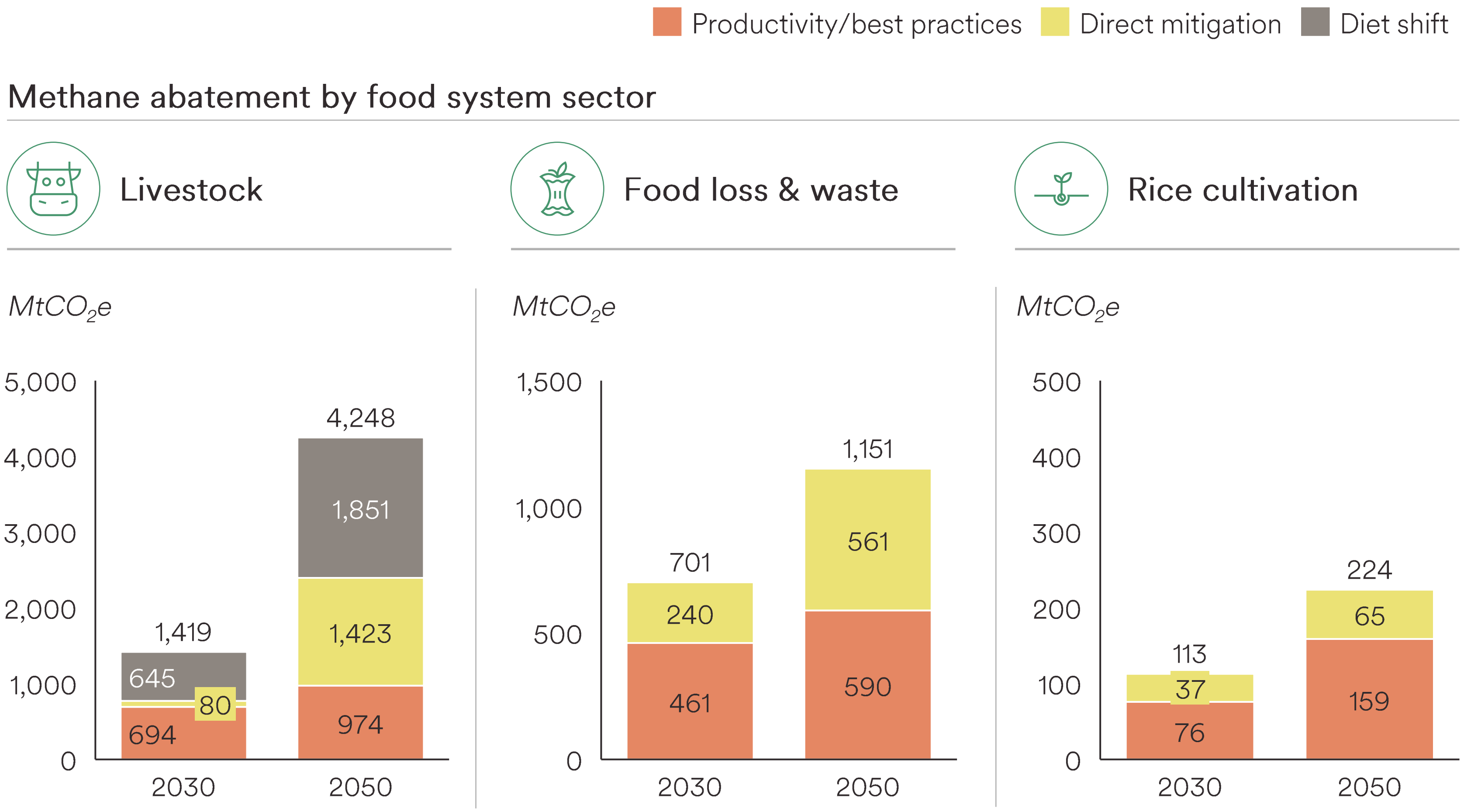
Innovations in the food system can contribute towards **reaching a 1.5°C climate target with no or limited overshoot, in line with aims of the Global Methane Pledge**

75%

of methane emissions from livestock enteric fermentation, rice cultivation, and food loss and waste could be mitigated through deployment of modelled innovations, by 2050

A large share of food system methane abatement is achieved through deployment of **low- to negative-cost productivity/best practice innovations**

Abatement is driven by low-cost best practices in the near-term, and diet shifts in the longer-term



Note: Scaling not standardized

Greater diffusion of **existing low-cost productivity/best practice measures**, together with diet shifts, **can support methane abatement in the shorter term (accounting for an estimated 1.2 $GtCO_2e$ in abatement by 2030)**

Direct mitigation innovations in livestock and food loss and waste sectors, as well as **diet shifts, can support abatement in longer term up to 3.9 $GtCO_2e$ by 2050),** as rising carbon prices and falling costs incentivize deployment (3.8 GtCO2e)

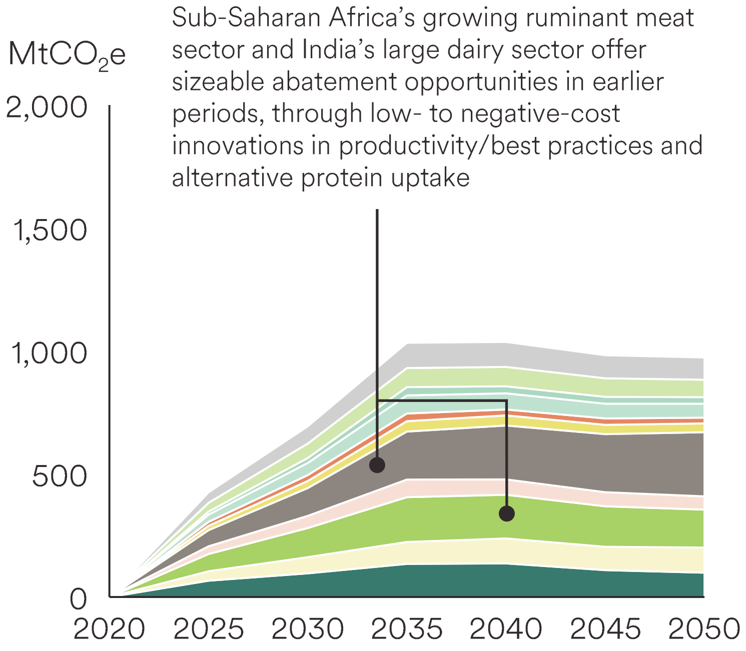
The livestock sector accounts for majority of abatement potential in longer term

Rice interventions offer smaller abatement opportunities relative to livestock and waste innovations, but many **are low cost and could also boost productivity and unlock other co-benefits in major rice growing regions**

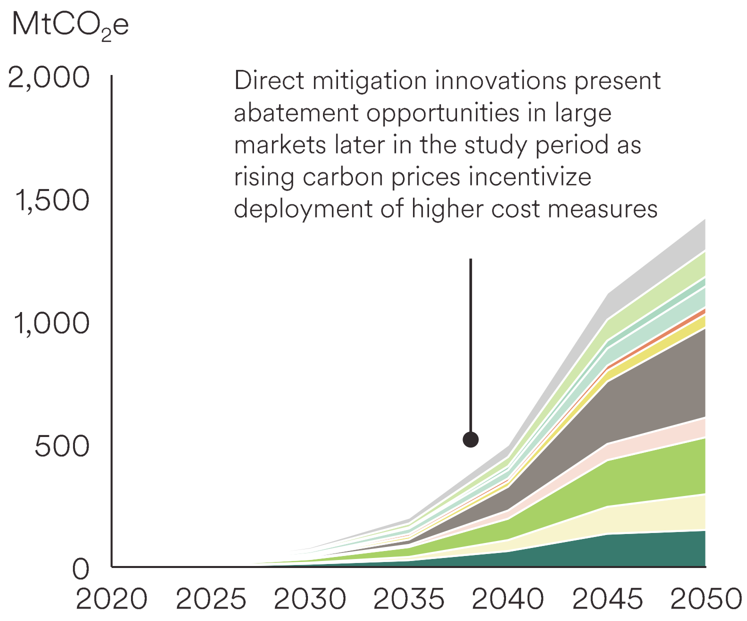
Abatement potential of livestock innovations is greatest in India, Sub-Saharan Africa, and China

Large livestock producing regions can contribute greatly to global abatement, including through low-cost productivity measures

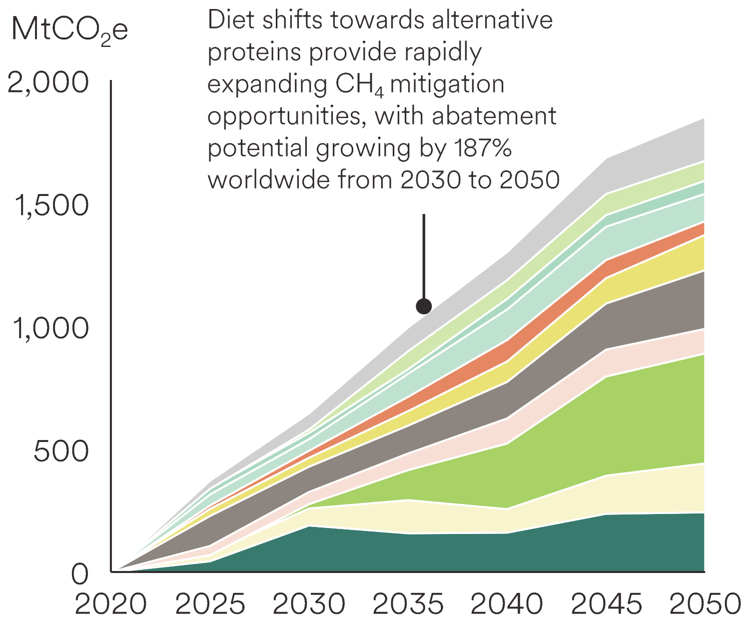
Productivity/best practices



Direct mitigation



Diet shift



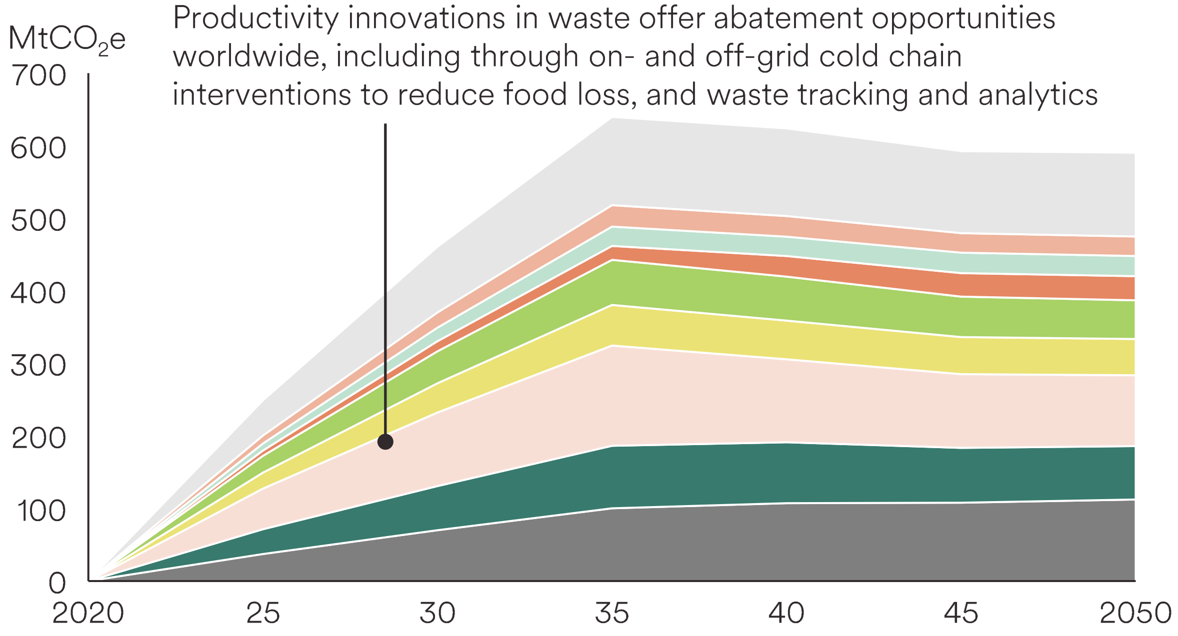
- China
- South Asia (excl. India)
- India
- Brazil
- Sub-Saharan Africa
- Southeast Asia & Pacific
- US & Canada
- Europe
- Australia & New Zealand
- Latin America & Caribbean (excl. Brazil)
- Other

Note: See appendix for analysis of shares in global abatement potential of food system methane innovations by top regions

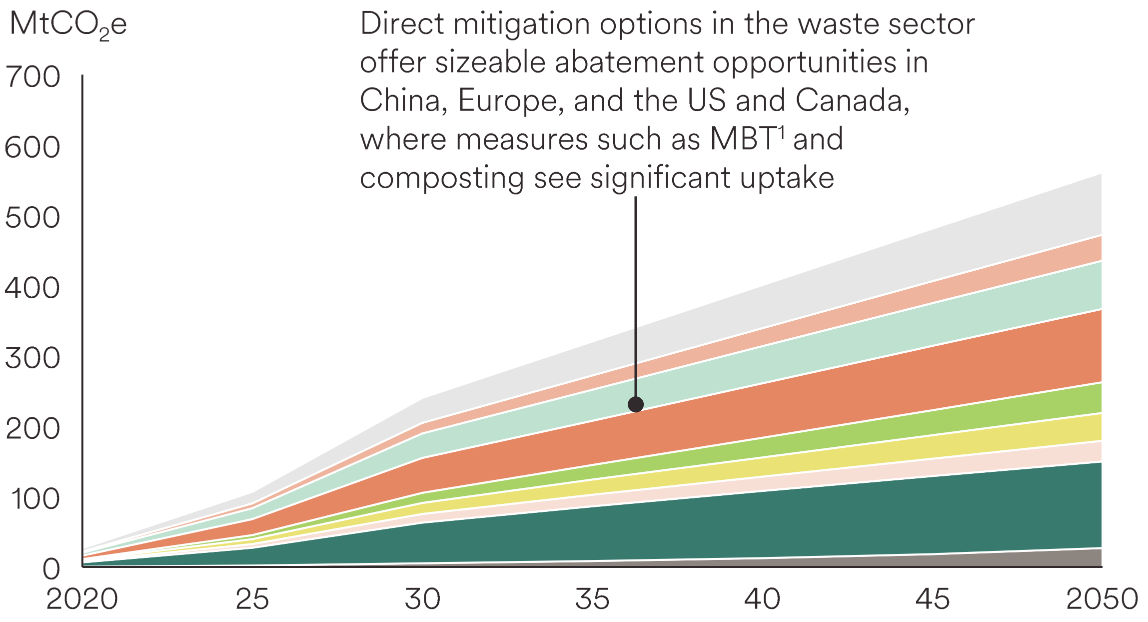
Abatement potential of food loss and waste innovations is greatest in Brazil, China, and Sub-Saharan Africa

Productivity measures have benefits worldwide, while direct mitigation is most impactful in the global North and China

Productivity/best practices



Direct mitigation



- Sub-Saharan Africa
- China
- Brazil
- Southeast Asia & Pacific
- India
- US & Canada
- Europe
- Middle East & North Africa
- Other

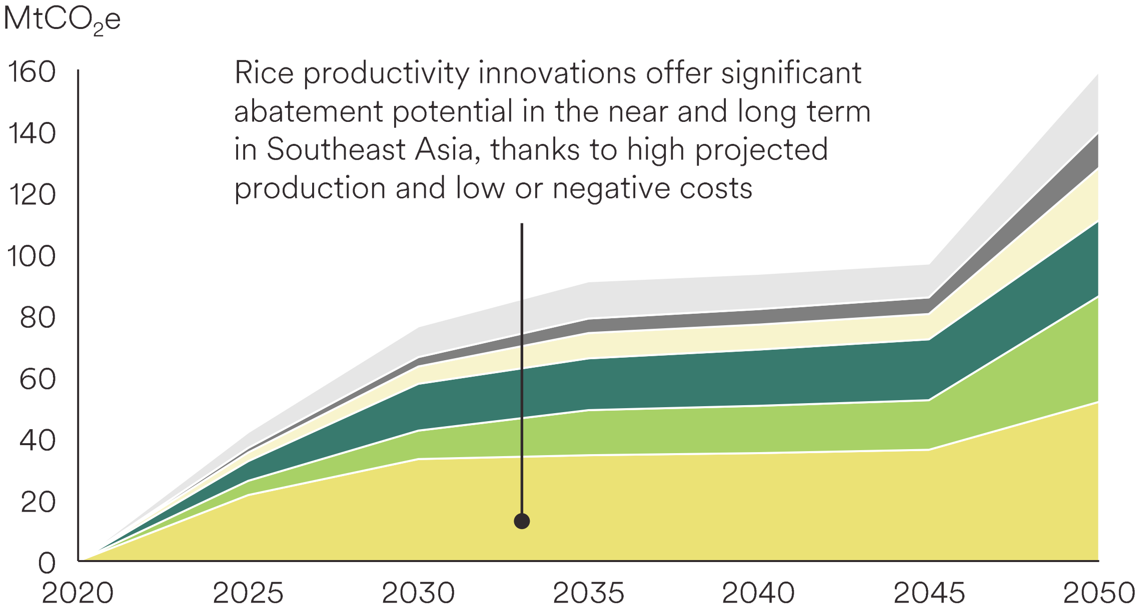
1. MBT: Mechanical Biological Treatment

Note: See appendix for analysis of shares in global abatement potential of food system methane innovations by top regions

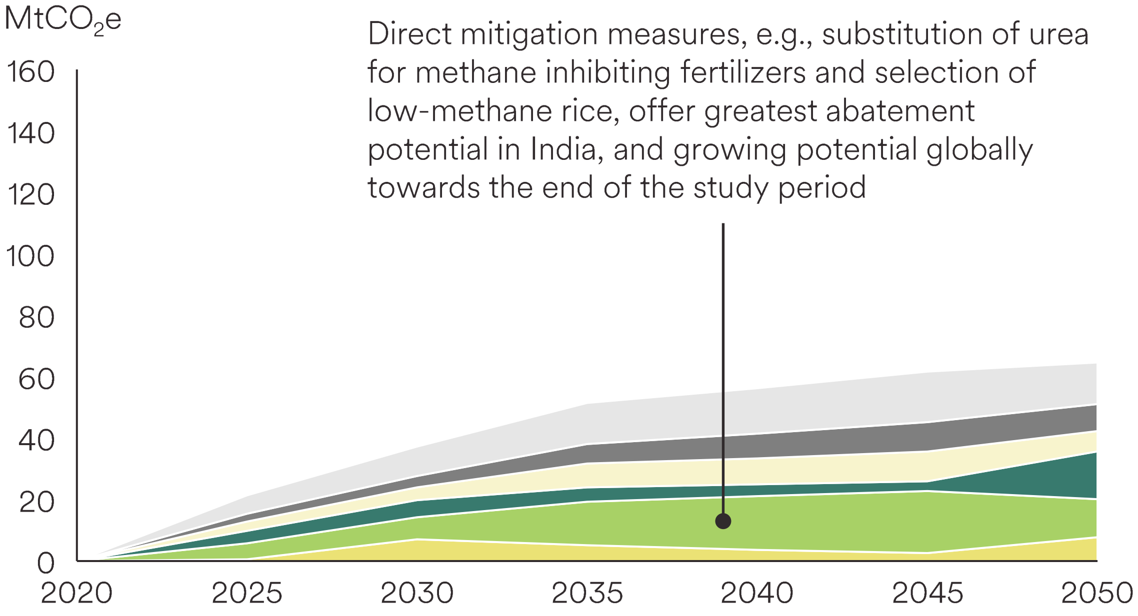
Abatement potential of rice cultivation innovations is greatest in large rice producing regions, including India and Southeast Asia

Large rice producers can abate effectively through a combination of best practice and direct mitigation measures

Productivity/best practices



Direct mitigation



Southeast Asia & Pacific
India
China
South Asia (excl. India)
Sub-Saharan Africa
Other

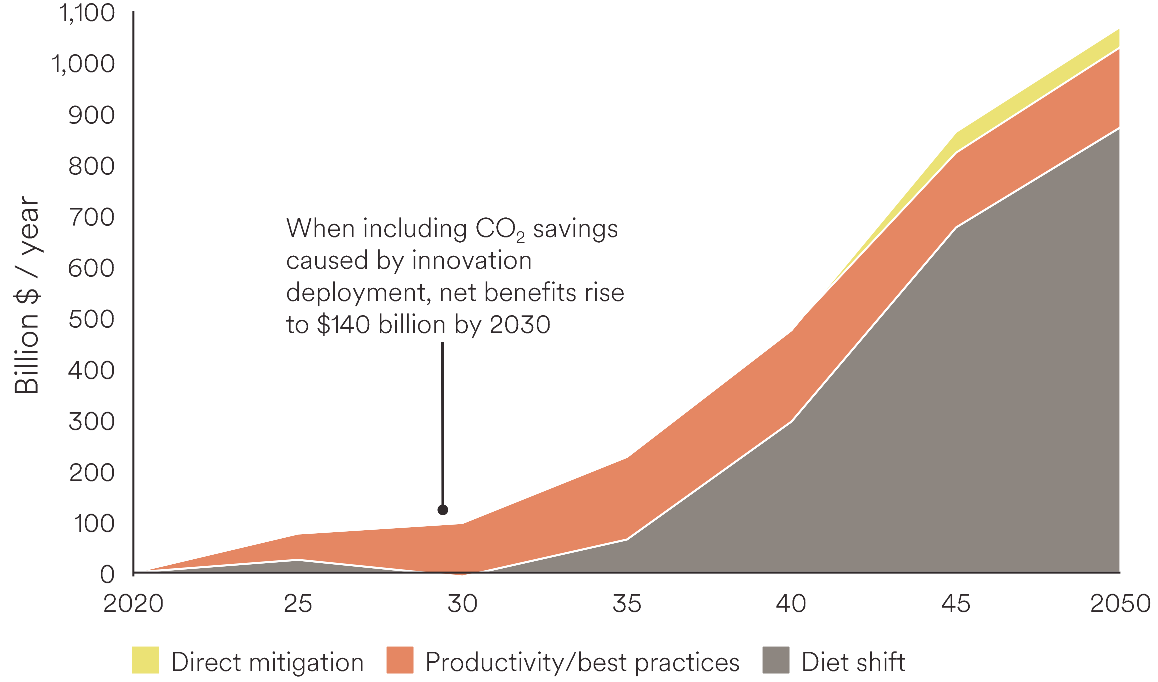
Note: See appendix for analysis of shares in global abatement potential of food system methane innovations by top regions

Part 3 – System benefits of innovation and impacts on GVA, jobs and communities

Innovations could collectively reduce the costs of achieving a 1.5°C temperature target by roughly $100 billion in 2030 and $1 trillion in 2050

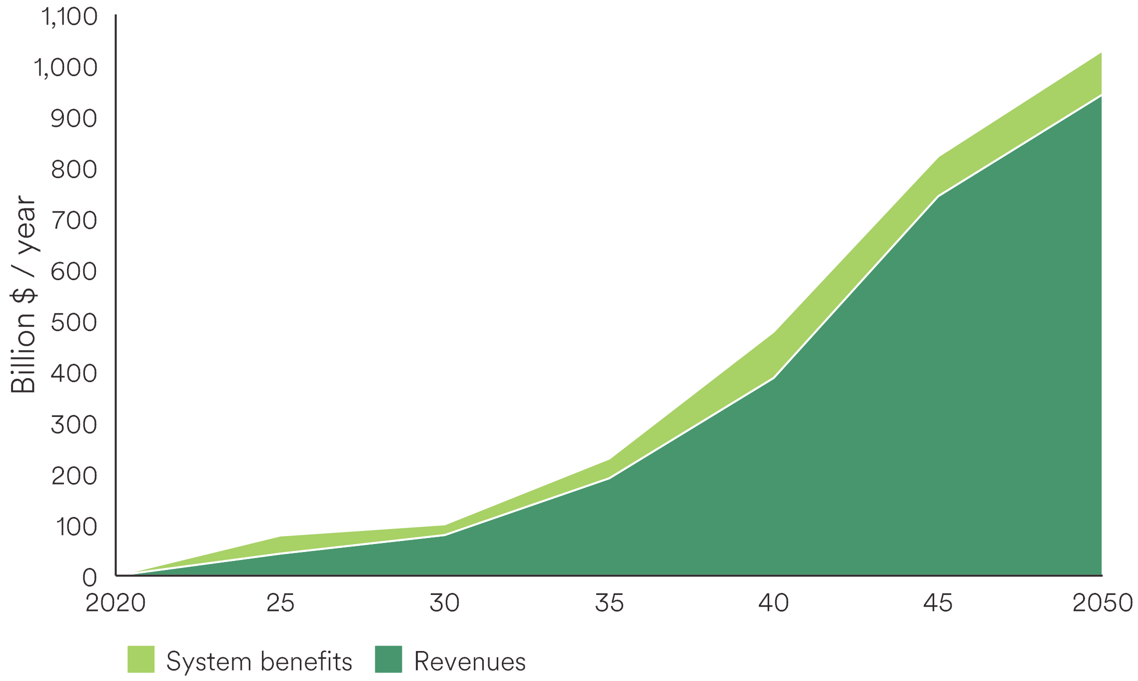
The bulk of net benefits accrue in measures that are **cost saving or require shifts in behaviour**, especially in productivity measures and alternative proteins

Net system benefits by technology family



Benefits accrue through both **abatement cost savings** (system benefits) and **revenues** generated relative to high-emissions alternatives

Cost-saving system benefits vs revenue-generating benefits

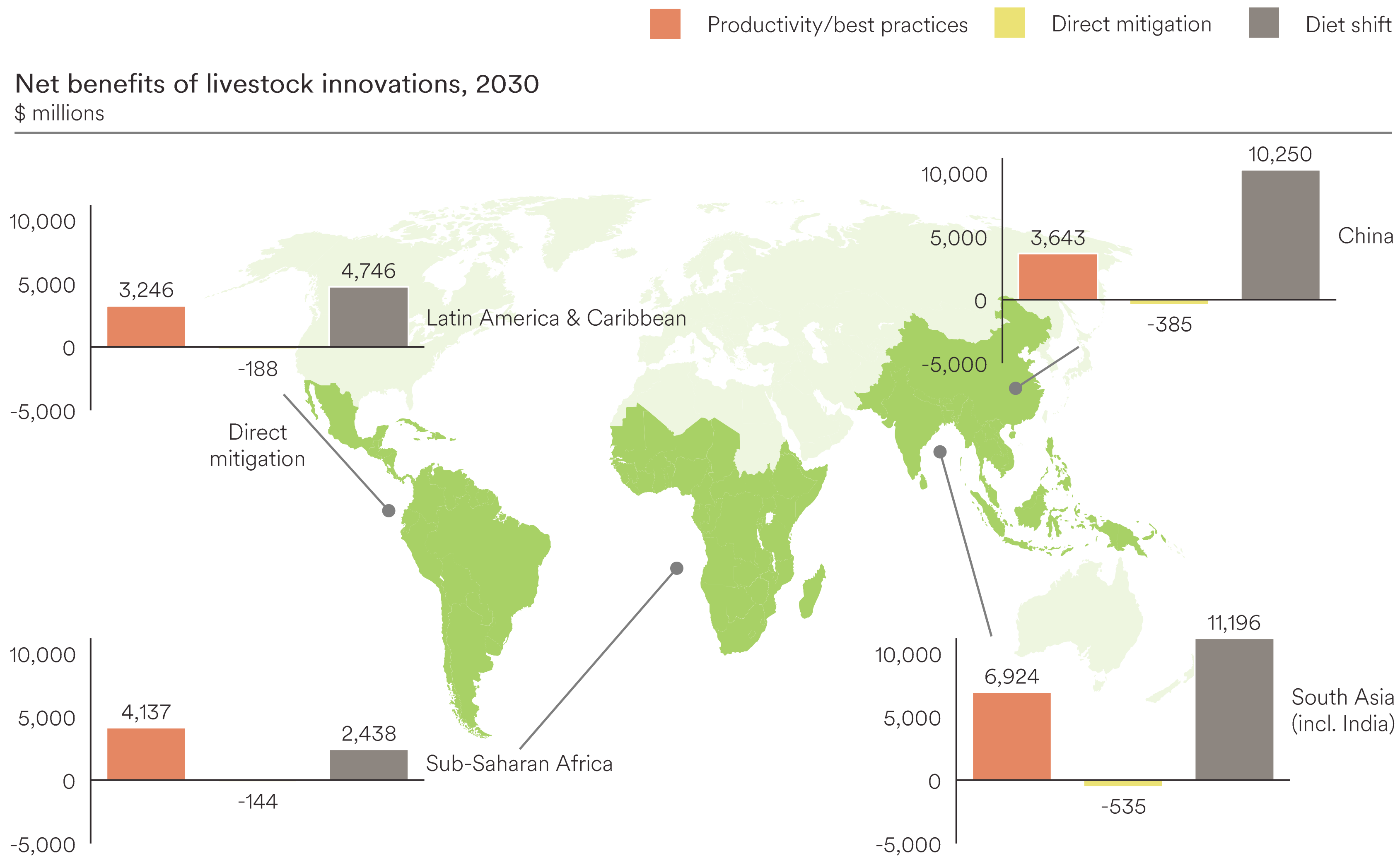


1. System benefits are subject to an uncertainty range of roughly $80 billion in 2050, depending on the sensitivity of system costs to changes in the carbon budget. See Technical Report for analysis of cost sensitivities.

The nearer term benefits of livestock innovations are most pronounced in major producing regions

These include South Asia, China, Sub-Saharan Africa and South America

Net benefits of livestock innovations, 2030
$ millions



$18 billion

In net benefits through low-cost or cost-saving **productivity/best practice** innovations in China, South Asia, Latin America and Sub-Saharan Africa by 2030

$28 billion

In net benefits could be generated through diet shifts towards alternative proteins in China, South Asia, Latin American and Sub-Saharan Africa in the near-term

Direct mitigation innovations yield negative benefits in nearer term

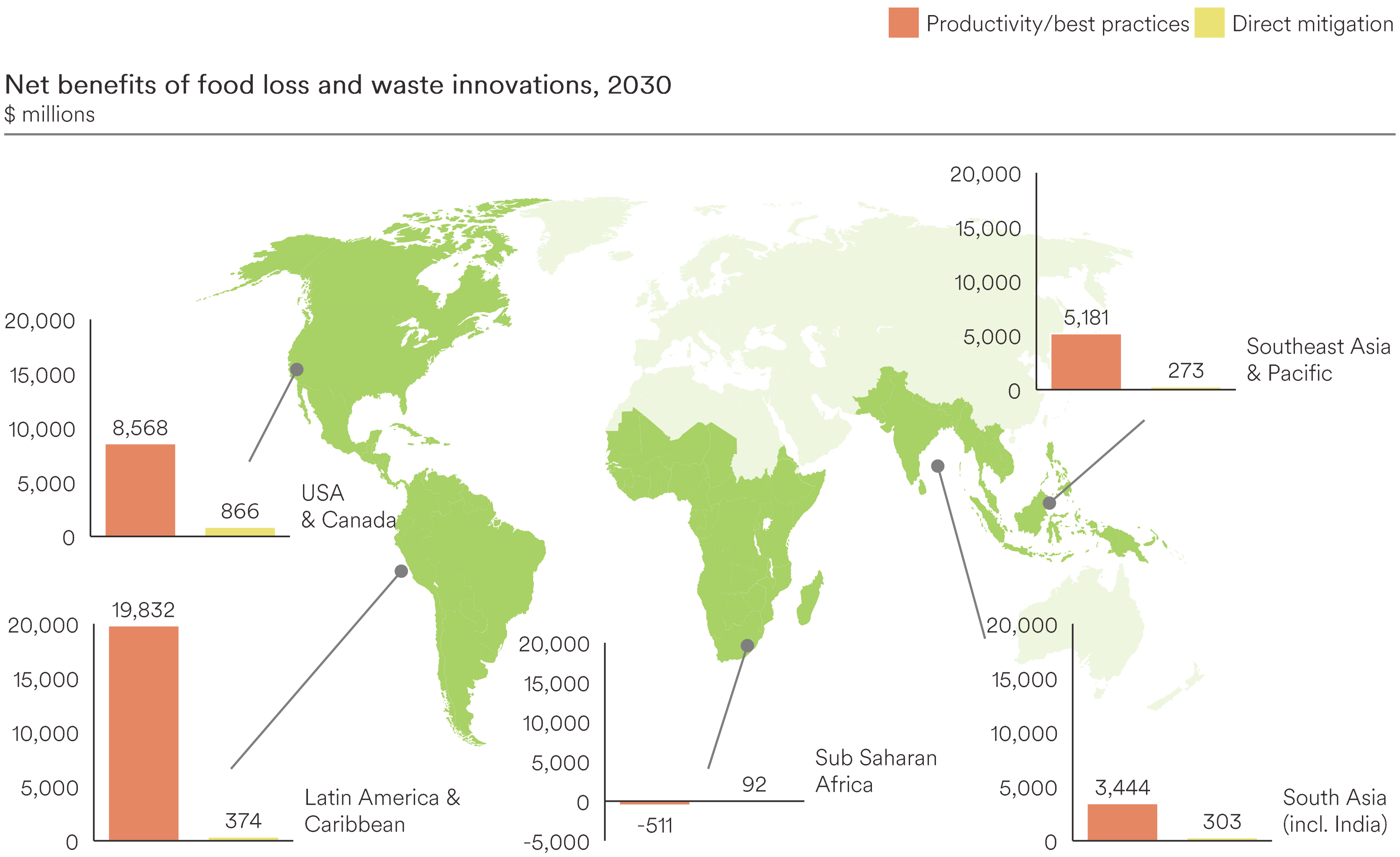
In the US & Europe, diet shifts produce **negative net benefits in earlier periods,** as consumers are willing to pay for low emissions goods, but positive net benefits in later periods

Food loss and waste innovations show high net benefits globally, including in low- and middle-income regions

Waste prevention measures can be implemented at low costs and enhance circularity

Net benefits of food loss and waste innovations, 2030

$ millions



1. See technical report for examples of promising waste innovation opportunities in low- and middle-income regions.

Benefits from methane innovations in food waste are dominated by productivity measures, specifically **cold chain technologies**, to 2030

$77 billion

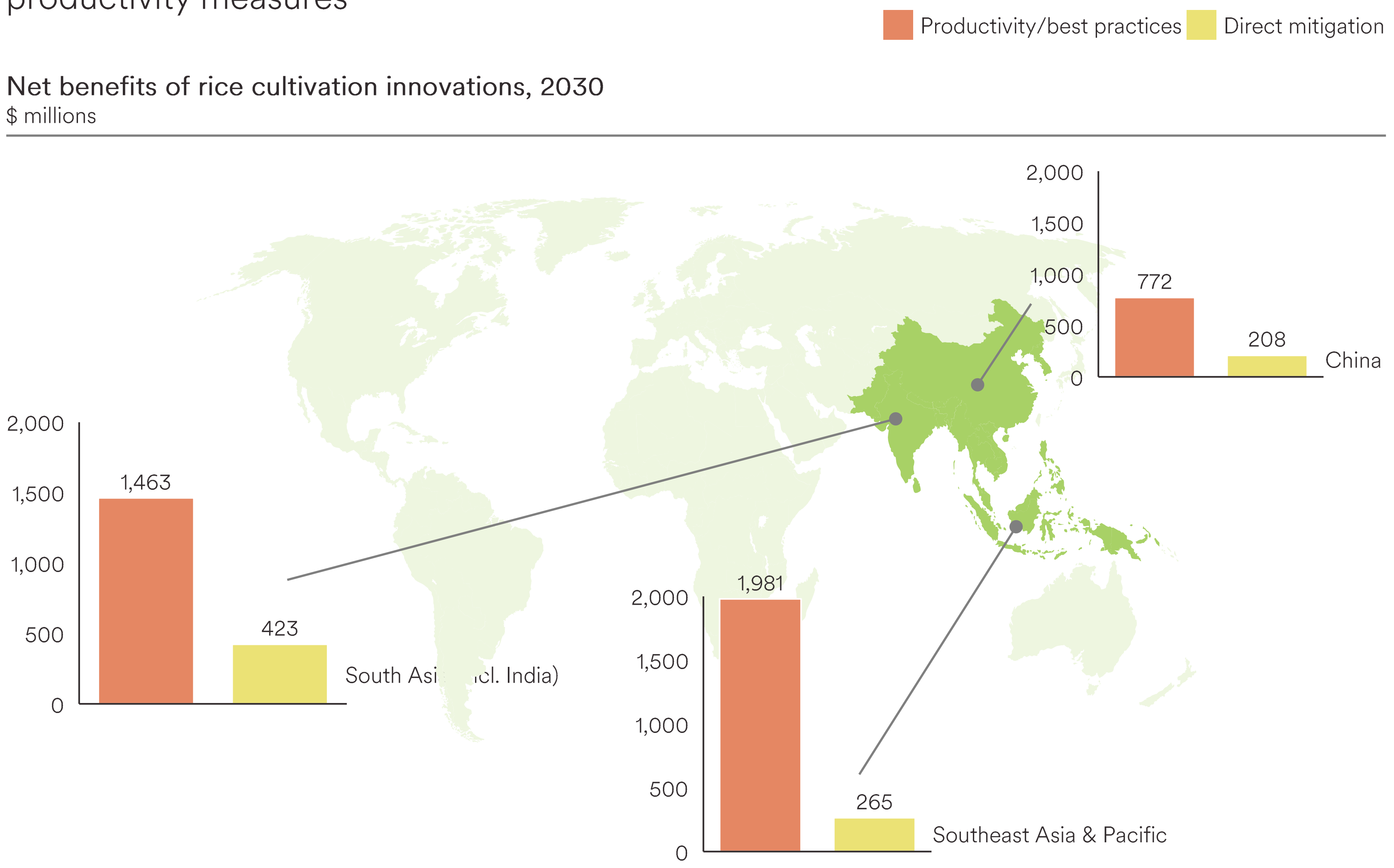
In net benefits can be generated through all food loss and waste sector methane interventions globally, by 2030

Cold chain innovations are highly promising in **low- and middle-income regions**, where refrigeration expansion can benefit greatly from innovative off-grid solutions and "cooling as a service" operations[1]

Rice cultivation benefits are concentrated in major growing regions and are dominated by best practice and productivity measures

Benefits accrue in developing rice producing regions, including in low- to negative-cost productivity measures

Net benefits of rice cultivation innovations, 2030
$ millions



Benefits from rice methane innovations are **dominated by productivity measures**, which make up roughly 80% of global rice innovation net benefits in 2030

$6.9 billion

In net benefits can be generated through all rice methane interventions globally, by 2030.

China, Southeast Asia and South Asia (including India) can generate roughly **$4.2 billion in net benefits through productivity measures** in 2030

Investing in food system methane innovations could support up to 118 million jobs and roughly $700 billion in GVA globally, by 2050

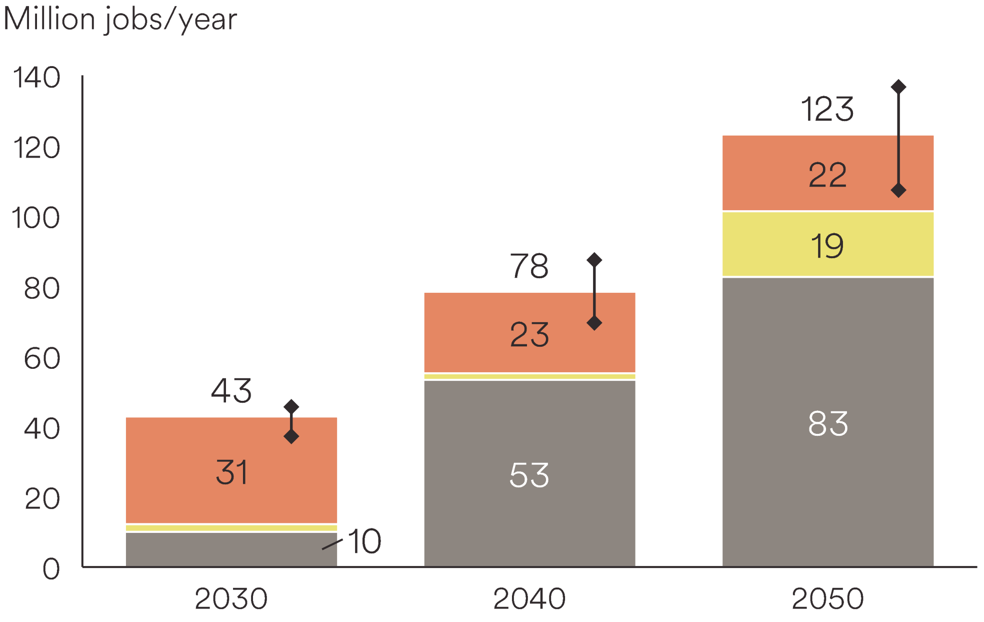
In low- and middle-income countries, investing in low-cost innovations could have synergies with sustainable development goals while in developed countries, novel technologies could promote sustainable value generation

Productivity/best practices | Direct mitigation | Diet shift | Error intervals[1]

Investing in methane innovations across the livestock, rice, and waste sectors could support over 120 million jobs by 2050.

Near-term job contributions are dominated by productivity innovations in cold chain technology and waste tracking and analytics

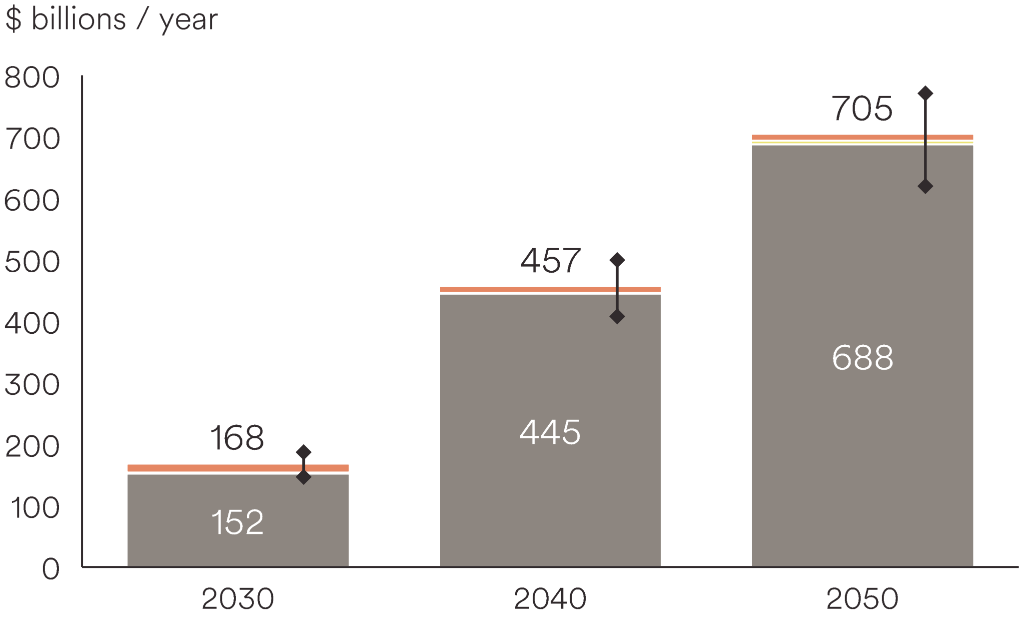
Longer-term job contributions are driven by the investment in alternative proteins required to facilitate a diet shift away from ruminant livestock products



GVA supported by investments in methane mitigation measures could reach roughly $700 billion by 2050, chiefly from alternative protein production.

Total value generation follows a similar pattern to job support, scaling from roughly $160 billion in 2030 to over $700 billion by 2050

Value addition is dominated by alternative proteins, representing 98% of total value generation by 2050



1. Job and GVA estimations are subject to an approximate +/-12% uncertainty range, based on average potential variation in input cost assumptions across innovations. See Technical Report for more detail.

Food system methane innovations can also support co-benefits such as food security by reducing prices

Modelled innovations do not increase prices and can work to reduce them in some cases

Food system methane innovations found not to be detrimental to food prices over period to 2050

- Food prices do not increase or decrease greatly due to a shift towards alternative protein-heavy diets, where alternative proteins are assumed to reach price parity with conventional proteins before consumer adoption.
- Low-emissions conventional proteins (i.e., conventional protein produced using innovations modelled in this study) and low-emissions rice have similar effects, due to the mix of costly and cost-saving innovations
- In practice any interventions targeting abatement in the food system should mitigate against potential adverse impacts to food security.

Some modelled innovations have wider benefits for food security

- Diet shifts towards alternative proteins can help diversify food supply, building resilience to physical risks faced by conventional food production[2]
- Best practice/productivity innovations can maintain or enhance yields while reducing reliance on increasingly scarce/risk threatened natural resources:
  - Alternate flooding and draining in rice production, reducing water demand
  - Herd management and genetic selection of high productivity livestock, reducing feed requirements per unit output

Innovations impacts on nutrition security are likely to vary based on specific practices or technologies

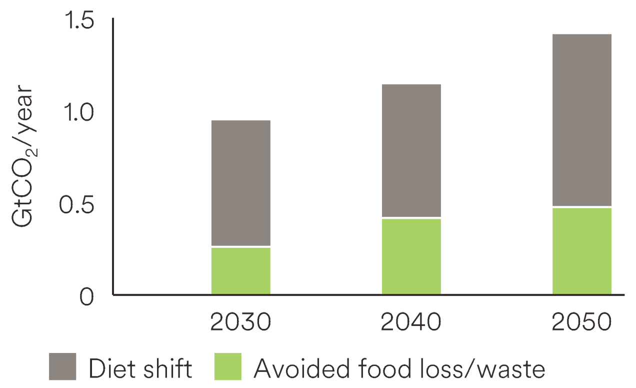
- The nutritional quality of diets improves as a greater diversity of food items and food groups is consumed. Nutrient-rich livestock products such as red meat and dairy address nutrient deficiencies, which must be balanced under diet shifts towards alternative proteins. In practice, diet shifts could be potentially detrimental or beneficial based on current levels of protein consumption
- Productivity/direct mitigation innovations in the livestock, food loss and waste, and rice cultivation sectors potentially beneficial due to increased production/improved food quality

1. While recognizing ruminant livestock in many parts of the world rely on land unsuitable for crop production
2. While recognizing alternative protein feedstocks are themselves subject to a different set of physical risks

Food system methane innovations can also reduce CO_2 emissions, reduce local air and water pollution, and enhance circularity

Interventions can produce CO_2 savings by impacting agricultural land use

- **Diet shifts** can create CO_2 savings by reducing agricultural land, with large reductions possible in Brazil & the USA
- Innovations that avoid food waste & loss reduce cropland needs, which could be potentially spared for increased carbon sequestration and habitat protection



Food system methane innovations can reduce air and water pollution

- Methane interventions can reduce harmful **ground-level ozone exposure**, which is estimated to cause one million premature deaths annually[1]
- Mitigating 1 $MtCH_4$ can avoid roughly **1,430 premature deaths annually** through reduced ozone exposure[2]; innovations could avoid approximately 1.3 million premature deaths over the period to 2050
- Food system innovations (e.g., livestock feeding practices or technologies) can also **reduce ammonia emissions**, bringing associated water and air pollution benefits
- Landfill interventions in developing countries could improve overall waste management practices and **reduce health risks associated with proximity to waste sites**[3]

Interventions can reduce the food system's water footprint while improving circularity

- With agriculture responsible for ~70% of global freshwater use, diet shifts, avoided food loss/waste and water management in rice cultivation could help **reduce the environmental risks of water shortages**
- Productivity improvements, efficiency practices and diet shifts can help **minimize agricultural resource use** and cut down on animal waste
- Waste processing innovations (e.g. MBT, composting) allow waste to be repurposed for **recycling and soil fertilization**

1. Malley et al. (2017). DOI: 10.1289/EHP1390
2. UNEP (2021). Available at: https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions
3. Tomita et al (2020). Available at: https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(20)30101-7/

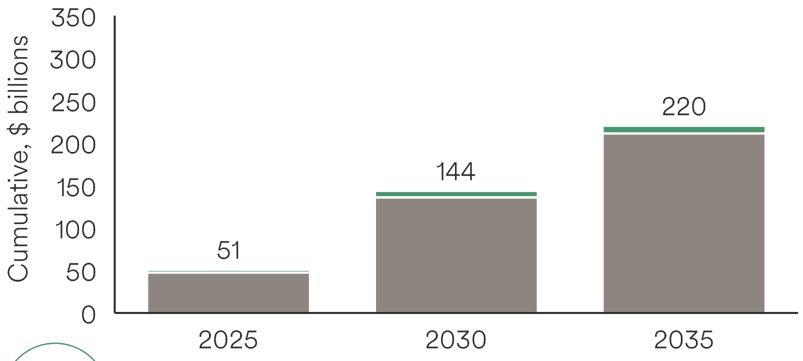
Part 4 – The policy and spending needs to unlock the benefits of food system methane innovation

A five times increase in investment in the near-term is required to maximize benefits of food system methane innovations

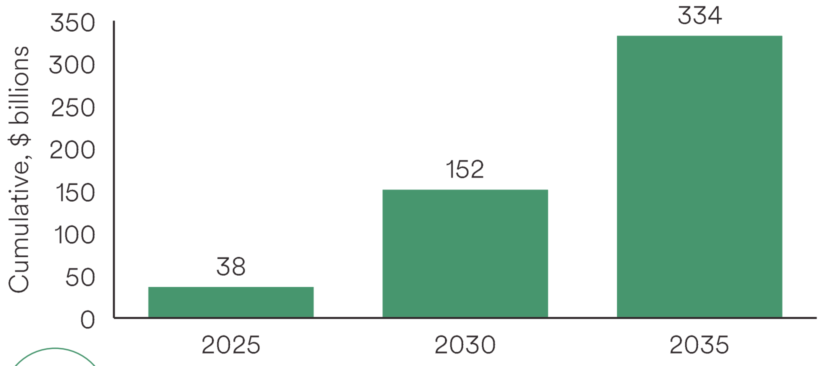
Spending can be channelled towards four categories of opportunity

Livestock Rice cultivation Food loss & waste

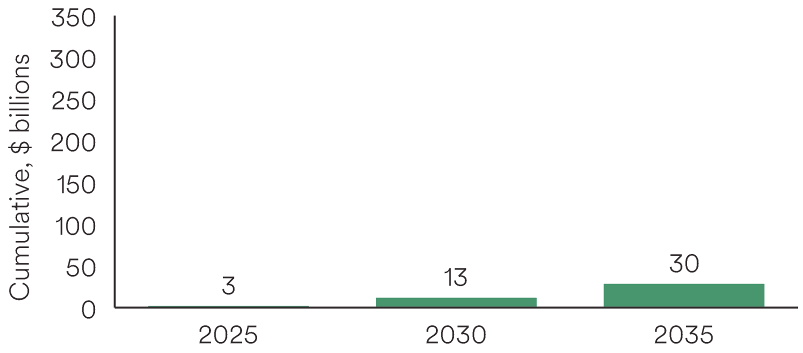
Agricultural extension & technology transfer



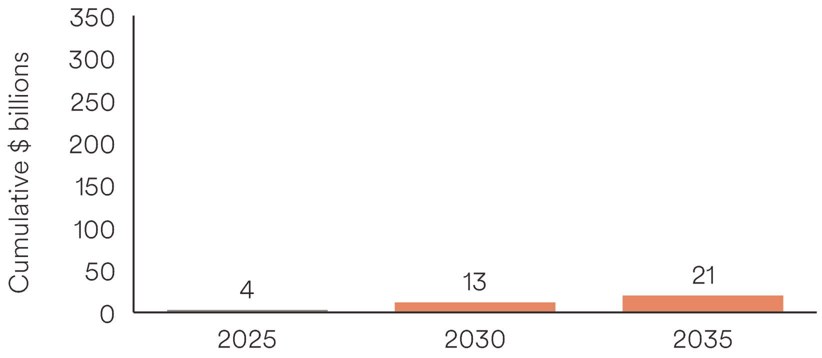
Biotechnology



Agricultural technology



Energy technology



- Current investments in targeted food system methane innovations are low **(~$10-$20 billion[1])** and efforts to scale funding nascent. Global investment in the wider food system also remains small.
- In contrast annual investment in **energy transition technologies**, including renewable energy, transport and heat electrification, energy storage and other technologies **totaled $1 trillion in 2022.**
- For the food system to contribute materially to reducing methane emissions, **investment must scale rapidly** by an estimated **$600 billion by 2035** and **$1.54 trillion by 2050**, or an additional **$60 billion per year (5x increase from current levels),** to overcome diffusion barriers faced by existing innovations and commercialize novel technologies.
- **Spending can be deployed across four categories of opportunity**, spanning agricultural extension/ technology transfer to research and commercialization of agricultural, bio- and energy technologies

1. Estimated from various sources including: Climate Policy Initiative (2022); US DoS (2022). Available at: https://www.state.gov/global-methane-pledge-from-moment-to-momentum; The FAIRR Initiative (2022). Available at: https://www.fairr.org/; World Bank (2018). Available at: https://ppi.worldbank.org/content/dam/PPI/documents/MSW%20Infographic%20Updated%201908.pdf. Excludes funding directed towards agricultural productivity measures with mitigation benefits and therefore may be underestimated total baseline spend.

Four categories of public spending opportunity span agricultural extension and technology transfer programs, to research and commercialization of agricultural, energy, and biotechnologies

Productivity/best practices | Direct mitigation | Diet shift

	Agricultural extension / technology transfer	Agricultural technology	Biotechnology	Energy technology
Description	The promotion of productivity/best practices, scientific and technology research, and practical information through advisory services and training (e.g., to farmers), demonstrations and pilots (e.g., cold chain technologies)	Investment in agricultural technologies with the aim of improving yield, efficiency, and profitability and/or reducing environmental impacts	Investment in developing biological processes including genetic manipulation and production of antibiotics and hormones	Investment in developing, improving and deploying energy technologies
Livestock	Management practices including: improvements in animal health/reproduction; genetic selection/breeding, herd management/feeding practices (Productivity/best practices)	Novel feeding additives (e.g., 3-NOP) (Direct mitigation)	Immunization against methanogens (Direct mitigation) Novel feeding additives (e.g., asparagopsis) (Direct mitigation) Alternative proteins (Diet shift)	
Food loss and waste	Cold chain technologies (Productivity/best practices) Waste tracking and analytics (Productivity/best practices) Composting (Direct mitigation)			Mechanical and biological treatment (Direct mitigation)
Rice cultivation	Productivity and improvement in rice management practices including: Rice paddy water management; Straw management; Direct dry seeding (Productivity/best practices) Low-methane varietal rice selection (Direct mitigation)	Methane inhibiting fertilizers (Direct mitigation)		

Spending across the four categories of opportunity should target RD&D, commercialization and technology transfer to unlock innovation benefits

Investments must address extension of low-cost best practices, and development and commercialization of nascent innovations

Public spending on technology transfer and agricultural extension

Agricultural extension promotes practices, research and practical information to farmers through advisory services and training.[1] Technology transfer boosts food security, productivity and farmer welfare, often at low cost.

Current investment & GINAs

- Agricultural extension remains underfinanced in low-income countries, where diffusion of best practices has high mitigation potential.[4]
- Targeted cold chain and MBT remains limited in developing countries,[5] although countries are increasingly recognizing the increased importance of financial support for cold chains alongside intensification of food production.[6]
- Existing best practices such as herd management will require agricultural and technology transfer spending to diffuse globally.

RD&D spending

Spending for the first steps of the technology development cycle. The private sector is unable to fully capture the societal benefits of knowledge spillovers and hence underinvests in RD&D.

Current investment & GINAs

- Agricultural RD&D spending totals ~$40 billion and has been increasing, but national agencies still require greater human and infrastructural resources.[3]
- GINAs estimates spending needed to drive costs down through RD&D, based on the historic relationship between RD&D and cost reductions for each technology.
- Nascent agricultural and energy technologies will require RD&D investment to reach large-scale viability.

Commercialization spending

Spending to bring a product from demonstration to market, profitably deploying at scale. High commercial risk for the private sector incentivizes underinvestment.

Current investment & GINAs

- GINAs estimates spending needed to bridge the gap between technology costs and market prices to raise deployment to a 'high innovation' pathway.
- Biotechnology investment opportunities such as alternative proteins will require commercialization spending to reach large-scale deployment and price parity with conventional market options.

1. IFPRI (n.d.). Available at: https://www.ifpri.org/topic/agricultural-extension
2. FAOSTAT (2023). Available at: https://www.fao.org/faostat/en/#data/CS
3. Alston et al. (2021). Available at: https://issues.org/rekindling-magic-agricultural-research-development-alston-pardey-rao/
4. NRI. Available at: https://www.nri.org/publications/thematic-papers/7-agricultural-extension-advisory-services-and-innovation/file
5. World Economic Forum (2023). Available at: https://www.weforum.org/agenda/2022/11/sustainable-food-cold-chains-feed-developing-countries
6. UNEP & FAO (2022). Sustainable Food Cold Chains. Available at: https://www.fao.org/3/cc0923en/cc0923en.pdf

Appendix

The GINAs methane study follows an overarching three-step approach to estimating innovation benefits

1. Energy and land system modelling

Land system modelling:

- Original GINAs 1.5°C central scenario, remodeled with to ensure consistency with historical data and improve regional granularity
- Estimates agricultural emissions, production, demand, and other relevant variables

Energy system modelling

- Original GINAs 1.5°C central scenario, modelled with energy system model
- Estimates economic benefits to transition through carbon budget sensitivities

2. Supporting research

Deep-dive research support insights from land and energy models, including across:

- Cost profiling, including temporal effects
- Regional heterogeneity in uptake patterns
- Abatement potential

3 Co-benefits estimation

Combine land and energy system model outputs to estimate economic and mitigative contribution of innovations

Key co-benefits of innovations highlighted via land system and input-output modelling:

- Job/GVA pathways modelled in input-output model
- Food price indicators from land system modelling analyzed against established frameworks
- Nutrition, water and air quality co-benefits examined against literature

GINAs 1.5°C Central scenario:

Represents the low innovation, high-cost route to 1.5°C

Carbon price trajectory consistent with achieving a 1.5°C climate target

Population and income growth consistent with historical trends

Crop and livestock productivity growth consistent with historical trends

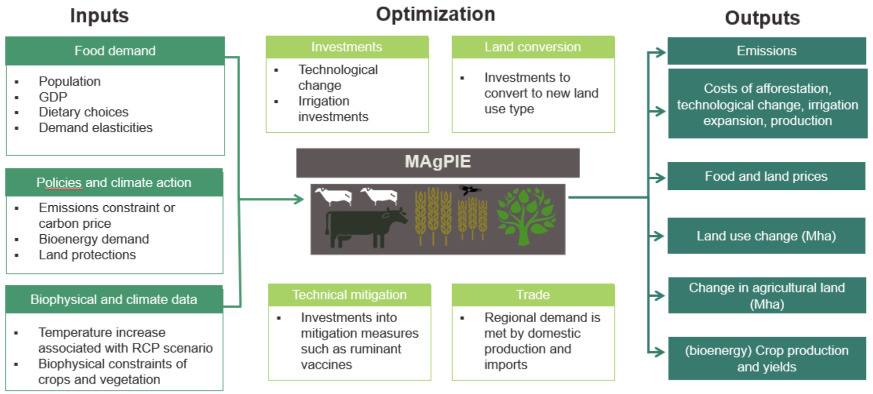
Optimistic bioenergy deployment

Conventional proteins (plant-based and non-ruminant livestock and fish protein) remain integral to diets

Areas protected in line with the World Database on Protected Areas

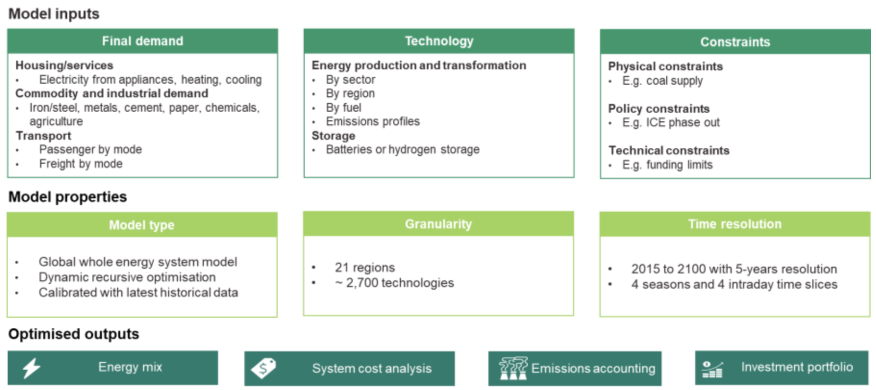
GINAs land and energy system model overview

This study leverages world leading land system modelling based on MAgPIE



This study models the global land system under a 1.5C climate transition with world leading modelling infrastructure based on the open-source Model of Agricultural Production and its Impact on the Environment (MAgPIE). MAgPIE is a spatially explicit partial equilibrium model that solves for the least-cost allocations of land uses and investment in technological change, to meet future demand for food and materials of agricultural origin. It accounts for both biophysical constraints on yield, land and water as well as for regional economic and demographic conditions. MAgPIE produces a land use change raster for modelled 5-year timesteps based on agricultural practices and policy assumptions, such as carbon pricing and conservation policies

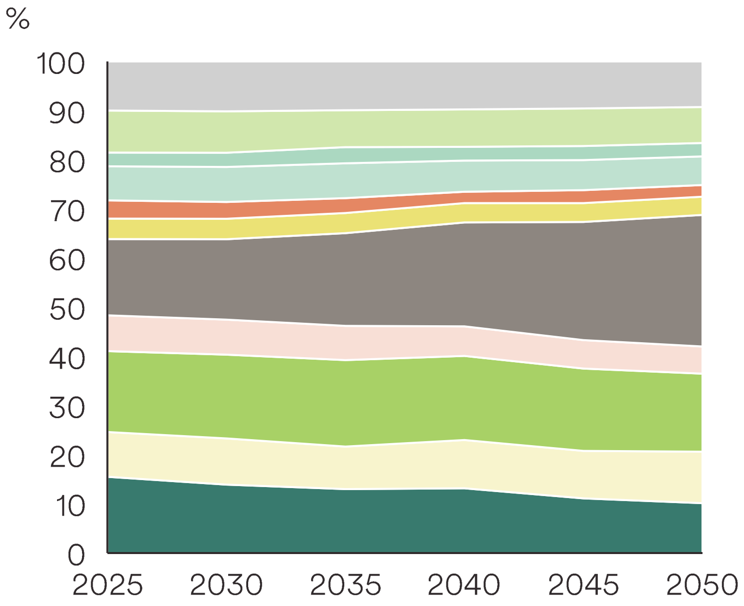
Features of the energy model leveraged for this GINAs study



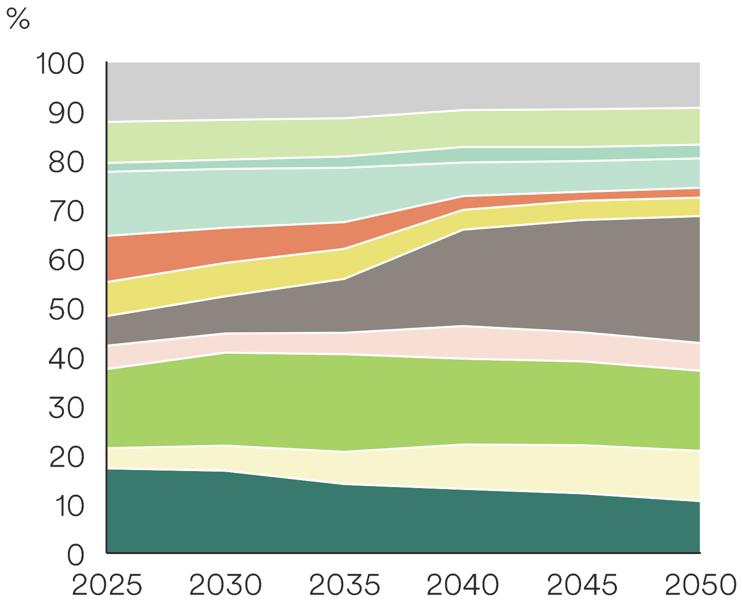
This study leverages the world's largest open-source energy system software model to generate system benefit insights. This energy system model leveraged in this study is built using OSeMOSYS, the world's largest open-source energy system software model. The model calculates the least-cost optimization of all energy carriers and technologies from both the supply and demand sides, given assumptions on economic growth, available resources, final demand, and other constraints, and consistent with the land system modelling

Livestock innovations – regional shares of global abatement potential

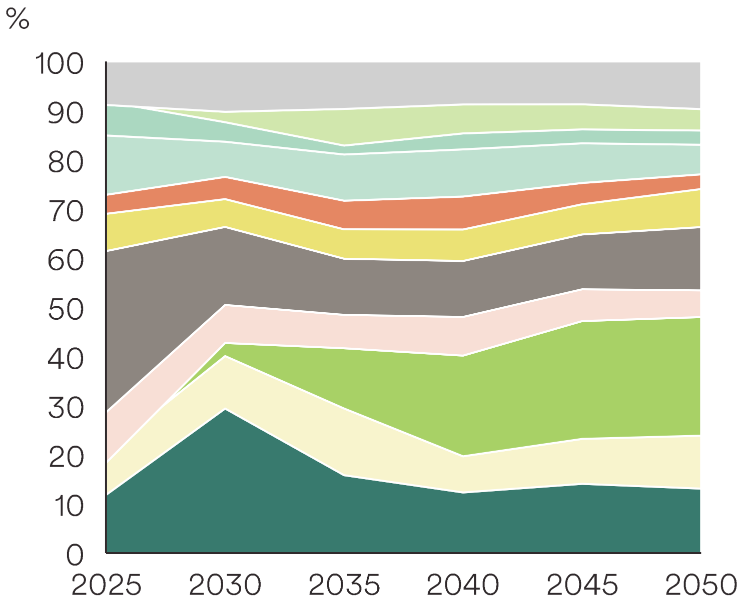
Productivity/best practices



Direct mitigation



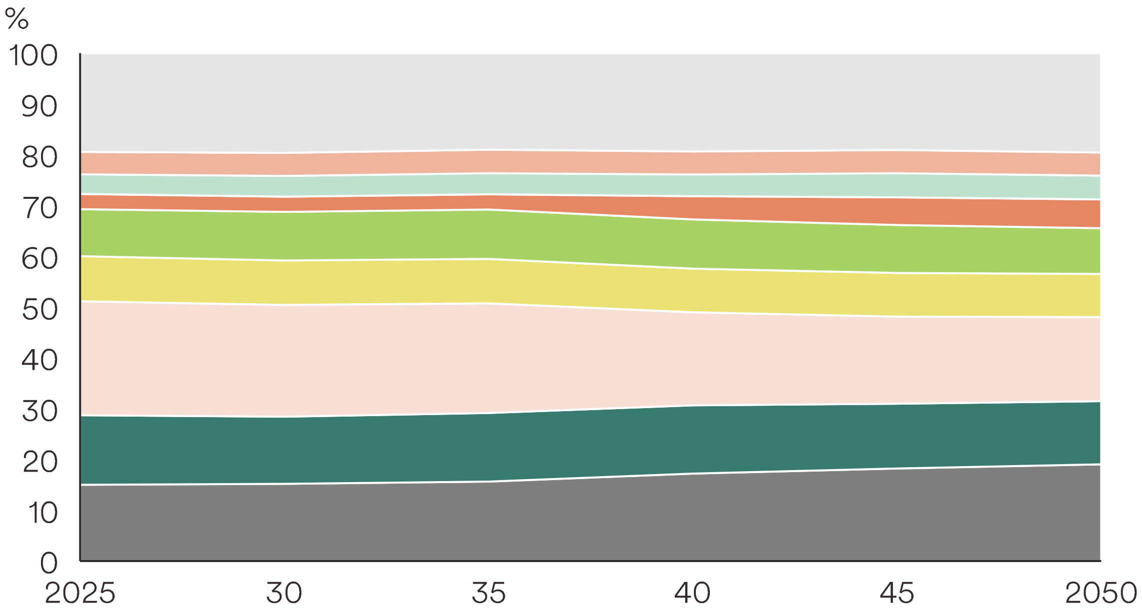
Diet shift



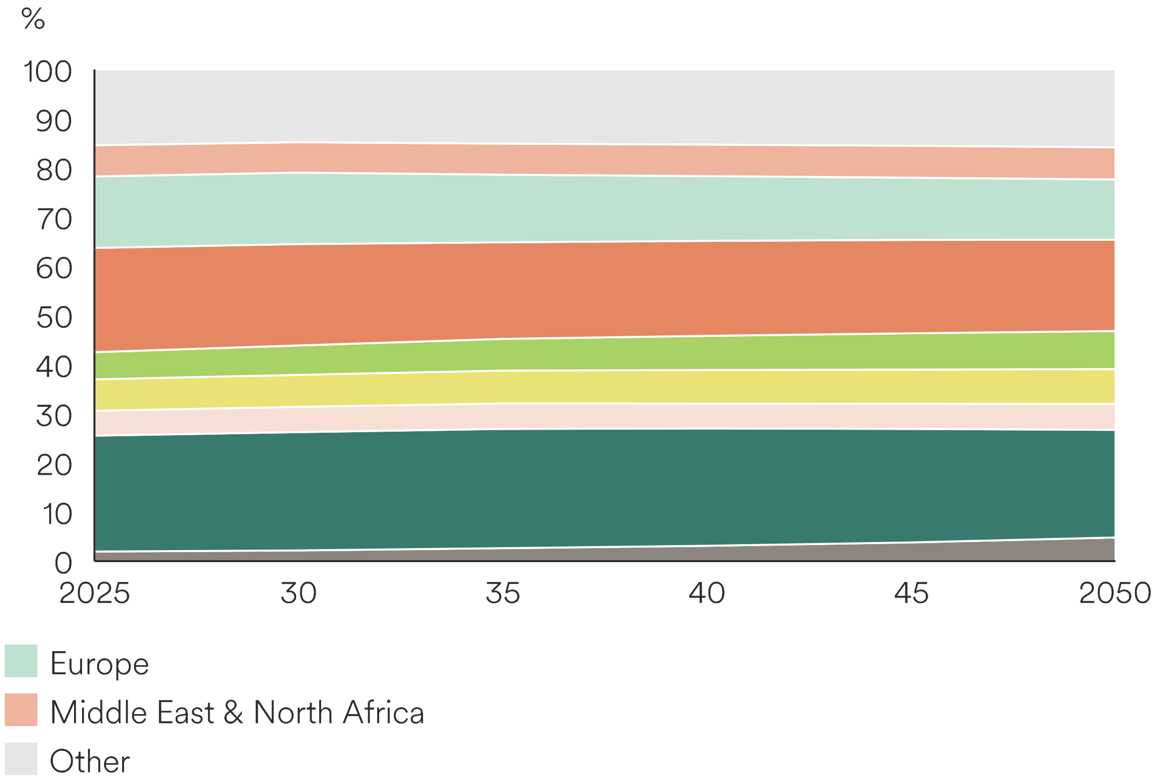
- China
- South Asia (excl. India)
- India
- Brazil
- Sub-Saharan Africa
- Southeast Asia & Pacific
- US & Canada
- Europe
- Australia & New Zealand
- Latin America & Caribbean (excl. Brazil)
- Other

Food loss and waste – regional shares of global abatement potential

Productivity/best practices

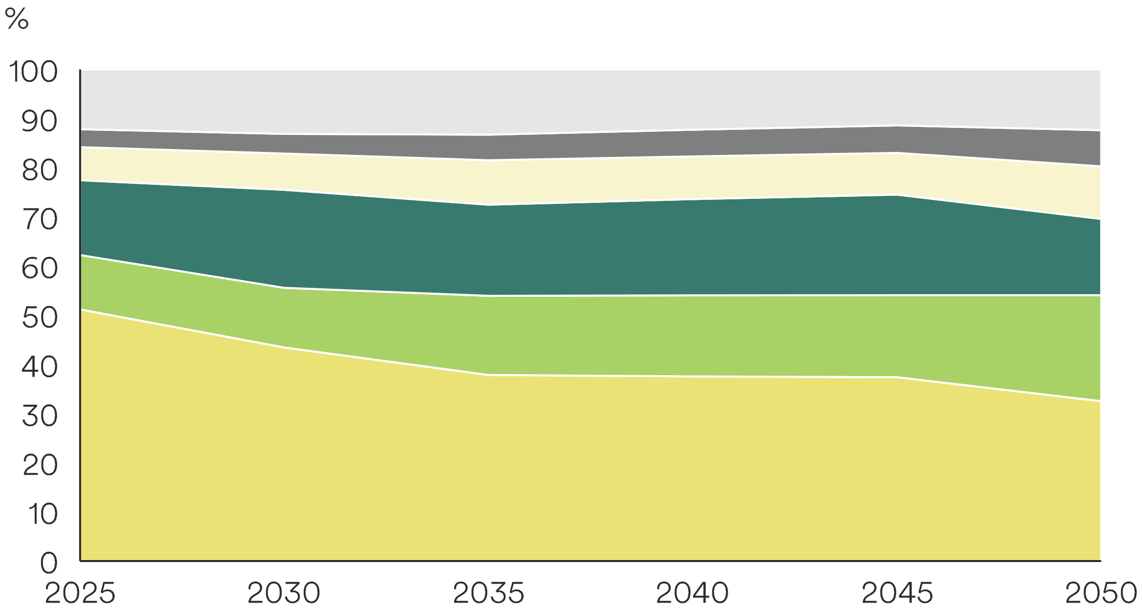


Direct mitigation

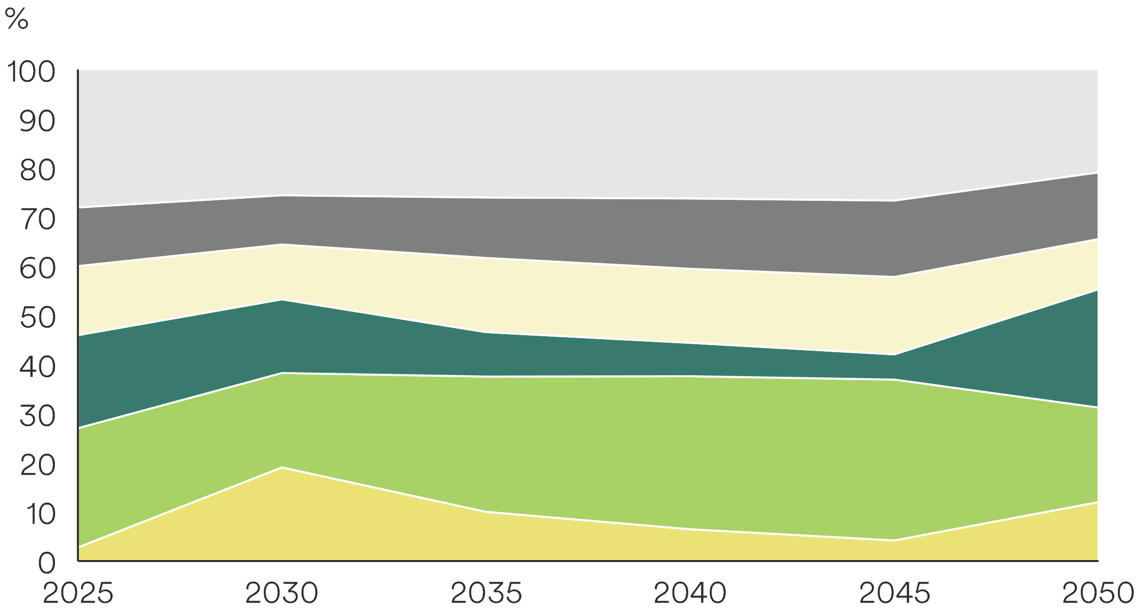


Rice cultivation innovations – regional shares of global abatement potential

Productivity/best practices



Direct mitigation



Southeast Asia & Pacific
China
Sub-Saharan Africa
India
South Asia (excl. India)
Other

Note: Note: See appendix for table on shares in global abatement potential of food system methane innovations by top regions (in 2030) and abatement potential per capita figures

Production versus consumption-based food system emissions and abatement opportunities

GINAs estimate mitigation potential based on each country's production emissions in accordance with UNFCC guidelines for reporting GHG emissions from food systems

Considering the global nature of agricultural trade and that food consumption in many high-income countries far exceeds what is environmentally sustainable, the study also considers food system emissions by country on a per capita consumption basis as reported in Springmann et al (2020) and a related EAT-Lancet study (which focuses on per capita emissions in 2010). This approach allows for a more accurate comparison of the mitigation efforts depicted in the GINAs with each country's per capita emissions from food systems.

- Among the G20 economies, North America, Europe, and Oceania show high per capita food-related, consumption-based GHG emissions, whereas Asia's per capita emissions are considerably lower.
- Outside the G20, Africa, South Asia, and Southeast Asia also have low per capita food-related GHG emissions

The ratio between total methane mitigated per capita in the GINAs innovation scenario (which includes both the mitigation necessary to achieve a 1.5°C target and additional mitigation from investment in innovation) and the consumption-side methane emissions per capita from 2010 serves as a rudimentary benchmark for comparing mitigation activities with historical contributions to emissions from food system methane.

- The analysis finds the highest mitigation-to-emissions ratios in middle-income countries like Brazil and China by 2030. By 2050, the highest ratios are expected to shift to lower-income countries in Africa and Southeast Asia.
- This comparison are crucial reference points for future policy analysis. Subsequent research and analysis can examine various aspects of mitigation, such as pollution control, dietary changes, and productivity improvements, as well as the sources of investment in food systems innovation and the beneficiaries of sector-wide mitigation.

1. Springmann et al. (2020) The healthiness and sustainability of national and global food-based dietary guidelines. Available at: https://www.bmj.com/content/370/bmj.m2322 ; EAT-Lancet (2020). Diets for a better future: Rebooting and reimagining healthy and sustainable food systems in the G20. Available at: https://eatforum.org/content/uploads/2020/07/Diets-for-a-Better-Future_G20_National-Dietary-Guidelines.pdf